The Great Trinity Forest Management Plan

Volume 13

Wetlands

GREAT TRINITY FOREST

Wetlands

Volume 13

Table of Contents

Riparian Systems

January 2007 *Fish and Wildlife Habitat Management Leaflet* *Number 45*

Introduction

Riparian areas are transitional zones between terrestrial and aquatic systems exhibiting characteristics of both systems. They perform vital ecological functions linking terrestrial and aquatic systems within watersheds. These functions include protecting aquatic ecosystems by removing sediments from surface runoff, decreasing flooding, maintaining appropriate water conditions for aquatic life, and providing organic material vital for productivity and structure of aquatic ecosystems. They also provide excellent wildlife habitat, offering not only a water source, but food and shelter, as well.

Soils in riparian areas differ from soils in upland areas because they are formed from sediments with different textures and subjected to fluctuating water levels and degrees of wetness. These sediments are rich in nutrients and organic matter which allow the soils to retain large amounts of moisture, affecting the growth and diversity of the plant communities.

Riparian areas typically are vegetated with lush growths of grasses, forbs, shrubs, and trees that are tolerant of periodic flooding. In some regions (Great Plains), however, trees may not be part of the historic riparian community. Areas with saline soils or heavy, nearly-anaerobic soils (wet meadow environments and high elevations) also are dominated by herbaceous vegetation. In intermittent waterways, the riparian area may be confined to the stream channel.

Threats to riparian areas have come from many sources. Riparian forests and bottomlands are fertile and valued farmland and rangeland, as well as prime water-front property desired by developers. Since the early 1900s, riparian areas have been cleared and converted to use as pastures, cultivated fields, and housing developments. Urban encroachment, channelization, and other water resource development activities have contributed to the destruction and alteration of native riparian areas. Symptoms of degraded riparian systems include erosion, hypoxia (or lack of oxygen), declines in water quality, colonization by invasive

NRCS

U.S. Fish & Wildlife Service

U.S. Fish & Wildlife Service

Riparian examples: California river (top); Maine lake (middle); and Wyoming intermittent stream (bottom)

plants which reduce habitat suitability for wildlife, and more frequent and expansive flooding.

The objective of this leaflet is to assist farmers, ranchers, watershed planners/managers, homeowners, and community members in understanding the importance of riparian areas and provide guidance in implementing land management practices to improve riparian health. Additionally, methods for assessing riparian conditions and identifying resources available to assist in management are provided.

Benefits and functions of riparian systems

Riparian systems look and function differently across the country. In spite of their differences, riparian areas possess some common ecological and hydrological characteristics; namely, water storage, flood control, nutrient cycling, and water quality protection. They provide recreational and economic benefits, as well.

Hydrology

The flooding is important to riparian ecosystems as it can affect stream morphology and vegetation. Water storage is recharged through seepage and channel overflow onto flood plains. Nutrients in riparian ecosystems are partially supplied by materials and water delivered during flood events. Additionally, overbank flooding ventilates soils and roots so that gases are exchanged more rapidly. Oxygen is supplied to roots and soil microbes, and the release of gaseous products of metabolism, such as carbon dioxide and methane, is enhanced.

Maine Department of Environmental Defense

Impervious surfaces, such as roads and parking lots, do not allow water to infiltrate the soil quickly. This increased runoff can quickly overflow storm drains, potentially causing flooding.

The hydroperiod, which includes duration, intensity, and timing of flooding, is the determinant of the ecosystem's structure and function. The timing of flooding is particularly important. Flooding in the growing season has a greater effect on ecosystem productivity than does flooding in the nongrowing season.

Ground water has a close relationship with surface water in streams and flood plains. The normal gradient and direction of ground water movement is toward surface water features through ground water discharge. During periods of high water, the gradient is reversed, and water moves from the stream to the aquifer. The recharge of ground water is vitally important. In the West, many streamside aquifers go dry late in the season due to poor livestock management in riparian areas, as well as beaver removal, mining, and poor upland watershed management as a whole.

Water storage and flood reduction

Riffles, pools, bars, and curves in the stream channel absorb the energy of flowing water. If the channel is not altered and remains in contact with the flood plain, floodwaters will spread out over the flood plain. As the floodwaters move through the riparian vegetation, plants dissipate erosive energy, reduce erosion, and increase the time for water to infiltrate the soils and be stored for slow release.

Nutrient cycling

When nutrient-rich sediment is deposited on the flood plain, it is modified by a number of different chemical and biological mechanisms and cycled through the system. Nutrients like nitrogen, phosphorus, calcium, magnesium, and potassium are rapidly taken up by shallow-rooted plants like grass. Easily dissolved nutrients that may leach downward through the soil into the ground water are taken up by deeper-rooted vegetation, such as trees. Some of the nutrients taken up by plants are returned to the system during autumn leaf fall or when the vegetation dies and is decomposed.

Energy transfer

Riparian areas are unique in the way in which energy contained in organic matter is transferred from organism to organism. Energy inputs from riparian vegetation are closely tied to the productivity of instream habitats. That is, energy contained in organic litter in the form of fallen leaves, twigs, and other dead plant parts, when transported laterally into waterways, provides fuel for instream animal communities both locally and downstream from the source of origin. As compared with purely aquatic or terrestrial ecosystems, organic matter produced in riparian ecosystems has the potential for supporting a diversity of food webs within the entire watershed.

Water quality protection

As flood waters spread over a flood plain, water velocity is reduced by the vegetation, which allows much of the sediment to settle, reducing the likelihood of its re-entering the stream. Riparian vegetation increases sedimentation of particulate matter in the flood plain by filtering additional sediment from runoff and floodwaters. The result is that riparian areas serve as effective sediment traps and reduce the amount of sediment that might otherwise enter a stream or downstream waterbody.

William Hohman, NRCS

Aerial photograph of a functional flood plain in northern Minnesota in spring. Meanders in the river help absorb the energy of flowing water. Functioning flood plains hold water and reduce downstream flooding.

Riparian vegetation also reduces sediments in the water by decreasing the rate of bank erosion. Deep-rooted woody vegetation has the greatest stabilizing affect on streams or riverbanks.

Nutrients, pesticides, and heavy metals are transported with sediment and trapped in the riparian area. Many of these are broken down by physical or biochemical processes and reduced to harmless forms. Some are taken up by riparian vegetation and incorporated into their living tissues during the growing season. Others bind to sediments and are permanently stored in the soils of riparian areas.

Recreational and economic benefits

Stable streams, made possible by an intact riparian system, protect and enhance river and lake environments for recreational uses such as hiking, camping, hunting, fishing, and boating. Clear water, free of noxious plant or algal growths, is important to swimmers and anglers. The scenic qualities of natural beauty, wildness, and privacy are enhanced by native streamside and lakeshore vegetation. In urban, residential, and campground areas, natural streamside and lakeshore vegetation provides a visual contrast and buffers the noise from nearby highways.

The ecological benefits, visual diversity, and aesthetic beauty of a riparian system can be considerable; however, there are some economic benefits to a riparian area, as well. In some cases, haying, logging, or alternative, low intensity agricultural enterprises (such as harvesting Christmas trees, strawberries, mushrooms, or nuts) can be conducted with minimal harm to the riparian area.

Washington State Department of Ecology

Black bears will utilize riparian areas for food and denning sites.

Wildlife use

General

Riparian areas are extremely valuable wildlife habitat. Site characteristics (high productivity, structural complexity) and landscape situation (habitats interwoven between terrestrial and aquatic systems throughout the watershed) contribute to the importance of riparian areas as wildlife habitat.

Vegetation (whether living, decaying or dead, standing or fallen) has a major influence on wildlife use of riparian areas. The shade, detritus, and coarse woody debris provided by streamside vegetation are very important for healthy fisheries. Leaves, branches, and even whole trees uprooted by rivers or other natural forces become food and shelter for aquatic organisms. Logs falling into streams often divert streamflow into new pathways, thereby increasing the complexity of the channel and helping to maintain a diversity of habitat niches for aquatic plants and animals. A multi-storied plant canopy of annual and perennial grasses and forbs, as well as juvenile and mature shrubs and trees, provides a variety of above-ground habitat for birds and other wildlife, and below-ground habitat for burrowing animals and soil organisms. Large numbers of migratory and resident birds rely on streamside habitat. More than 100 native species of land mammals in the United States are dependent on riparian zones.

Mammals

Mature riparian forests provide important habitat for small to large mammals. Black bears may be found in riparian areas, particularly where there is brushy cover for hiding and mature hardwoods for denning and food production. White-tailed deer make use of these areas for forage and cover. Land mammals use riparian areas as corridors for movement and routinely hunt along waterways. Many mammals use riparian areas as travel corridors as they disperse from their dens. Other mammals commonly associated with riparian areas are beaver, mink, muskrat, and river otter.

Reptiles and amphibians

Connections to uplands within and beyond the riparian area are important to reptiles and amphibians and need to be managed. Many species of amphibians rely on aquatic habitat during the breeding season and then spend most of their lives in upland habitat, often at a considerable distance away. The reverse is true for many reptiles as they need dry upland sites for nesting. Fallen trees and snags (remaining dead trees) are used as shelter and a source of food for many species of amphibians and reptiles.

Birds

Birds use riparian areas as nesting, migrational, and wintering habitat. Abundant invertebrate foods produced in riparian areas and adjacent aquatic zones are especially important to birds during migration and nesting, when nutritional demands are great. Winter flooding of riparian areas provides access to foods at southern latitudes. When large trees mature and die, the standing snags provide habitat for cavity nesting birds. Bird use of riparian areas has been shown to be positively associated with the number of snags, canopy layers, saplings, tree size, and diversity of vegetation. Residents use riparian corridors for local movements throughout the year.

Aquatic communities

Riparian areas provide organic matter and substrate required by instream organisms. Organic material in the form of twigs, branches, bark, leaves, nuts, fruits, and flowers originating in riparian vegetation adjacent to the stream is broken down by aquatic microorganisms and stream invertebrates.

Overbank flooding of streams and rivers also provides organic matter and nutrients used by aquatic communities. During periods of high water levels, rivers and streams expand into the adjoining riparian flood plain, picking up large amounts of organic matter, nutrients,

NRCS

Riparian areas serve as wildlife corridors providing important routes for the yearly migrations of land animals and birds. As seen in this image, connecting corridors allows wildlife to travel without entering farmland or developments.

and small organisms. When flood waters recede, this nutrient-enriched water further supports the growth of aquatic plants and microorganisms. At the same time, flooding allows fish to migrate from the stream channel to feed and spawn in the flood plain.

Riparian vegetation can have a great impact on water temperature, which is critical to many aquatic organisms. Reduced stream temperature can increase a stream's oxygen-carrying capacity. Vegetation shades the water from the sun, particularly important during the hot summer months.

Riparian system structure

The plant species of riparian areas vary depending on the location of the watershed, as well as the stream slope, light and water availability, flooding, and soil conditions. However, regardless of the species composition, the vegetation is organized into zones or ecosystem bands based largely on site-specific moisture regimes.

Riparian systems may have one to three zones, depending on the location and habitat structure. Some systems are very simple with a single zone of grasses and sedges. Other systems have additional zones of primarily woody vegetation and mixes of upland and riparian vegetation. The expression of zones in an area is a reflection of disturbance such as fire, wind, herbivory, and flooding. Each zone consists of vegetation adapted to survive in the specific moisture/disturbance regime of that area and able to perform specific ecological functions.

- Zone 1—This band hosts species found along the water's edge. The most prevalent species are sedges and rushes that are water-loving and capable of stabilizing streambanks with their deep, strong roots. These species are critical for promoting water recharge and decreasing depth to water table.
- Zone 2—This zone contains species that are found in wet ground and consist of shrubs, trees, moisture loving grasses, and water-tolerant broad leaved plants. These plants catch water and facilitate absorption of nutrients transported into the area by runoff and ground water and provide habitat for terrestrial animals.
- Zone 3—This zone is located where the riparian zone merges with the uplands and includes a mixture of riparian and upland species. The area is also host to many terrestrial animals including many early successional, edge-loving species.

AFS Fisheries Techniques Visuals

Zone 1 contains water-loving plants that help to stabilize streambanks and promote water recharge.

www.clr.utoronto.ca

Zone 2 is represented by the background trees in this image. Zone 2 contains species of shrubs, trees, and moisture-loving grasses and forbs.

Virginia Department of Game and Inland Fisheries

Zone 3 contains a mixture of upland and riparian species. As seen in this image, zone 3 can create a forest edge habitat and, thus, contains many early successional species.

Degraded riparian systems

When a riparian system is degraded, heavy runoff moves through the riparian zone directly into river channels. Fine sediments eventually fill up stream pools, altering the shape of the stream channels and covering rocky stream bottoms, thereby impairing important food-producing, shelter, and spawning areas. Runoff can bring seeds of nonnative and nonriparian plant species, reducing habitat for native species, and the water table can be lowered by crowding out more native riparian species. Degradation of the native plant community can create a fire risk by increasing fuel loads. Furthermore, streamsides lose their ability to buffer and protect streams, resulting in damage to aquatic habitat, increased costs for treating drinking water, and loss of aesthetic appeal.

Misuse of riparian areas

Forest management

Improper forest management practices can destroy riparian area benefits and functions. Sediment is the most prevalent pollutant coming from poorly managed forests. Sediment comes from erosion of exposed soils due to improperly constructed access roads that concentrate runoff. Improper harvesting practices can also impact riparian areas. Inadequate riparian buffers contribute to bank erosion and cause water temperatures to rise. Skidder traffic causes erosion of soils and soil compaction, which in turn affects the regrowth of vegetation on impacted areas.

Agricultural management

Grazing animals with unrestricted access to riparian areas may remove streamside vegetation, compact or disturb soils, and break down banks, resulting in both channel incision and widening of stream channels. Additionally, when grazing animals have free access to riparian areas, their manure is deposited or washed into streams. This results in excessive nutrients, organic matter, and pathogenic organisms.

Riparian areas have often been converted to cropland because of soil fertility and convenient access to irrigation water. Intensive use of the land for growing crops can have negative environmental consequences due to the scale of operation. Agricultural practices such as chisel-plowed row cropping and installation of surface and subsurface drains, adversely affect the hydrology and water quality of riparian areas. Agricultural processes can remove permanent vegetation, which reduces the rate at which water infiltrates through the soil and moves into the body of water. Removal of vegetation increases sunlight that enters the channel resulting in increased water temperatures. Vegetation removal also exposes soil to raindrop impact runoff, increasing erosion.

Urbanization

Often sediment and erosion controls at development sites are inadequate for the type of land being developed. Some construction sites have improper erosion and sediment control measures from the beginning of work, and the remaining riparian areas are unable to mediate the sediment load entering the water.

Impervious surfaces, such as parking lots and roads, create a water movement system quite different from a natural watershed. Rain quickly runs off the impervious surfaces into river channels, resulting in earlier and higher peak flow. Runoff in watersheds with substantial amounts of impervious surfaces has the potential to carry increased sediment loads and other materials such as fertilizers, pesticides, trace metals, and other toxic materials that were improperly applied or disposed.

Water flow modifications

Dams, levees, and stream channelization significantly alter water movement and storage in riparian systems. Additionally, these modifications can severely alter the suitability of rivers and streams to spawning and migratory fishes such as cutthroat and bull trout.

Sally Letsinger

Bank sloughing, as seen in this image, is a sign of degraded riparian system.

In the Great Plains and arid West, diversions for irrigation are common and have important implications for plant life, as well as life cycles and movement patterns of aquatic organisms. In some cases, the withdrawals are indirect, resulting from extensive pumping of ground water in close proximity to the stream or river reducing flows.

Wetland loss

Since European settlement, many wetlands have been lost or degraded for agricultural, commercial, and industrial developments. Additionally, wetland habitats have been affected by the invasion of nonnative plants and introduced animals. On many sites, these nonnative species have become well established, commonly replacing native species or exerting large influences on the functional dynamics of existing native habitats. Wetland loss and degradation in the watershed is an important planning consideration when seeking to reestablish riparian functions.

Riparian assessment

A large number of riparian classification, inventory, and evaluation procedures have been developed; however, most of these were created to fit local needs or specific programs. Some are comprehensive, requiring detailed onsite surveys; others are very general. Currently, the Stream Visual Assessment Protocol, developed by the NRCS, is used in all 50 states by landowners and field staff. This protocol includes riparian areas and can be found at *http://www.nrcs.usda.gov/technical/ECS/aquatic/svapfnl.pdf*.

Asolin County Conservation District

Once decisions are made, the plan should be implemented, paying close attention to detail. In this image, revegetation is taking place along a streambank.

The appearance of unstable riparian areas is often quite different from that of stable systems. When assessing for system stability, indicators such as bank sloughing, seepage in the banks, lack of vegetation, straightened channels, and invasions from nonnatives should be addressed. A more detailed description of instability indicators can be found in table 1.

Management and restoration

Restoration and enhancement projects are often complicated as the hydrology at both local and watershed scales, climate, and current and historic plant and animal communities must be considered. Extensive planning must be done before a riparian restoration or enhancement project can be implemented.

Landowners must first identify and understand the problems (loss of vegetation, overgrazing) and opportunities (how lost functions can be restored). Local landscape and historical factors that led to the creation and function of the riparian ecosystem must first be understood. These factors may include land use, topography, water quality, climate, and precipitation.

Once the problems and opportunities are identified, objectives for restoration must be outlined. Objectives might include planting riparian buffers, fencing livestock from riparian areas, and conducting controlled grazing or burning. The available resources required to undertake the restoration or enhancement project must be identified and analyzed to formulate a plan of action and any alternative plans of action that might be considered. Available resources might include riparian restoration expertise or financial resources. Armed with all this information, landowners will be well equipped to decide on the proper plan of action for their riparian restoration or enhancement project.

Before implementing their plan, landowners and managers are strongly urged to discuss their riparian restoration or enhancement plans with experts from Federal, State, or local government agencies or qualified personnel from conservation organizations. Evaluation of the plan throughout the planning process, as well as during and after its implementation, is vital to the success of the project, as well as future riparian restoration and enhancement projects.

Riparian buffers

A riparian buffer is an area of varying size managed to reduce the impact of adjacent land uses on aquatic ecosystems. With careful design, buffers can serve several important riparian functions. Like a natural

Table 1 Signs of a degraded riparian system

Headcutting and downcutting	A headcut is a discontinuity in the base of the stream. Downcutting occurs when something causes the stream to increase its velocity and erode away the channel bottom. As the channel cuts downward, the ground water table is lowered. Consequently, water-loving plants isolated on the old flood plain and streambanks may no longer get the moisture they need
Bank sloughing	Localized bank collapse indicates a stability problem. Bank sloughing may be caused by undercutting of the toe (bottom of the bank), bank seepage, or saturation of very loosely deposited material
Steep banks	Steep banks indicate that the stream is adjusting laterally or that the bank toe has been lost. This often occurs in channels that have been downcut and are reestablishing a flood plain
Seepage in banks	Seepage often affects incised channels. When water tables rise, the seepage exits through the streambank. Soil particles are dislodged if seepage forces are sufficient. Even if soil is not removed, the saturated area represents a weak point the next time high flows occur
Lack of vegetation	Lack of vegetation covering the banks can indicate that the area was recently subject to scour or deposition or the area has unfavorable moisture patterns for plant growth. Sparse vegetation or changes in species composition may be due to lack of moisture resulting from severe degradation or a dropping water table
Straightened channels	Frequently, streams and other waterbodies are altered to facilitate farming activities. This increases the slope by reducing the length. Streams often downcut to return to the original slope or original natural meandering pattern. Straightening can increase the speed of sediment and water movement and can reduce viable habitat for many aquatic organisms
Shallow-rooted vegetation with relatively low productivity	Riparian vegetation must have deep, strong roots to provide bank support. Shallow roots will not perform this function, and bank sloughing and erosion will become more common
Lack of shade and overhanging vegetation	Shade protects the water temperature in a riparian system. The absence of shade is an indicator of poor riparian health due to lack of shade-producing vegetation
Wide stream channel with shallow, muddy water	Waterbodies in riparian systems should be clear and free from floating sediment. If water appears muddy or murky, sediment is being disturbed by increasing flow or other factors
Invasion of undesirable plant species	Riparian vegetation has adapted to the moist, flooded environment situated near the banks. Many invasive species have not adapted to the specific ecology of riparian systems and may indicate a change in soil regimes

system, well-designed buffers can preserve the characteristics of the waterbody, protect water quality, and improve habitat for wildlife in the surrounding area. To optimize their effectiveness in controlling agricultural contaminants, riparian buffers should be designed with awareness of adjacent land uses and management. For severely eroded banks or deeply entrenched creeks, stream restoration, in addition to buffers, may be required.

A well-designed buffer system may include not only a buffer area established on land next to a stream, but also plantings that stabilize the streambank and wetlands constructed to absorb stream runoff. Buffer design techniques are outside the scope of this leaflet; however, for more information on riparian buffer creation and management, reference the Stream Corridor Restoration Manual at *http://www.nrcs.usda.gov/technical/stream_restoration/newgra.html* and the Grassed Waterways Job Sheet at *http://efotg.nrcs.usda.gov/references/public/IL/waterway.pdf*.

Assessing stream stability and sensitivity

Assessing existing stream conditions is imperative before initiating riparian restoration or management projects. Assessing the stability of the existing system and the sensitivity of the waterway to management practices requires examination of upstream and downstream areas.

Stability assessment

There are a number of visual indicators that can reveal the stability of a waterbody. Healthy streams generally have a meandering pattern with alternating areas of shallow water with rapid flow and areas of calmer, deeper water. Additionally, stable riparian areas have vegetated banks and an established flood plain.

Sensitivity to management practices

Riparian area sensitivity to management practices (such as grazing or timber management) is determined primarily by its dominant bank and bed material, the relative height and steepness of its banks, and its vegetative cover. Field reviews should be certain to document these factors.

Water courses comprised primarily of gravel, sand, silt, or low-plasticity clay are much more sensitive to outside influence than cobble-, boulder-, or bedrock-dominated streams. Likewise, streams with low, relatively flat banks are not as susceptible to change as those with high, steep banks.

Vegetation also plays a critical role in streambank and riparian area protection. Its importance becomes even more apparent in systems with easily disturbed soil materials. As previously mentioned, vegetation provides a number of functions, including bank stabilization, moderating moisture regimes, and protecting banks from streamflow. A dense mixture of vegetation over the entire bank is desired to reduce sensitivity. Various age classes and plant types should be represented with little or no exposed soil.

Vegetation management

Haying and Mowing

Haying at appropriate times of the year using suitable methods can be an effective way to maintain warm-season grasses. Grasses should be cut to a minimum height of 6 inches, and it is important to rotate harvested areas on an annual basis.

NRCS

Bear Creek buffer demonstration site in central Iowa

Mowing warm-season grasses can also be used as a maintenance plan; however, this is not the most desirable alternative. Mowing keeps woody growth from encroaching, but repeated mowing creates a layer of litter on the ground that eventually crowds out grass seedlings. Additionally, this litter layer hinders the movement of young birds on the ground and makes the area less attractive to the insects they feed on. If mowing is necessary, a third of the area should be mowed every year. Additionally, it may be necessary to lightly disk the stand every 3 to 4 years to turn over the litter layer, destroy woody growth, and encourage germination of dormant native vegetation. For more information, see Fish and Wildlife Habitat Management Leaflet Number 25: Native Warm-season Grasses and Wildlife.

Controlled burning

Established, prescribed, or controlled burning is a very effective way to maintain and rejuvenate a stand of warm-season grasses. A third of the area should be burned annually which will help ensure a cleaner, more valuable stand over a longer period of time. Permits are required, and caution must be exercised during the burning process. Consultation with a fire management specialist is highly recommended. Local NRCS or Conservation District offices can offer additional assistance in developing a prescribed burn management plan to meet specific objectives.

Controlled grazing

Controlled grazing can be an effective vegetative management plan when used correctly. However, riparian areas are very sensitive to unmanaged grazing. Generally, riparian areas tend to be more productive than surrounding uplands because of the additional moisture available to plants. Thus, even if forage is readily available in upland areas, livestock may congregate and overuse riparian zones. Because of this, simply reducing the number of animals is not the answer. Unrestricted access can create trails which cause erosion and compromise the integrity of the streambanks. When overgrazed or trampled, remaining plants become widely spaced. Continuous grazing eliminates young plants and weakens established ones. Many of these effects are site specific, so it is recommended that land managers consult with wildlife professionals to establish a location appropriate grazing program.

There are four controlled grazing options to consider for vegetation management. Each option should be considered after inspection of the specific site.

- Encourage livestock to use upland areas—Moving salt/minerals and feeding locations, oilers, dust bags, shelters, shade facilities, and water sources to upland areas can attract livestock away from the riparian area. Improving upland forage can encourage livestock to graze away from streambanks.

Greg Sneider

Livestock trampling and loitering can create trails and cause serious bank damage.

NRCS

Controlled access points made from crushed rock or other suitable materials can reduce the amount of riparian damage by only allowing livestock passage through certain areas.

- Fencing riparian areas into separate pastures—Reserving the fenced riparian areas for forage or dormant season grazing can reduce stress to the area while benefiting the riparian plant community.
- Total exclusion—Erecting fencing to exclude livestock from the entire riparian area (being sure to provide alternative water sources) is a means to completely eliminate grazing stress to the system, but also eliminates grazing benefits.
- Construction of controlled access points—Ramps made from crushed rock or other suitable materials prevent damage to streams from trampling. Electrical fencing has been successfully used for this purpose.

There are several other management practices that will help maintain a successful grazing program in riparian areas.

- Allow plants to reach height of 4 to 12 inches before introducing grazing animals.
- Rotational grazing strategies used at different times of the year can have a positive impact on vegetation. Consulting with a wildlife professional to establish site-specific needs can help prevent unsuccessful or detrimental grazing practices.
- Select a key plant by which to judge the extent of grazing. This plant may change as the plant community changes. The key plant or plants should receive a significant amount of grazing and be important to the riparian community.
- Monitor riparian areas for suitable times to rotate livestock. Stake heights can be set that become visible when grasses are grazed to the proper height signaling the time to rotate.
- Grazing management should provide ample time for key plants to recover.

Timber harvest

Harvesting fast-growing trees as early as possible removes the nutrients and chemicals stored in the woody stems and promotes continued vigorous growth. Logging should not be conducted within the first 15 feet from the top of the streambank; however, when banks have been undercut or the channel is deeply incised, the careful harvest of a large bank tree can help protect bank stability. When harvesting trees, stream crossings should be minimized, and roads should not be built except those required to cross the stream. Skidders should be kept away from the streambanks and not skidded across stream channels. Avoid rutting during wet weather, and use cable and chokers to skid logs.

Upland practices

In addition to the creation and management of riparian areas, there are several upland practices that can be implemented to minimize the movement of nutrients, chemicals, and sediment into riparian systems. Maintaining vegetative cover over the soil throughout the year will reduce the amount of sediment and erosion. Minimizing animal trampling and vehicle traffic on wet soils will protect the soil and vegetative integrity. Avoiding the overuse of fertilizer, herbicides and other agricultural chemicals, and manure will reduce the risks of harmful chemicals and nutrients entering the system. Managing riparian areas to favor native plants will help to maintain their attractiveness and suitability for wildlife. Finally, avoiding practices that artificially alter stream hydrology will help maintain watershed integrity and riparian management. Sound upland practices, as reflected in proper function and condition of streams, are essential for healthy and productive watersheds.

Case studies

Fox Creek riparian zone restoration project

The upper two-thirds of Fox Creek Canyon in Oregon was severely degraded by open-range cattle grazing. Affected landowners, working in collaboration with adjoining Daybreak Ranch, U.S. Department of Interior, Bureau of Land Management, and a number of other partnering agencies, developed and implemented a restoration plan for Fox Creek Canyon. The restoration project also set the stage for reintroduction of beaver into the canyon.

In 2003, 4,000 cuttings and seedlings were planted including willow, redosier dogwood, cottonwood, mock orange, ponderosa pine, aspen, plum, walnut, and golden current. The planting was followed by the installation of 7 miles of fencing to exclude cattle from sensitive areas. Additionally that year, 16 acres were seeded with native grasses. Beaver will be reintroduced once there is sufficient habitat.

The project received a Conservation Reserve Program (CRP) contract along with advice, grants, and support from a number of other groups and agencies.

Fox Creek Farm

Fox Creek Farm

The top photo was taken at Fox Creek in 2002 and shows trampling and dung deposits from cattle. The bottom photo was taken at the same location in 2004 after restoration and shows grasses and forbs closely surrounding the creek.

Buffalo Creek riparian buffer restoration

The Buffalo Creek Watershed, which is located in western Pennsylvania and empties into the Monongahela River in West Virginia, covers approximately 107,000 acres across the two states. The creek has long suffered from nonpoint source pollution, especially from cattle wandering along riverbanks, degrading the riparian zone and damaging water quality. Currently, more than 60 miles of riparian fencing has been installed. Other activities include instream restoration, construction of cattle crossings and alternate watering sources, and planting of native grasses on less productive areas to expand forage and provide better wildlife habitat.

The U.S. Fish & Wildlife Service Partners for Fish and Wildlife Program is encouraging farmers to fence streambanks to keep cattle out of streams, allowing trees and brush to regenerate and keeping excess sediment, nutrients, and bacteria out of the water. New vegetation shades the stream, making it more hospitable for fish, plants, and animals.

Landowner assistance

Landowners may need financial or technical assistance to manage riparian areas on their property. There are a number of governmental agencies and other organizations willing to provide assistance to landowners wishing to manage riparian systems. Landowners are encouraged to begin their riparian management activities by contacting these organizations. Table 2 lists programs that can provide technical and/or financial assistance for riparian management practices.

Conclusion

The ultimate solution to maintaining/re-establishing watershed health is proper management of upland and riparian systems. Awareness of current conditions and relationships between land uses and resource goals is essential for successful restoration of riparian systems.

Table 2 Assistance programs for riparian systems management

Program	Land eligibility	Type of assistance	Opportunities for riparian area management	Contact
Conservation Reserve Program (CRP)	Highly erodible land, wetland, and certain other lands with cropping history. Streamside areas in pasture land, filter strips, forest buffers, and flood plain wetlands	50% cost-share for establishing permanent cover and conservation practices and annual rental payments for land enrolled in 10- to 15-year contracts. Additional financial incentives are available for some practices	Annual rental payments may include an additional amount up to $5 per acre per year as an incentive to perform certain maintenance obligations including riparian habitat	NRCS or FSA State or local office
Environmental Quality Incentives Program (EQIP)	Conservation practices such as riparian buffers, grazing systems, filter strips, manure management buildings, and wildlife habitat improvement	Up to 75% cost-share, as well as incentive payments to landowners who employ nutrient, manure, and integrated pest management practices. Also provides technical assistance and education to landowners	Incentive payments may be provided for up to 3 years to encourage producers to carry out management practices such as prescribed burning, that may not otherwise be carried out	NRCS State or local office
Partners for Fish and Wildlife Program (PFW)	Wetlands retained, created, or managed for wildlife	Up to 100% financial and technical assistance to restore wildlife habitat under minimum 10-year cooperative agreements. This program is used in conjunction with CREP to provide financial assistance in establishing riparian buffers	Restoration projects may include restoring wetland hydrology and wildlife habitat	Local office of the U.S. Fish & Wildlife Service
Wetlands Reserve Program (WRP)	Previously degraded wetland and adjacent upland buffer, with limited amount of natural wetland and existing or restorable riparian areas	Technical and financial assistance to address wetlands, wildlife habitat, soil, water, and related natural resource concerns in an environmentally beneficial and cost-effective manner; 75% cost-share for wetland restoration under 10-year contracts and 30-year easements; 100% cost-share on restoration under permanent easements	Can provide technical and financial assistance for riparian corridors providing the protected wetlands are no more than 1 mile apart; corridors must be used to connect two or more wetlands; and corridors must average no more than 200 feet wide on one side. Also restoring wetland hydrology and native vegetation	NRCS State or local office
Wildlife at Work	Corporate land	Technical assistance on developing habitat projects into a program that will allow companies to involve employees and the community	Can provide state-specific advice and/or contracts for prescribed burning, managed grazing, or other practices for riparian area management	Wildlife Habitat Council
Wildlife Habitat Incentives Program (WHIP)	Habitat restoration on private lands. Projects for outdoor education on locally owned public lands are also eligible	Up to 75% cost-share for conservation practices under 5- to 10-year contracts	Technical assistance is provided to help the participant maintain wildlife habitat	NRCS State or local office
Stewardship Incentive Program (SIP)	Acreage between 1 and 1,000 in nonindustrial private forest land	Up to 65% cost-share and technical assistance	Can provide technical and financial assistance for forest management plan development, tree planting, riparian and wetland improvement, and recreation and wildlife habitat improvement	NRCS State or local office

References

Online sources

Baker, T.T. What is a riparian area? *http://www.cahe.nmsu.edu/riparian/WHTRIPAREA.html* [Accessed 8 December 2005].

Bellows, B.C. 2003. Managed grazing in riparian areas. *http://attra.ncat.org/attra-pub/managedgraze.html* [Accessed 5 December 2005].

Malheur Agricultural Experiment Station. 2003. Riparian areas. *http://www.cropinfo.net/ripiarian.htm* [Accessed 11 December 2005].

Maryland Cooperative Extension. n.d. Riparian buffer systems. *http://www.riparianbuffers.umd.edu* [Accessed 1 December 2005].

Oklahoma Cooperative Extension Service. 1998. Riparian area. *http://www.okstate.edu/OSU_Ag/e-952.pdf* [Accessed 2 December 2005].

U.S. Department of Agriculture, Natural Resources Conservation Service. 1998. Stream visual assessment protocol. *http://www.nrcs.usda.gov/Technical/ECS/aquatic/svapfnl.pdf* [Accessed June 21 2006].

U.S. Department of Agriculture, Natural Resource Conservation Service. 1999. Conservation buffers. *http://www.wsi.nrcs.usda.gov/products/buffers.html* [Accessed 30 November 2005].

U.S. Department of Agriculture, Natural Resource Conservation Service. 2000. Conservation buffers to reduce pesticide losses. *http://permanent.access.gpo.gov/lps9018/www.wcc.nrcs.usda.gov/water/quality/common/pestmgt/files/newconbuf.pdf* [Accessed 21 June 2006].

Printed sources

Behnke, R.J, and R.F. Raleigh. 1978. Grazing and the riparian zone: impact and management perspectives. *In* Strategies for protection and management of flood-plain wetlands and other riparian ecosystems. USDA Forest Service. General Technical Report WO–12:263–267.

Briggs, M. 1993. Evaluating degraded riparian ecosystems to determine the potential effectiveness of revegetation. *In* Proceedings: Wildland Shrub and Arid Land Restoration Symposium. B.A. Roundy, E.D. McArthur, J.S. Haley, and D.K Mann. 1995. General Technical Report INT-GTR–315. U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Ogden, UT.

Brinson, M.M., B.I. Masters, and R.C. Plantico, J.S. Barclay. 1981. Riparian ecosystems: their ecology and status. U.S. Fish & Wildlife Service. Biological Services Program. FWS/OBS–81–17.

Castelle, A.J., A.W. Johnson, and C. Conolly. 1994. Wetland and stream buffer size requirement-a review. Journal of Environmental Quality 23:878–882.

Claire, E.W. 1980. Stream habitat and riparian restoration techniques: guidelines to consider in their use. *In* Proceedings of a workshop for design of fish habitat and watershed restoration projects. County Squire, OR.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, and V.O. Shanholtz. 1988. Evaluation of vegetated filter strips as a best management practice for feedlots. Journal of the Water Pollution Control Federation 60:1231–1238.

Kauffman, J.B., and W.C. Krueger. 1984. Livestock impacts on riparian ecosystems and streamside management implications—a review. Journal of Range Management 37:430–438.

Miranowski, J.A., and R.L. Bender. 1982. Impact of erosion control policies on wildlife habitat on private lands. Journal of Soil and Water Conservation 40:87–91.

Peterjohn, W.T., and D.L. Correll. 1984. Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. Ecology 65:1466–145.

Swift, L.W., Jr. 1986. Filter strip width for forest roads in the Southern Appalachians. Southern Journal of Applied Forestry 10:27–34.

U.S. Department of Agriculture, Forest Service. 1969. Wildlife Habitat Improvement Handbook. FSH2509.11. U.S. Government Printing Office. Washington, DC.

U.S. Department of Agriculture, Forest Service. 1996. Riparian forest buffers: function and design for protection and enhancement of water resources. Publication Number NA–PR–07–91.

U.S. Department of the Interior, Bureau of Land Management. 1993. Riparian area management: process for assessing proper functioning condition. USDI–BLM Technical Reference. 1737–9.

Natural Resources Conservation Service

Mailing address:

P.O. Box 2890
Washington, DC 20013

Street address:

14th and Independence Avenue SW
Washington, DC 20250

The Natural Resources Conservation Service provides leadership in a partnership effort to help people conserve, maintain, and improve our natural resources and environment.

www.nrcs.usda.gov

Wildlife Habitat Council

8737 Colesville Road, Suite 800
Silver Spring, MD 20910

(301) 588–8994

The mission of the Wildlife Habitat Council is to increase the amount of quality wildlife habitat on corporate, private, and public land. WHC engages corporations, public agencies, and private, nonprofit organizations on a voluntary basis as one team for the recovery, development, and preservation of wildlife habitat worldwide.

www.wildlifehc.org

Primary author: **Erika T. Machtinger**. Drafts reviewed by **Raissa Marks**, Wildlife Habitat Council; **William Hohman**, Natural Resources Conservation Service (NRCS); **Scott Crave**, University of Wisconsin; **Gene Barickman**, NRCS; **Rich Nelson**, NRCS; and **Terrell Baker**, New Mexico State University.

Great Trinity Forest Management Plan

Wetlands

An Introduction to Water Erosion Control

An Introduction to Water Erosion Control

Introduction

Soil loss due to water erosion reduces crop yields. Managing your soil and water resources is the best way to prevent soil from being washed away. This publication describes cost-effective ways to maintain successful crop production while protecting soil and water quality.

Snowmelt and rainfall are the driving forces for water erosion on the prairies. Bare soils are very vulnerable to erosion. Steep slopes and long, uninterrupted slopes are especially prone to water erosion. Silty soils, soils low in organic matter, and soils with an impermeable subsoil layer are also more susceptible to water erosion.

Bare soils are very vulnerable to erosion.

Plant cover - either growing plants or crop residue - protects soil from the erosive power of flowing water and rain drop impact. Conservation farming methods maintain a protective cover on the soil. These land use and management practices can be adapted to fit the needs of any farm operation. Some areas of Alberta suffer from severe water erosion. In these areas, special measures may be needed to control erosion.

A crop residue cover protects the soil.

Research shows that soil erosion substantially lowers crop yields.

Land Use and Management Practices

Select appropriate land use
Farm management decisions should consider the potential for erosion under different practices, especially on land that is marginal for annual crop production. Areas at high risk for erosion due to steep slopes or erodible soils may be better suited for forage production or grazing. Steeply sloped lands under cultivation can be converted to permanent cover to minimize erosion. Wooded areas with poor soils and steep slopes can be left in their natural state and managed profitably as woodlots. Alternative land uses can conserve the soil and have environmental benefits, while remaining profitable to the farm operation.

Steeply sloped land can be used for forage production.

Wooded areas with poor soils and steep slopes can be managed as woodlots.

Maintain organic matter
Soil organic matter is very important for good crop production and for reducing soil erosion. Organic matter is made up of dead plant material. During decomposition, this material releases nutrients for plants. Organic matter also improves soil structure and tilth. Organic matter and micro-organisms cement individual soil particles into larger aggregates. Soils high in organic matter have large, stable aggregates which resist erosion. A soil with stable aggregates also has more large pore spaces to hold water. With this increased moisture-holding ability, there is less ponding in fields, and less runoff and erosion.

To maintain soil quality and fertility, new additions of plant material must equal the rate of organic matter decomposition and nutrient use by plants. Conventional tillage and fallowing practices increase soil temperature and also mix and aerate the soil, causing faster organic matter decomposition. The result has been a long-term decline in soil organic matter on the prairies.

Returning crop residue to the soil helps to replace organic matter and plant nutrients. Rotations which include forages return more residues to the soil and increase fertility. Manure applications and legume plowdown are also good sources of organic matter and nutrients.

Soils high in organic matter are better able to resist erosion.

Maintain crop residue cover
One of the best ways to reduce erosion is to protect the soil surface with a cover of growing plants or crop residue. Surface cover cushions the impact of rain drops so soil particles are not as easily dislodged and moved. It also slows the flow of water, giving the soil time to absorb more water and thereby reducing runoff and erosion. An Alberta research study has shown that any increase in infiltration is directly related to a decrease in runoff. As well, crop residue traps snow and reduces evaporation for higher soil moisture which can improve crop yields, especially in a dry year.

Standing stubble and evenly spread straw and chaff protect the soil during spring runoff. Tillage should be kept to a minimum because it reduces the crop residue cover. Conservation tillage systems that leave most of the crop residue on the surface will reduce erosion and may have other benefits, such as lower equipment operating costs and labour inputs.

A wide blade cultivator manitains a good crop residue cover.

Reduce tillage
Conventional tillage buries the protective crop residue cover and disturbs the soil. The loose soil particles are easily detached by rain drops and running water. These factors lead to increased runoff and erosion.

Alberta research shows that switching to reduced or zero tillage systems is needed to protect soils on steeper and longer slopes from erosion. Reduced and minimum tillage systems leave a good crop residue cover to prevent erosion and conserve soil moisture. These systems also save time and energy, and costs are usually similar to or lower than those for conventional tillage systems.

Tillage is reduced by replacing some tillage operations for weed control with herbicide applications, or by using alternative tillage equipment that helps maintain a good residue cover (see table).

Residue management is important in all conservation tillage systems. Straw and chaff must be spread evenly at harvest to avoid or reduce such problems as: plugging during subsequent operations; poor seed germination; disease, weed and insect infestations; and nutrient tie-up.

Use zero tillage or direct seeding
Zero tillage systems minimize soil disturbance to maintain as much crop residue cover as possible to conserve soil moisture and prevent erosion. Long-term zero tillage also increases soil organic matter and improves soil quality and fertility.

Direct seeding also aims to conserve both soil moisture and soil. It differs from zero tillage in that some tillage options remain open. Minimal disturbance tillage operations (which leave the stubble standing) are sometimes used to apply fertilizer or incorporate herbicides or manure. A high percentage of crop residue remains on the surface to protect against erosion.

In both zero tillage and direct seeding systems, straw and chaff should be spread evenly across the entire width of the cut during combining. Harrowing may be needed to achieve uniform distribution, especially for heavy crop residues. The crop is seeded into the previous crop's stubble with minimal soil disturbance. Fertilizer is usually banded in a row near the seed. Herbicide applications replace tillage to control weeds. Management practices such as crop and herbicide rotations can be used to reduce weed problems.

Direct seeding and zero tillage systems save time and may have lower operating costs than conventional tillage systems. Although herbicide costs may increase, tillage-related costs decrease. Improvements in herbicides and sprayers, and the availability of seed drills able to operate in crop residues have made it easier to switch to zero tillage and direct seeding.

Direct seeding drills can seed into standing stubble.

Use conservation fallow

The long-term use of conventional fallow has caused serious soil degradation problems. In conventional fallow, weed control and seedbed preparation are done by tillage. Tillage buries crop residues, leaving the soil at risk from erosion for a long period.

While the soil is fallow, organic matter decomposes. This releases nitrogen and other nutrients for the following crop. However, with no residue input from crops during the fallow period, the amount of organic matter declines. The resulting poorer soil structure lowers the soil's ability to absorb water and increases runoff and erosion.


Fallow fields with no residue cover are very erosion prone.

If summerfallow is necessary, maintain a crop residue cover by minimizing surface disturbance. Herbicides can be used to control weeds, and one spray operation can replace two tillage operations. Wide blade cultivators or rod weeders minimize residue disturbance. Reducing tillage will protect the soil, conserve soil moisture and may also lower equipment operating costs and labour needs.


Conservation fallow maintains a crop residue cover to protect the soil.

Grow forages and use crop rotations
Forage crops are a component in many conservation farming systems. Forages can be grown on poorer soils or steep slopes not suitable for other crops, or used in rotations to build organic matter or break disease cycles. Forage cover protects the soil from erosion, and the fibrous roots hold the soil in place. As a perennial crop or plowdown, forages add organic matter and improve soil quality and structure. Improved soil structure allows the soil to absorb more water which reduces runoff and erosion.

Forage crops protect and improve the soil.

Legumes protect the soil and add nitrogen and organic matter.

Crop rotations for erosion control alternate forages with cereals and oilseeds or legumes. A well-planned rotation will improve soil quality and reduce erosion. Legumes in the rotation also add nitrogen and improve soil fertility. In drier areas, forages are harder to establish and may deplete moisture in a short-term rotation. An alternative annual crop such as a legume can be grown in these areas, or the forages can be maintained as a longer term crop.

Use direct seeding for pasture conversion
Direct seeding is a good option for converting hay or pasture land to annual crop production. It produces crop yields similar to those from conventionally plowed systems, and also prevents soil erosion and moisture loss. In conventional systems, intense operations such as plowing, heavy discing and cultivations are used. They are costly and time consuming, and expose soil to erosion.

Annual crops such as barley, oats and peas can be direct seeded into pasture sod after the pasture vegetation has been killed by a herbicide, usually glyphosate (Roundup). Fall spraying is usually preferred over spring spraying for better annual crop yields, weed/pasture plant control, and moisture conservation.

Both a disc drill (left) and an air drill (right) work well for direct seeding into sod.

Controlling Severe Erosion

The following measures control gullies and other severe erosion problems. For severe erosion, it is a good idea to get technical advice to find the best solution for your situation.

Grassed waterways

Gully erosion can often be controlled with a grassed waterway. A grassed waterway is a wide, shallow grassed channel that can carry a large volume of water quickly down a steep slope. It can be crossed by lifting tillage equipment.

Grassed waterways on agricultural land need to be able to carry peak runoff events from snowmelt and rainstorms (up to one cubic metre of water per second). The size of the waterway depends on the size of the area to be drained. A typical grassed waterway cross-section is saucer-shaped with a nearly flat-bottomed channel, a bottom width of 3 m and channel depth of at least 30 cm (see figure). Side slopes usually rise about 1 m for every 10 m horizontal distance. The waterway should follow the natural drainage path if possible.

Grassed waterways are shallow and easy to cross.

Some landowners produce hay on their waterways.

Cross-section of a typical grassed waterway.

The grass cover must be well established to handle high flows without erosion. A fast-growing cover crop, such as oats, provides initial, temporary protection for the waterway until the grass cover is established. Steeper portions of the waterway which are very susceptible to erosion can be protected by bio-degradable erosion control mats until the grass is established. Commercially available mats are made from straw, jute or aspen wood shavings.

A newly constructed waterway may need protection until the grass cover is established.

A well-built and maintained grassed waterway is very durable and erosion-resistant. The waterway should be mowed regularly, and weeds and brush must be controlled for the waterway to remain effective.

Lined channels
Lined channels are a means of dropping water to lower elevations along steep parts of a waterway. Those portions of the waterway are precisely shaped and carefully lined with heavy-duty erosion control matting, a type of geotextile product. The lining is covered with a layer of soil and seeded to grass. The resulting channel is highly resistant to erosion. Lined channels are appropriate for waterways that only carry water occasionally and have slopes up to 10 per cent. Companies that sell geotextile products provide detailed information on installation of their products.


An eroded gully.


Installing erosion control matting to create a lined channel.


After seeding the lined channel.

Drop structures
Drop structures are constructed along waterways to drop water to lower elevations without causing erosion. They are constructed of concrete, wood, metal or rock. Drop structures are the most costly but occasionally the most appropriate form of erosion control at specific locations along a waterway.

Small, intermittent waterways entering Alberta's deep river valleys are capable of causing very large gullies. ***Pipe drop structures*** are effective and economic for controlling this kind of erosion. Concrete sewer manholes or vertical corrugated steel pipes used with smaller diameter corrugated plastic or metal pipe, can transport water safely down long, steep slopes. A crawler tractor with a blade is used to form a firm bed down the length of the gully beginning at the top. A small track hoe is used to dig and install any buried sections of pipe. Above-ground portions of installed pipe can be secured with posts made of angle iron.


Crawler tractor forming a firm bed for a pipe drop structure.

Cross section of a pipe drop structure.

A ***slow release drop structure*** is an inexpensive and effective measure to control gully erosion. An earth berm is constructed upstream from the gully. Runoff water is held back temporarily by the berm. The water drains slowly through a small diameter plastic pipe (75 mm to 200 mm diameter) which runs under the berm and down the slope, and outlets at the bottom. A durable, high density polyethylene pipe is recommended. The small pipe can be held in place on the slope where needed with steel pins. This structure can only be used where there is an area with enough storage capacity upstream of the gully. The flooded area is fully drained within two days to prevent crop damage. In fact, the temporary backflooding benefits the crop by increasing soil moisture.

Slow release drop structure.
Inlet

Terracing

Water erosion over long, wide slopes without well-developed channels can be controlled with terracing. A channel and berm with up to 1 m difference in elevation are constructed across the slope to intercept runoff and carry it safely off the field. The material excavated to create the channel is used to build the berm. A survey is essential to find the best terrace location on the slope and to maintain proper grade for drainage. The project should be staked before construction to guide the equipment operators. Heavy-duty road construction equipment, such as a motor scraper, is needed to construct terraces.

Cross-section of one type of terrace.

Terraces are practical only when crop returns from the land are high enough to justify construction costs. Tillage and residue management options should be evaluated before considering terraces.

Terraces intercept runoff.

Summary

Many on-farm water erosion problems can be solved by the farm operator with minimal expense or inconvenience. Modifying tillage practices to keep crop residue on the surface can greatly reduce erosion. A crop residue cover also conserves soil moisture and improves soil tilth and fertility for better crop production. Costs for conservation tillage systems are usually similar to or lower than costs for conventional tillage systems over the long term. Preventing soil erosion helps to ensure the sustainability of the farm operation.

Grassed waterways, drop structures, lined channels or terraces are used to control more severe water erosion problems. Technical advice may be needed to implement some of these special measures.

Prepared by:
Douwe Vanderwel and Syd Abday

Source: Agdex 572-3.

Great Trinity Forest Management Plan

Wetlands

Basic Ground Water Hydrology

BASIC GROUND WATER HYDROLOGY

This overview of the science necessary to understand groundwater issues is taken from Chapter 2 of the Washington State, Department of Ecology, Ground Water Resource Protection Handbook, Published December 1986.

HYDROLOGIC CYCLE

The hydrologic cycle is a constant movement of water above, on, and below the earth's surface. It is a cycle that replenishes ground water supplies. It begins as water vaporizes into the atmosphere from vegetation, soil, lakes, rivers, snowfields and oceans-a process called **evapotranspiration**.

As the water vapor rises it condenses to form clouds that return water to the land through precipitation: rain, snow, or hail. **Precipitation** falls on the earth and either percolates into the soil or flows across the ground. Usually it does both. When precipitation percolates into the soil it is called **infiltration**; when it flows across the ground it is called **surface runoff**. The amount of precipitation that infiltrates, versus the amount that flows across the surface, varies depending on factors such as the amount of water already in the soil, soil composition, vegetation cover and degree of slope.

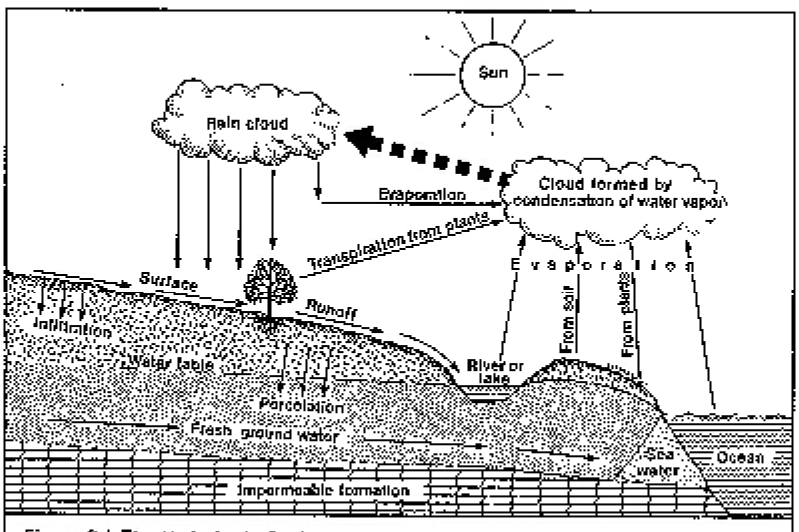


Figure 2.1 The Hydrologic Cycle

Surface runoff eventually reaches a stream or other surface water body where it is again evaporated into the atmosphere. Infiltration, however, moves under the force of gravity through the soil. If soils are dry, water is absorbed by the soil until it is thoroughly wetted. Then excess infiltration begins to move slowly downward to the water table. Once it reaches the water table, it is called **ground water**. Ground water continues to move downward and laterally through the subsurface. Eventually it discharges through hillside springs or seeps into streams, lakes, and the ocean where it is again evaporated to perpetuate the cycle

GROUND WATER AND SUBSURFACE WATER

Most rock or soil near the earth's surface is composed of solids and voids. The voids are spaces between grains of sand, or cracks in dense rock. All water beneath the land surface occurs within such void spaces and is referred to as underground or subsurface water.

Subsurface water occurs in two different zones. One zone, located immediately beneath the land surface in most areas, contains both water and air in the voids. This zone is referred to as the **unsaturated zone**. Other names for the unsaturated zone are zone of aeration and vadose zone.

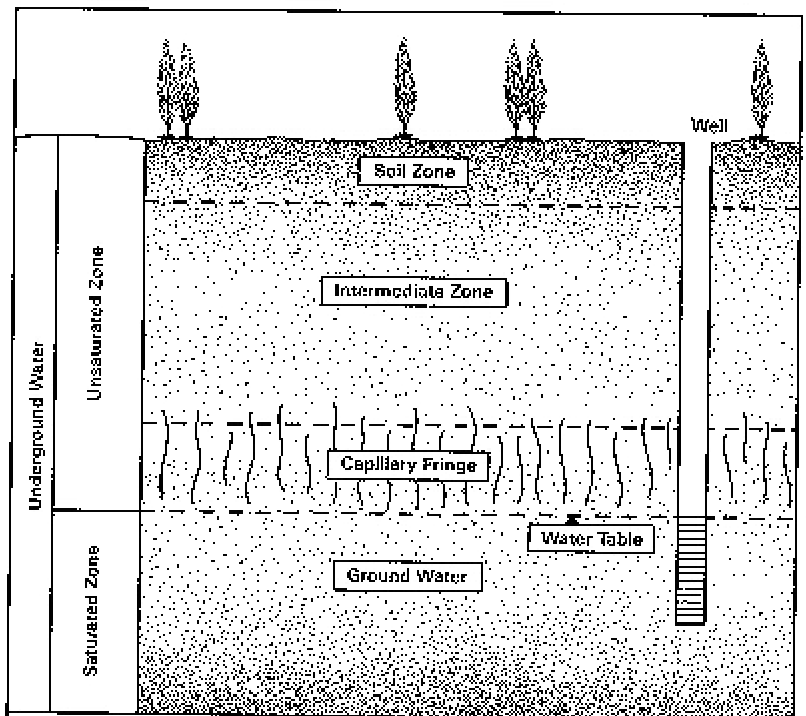


Figure 2.2 Zones of Underground Water

The unsaturated zone is almost always underlain by a second zone in which all voids are full of water. This zone is defined as the **saturated zone**. Water in the saturated zone is referred to as **ground water** and is the only subsurface water available to supply wells and springs.

Water table is often misused as a synonym for ground water. However, the water table is actually the boundary between the unsaturated and saturated zones. It represents the upper surface of the ground water. Technically speaking, it is the level at which the hydraulic pressure is equal to atmospheric pressure. The water level found in unused wells is often the same level as the water table, as shown in Figure 2.2.

AQUIFERS AND CONFINING BEDS

All geologic material beneath the earth's surface is either a potential aquifer or a confining bed. An **aquifer** is a saturated geologic formation that will yield a usable quantity of water to a well or spring. A **confining bed** is a geologic unit which is relatively impermeable and does not yield usable quantities of water. Confining beds, also referred to as aquitards, restrict the movement of ground water into and out of adjacent aquifers.

Ground water occurs in aquifers under two conditions: confined and unconfined. A **confined aquifer** is overlain by a confining bed, such as an impermeable layer of clay or rock. An **unconfined aquifer** has no confining bed above it and is usually open to infiltration from the surface.

Unconfined aquifers are often shallow and frequently overlie one or more confined aquifers. They are recharged through permeable soils and subsurface materials above the aquifer. Because they are usually the uppermost aquifer, unconfined aquifers are also called water table aquifers.

Confined aquifers usually occur at considerable depth and may overlie other confined aquifers. They are often recharged through cracks or openings in impermeable layers above or below them. Confined aquifers in complex geological formations may be exposed at the land surface and can be directly recharged from infiltrating precipitation. Confined aquifers can also receive recharge from an adjacent highland area such as a mountain range. Water infiltrating fractured rock in the mountains may flow downward and then move laterally into confined aquifers.

Windows are important for transmitting water between aquifers, particularly in glaciated areas such as the Puget Sound region. A window is an area where the confining bed is missing.

The water level in a confined aquifer does not rise and fall freely because it is bounded by the confining bed--like a lid. Being bounded causes the water to become pressurized. In some cases, the pressure in a confined aquifer is sufficient for a well to spout water several feet above the ground. Such wells are called **flowing artesian wells**. Confined aquifers are also sometimes called artesian aquifers.

When a well is drilled into an unconfined aquifer, its water level is generally at the same level as the upper surface of the aquifer. This is, in most cases, the water table. By contrast, when a well is drilled into a confined aquifer, its water level will be at some height above the top of the aquifer and perhaps above the surface of the land-depending on how much the water is pressurized. If a number of wells are drilled into a confined aquifer, the water level will rise in each well to a certain level. These well levels form an imaginary surface called the **potentiometric surface**. The potentiometric surface is to a confined aquifer what the water table is to an unconfined aquifer. It describes at what level the upper surface of a confined aquifer would occur if the confining bed were removed.

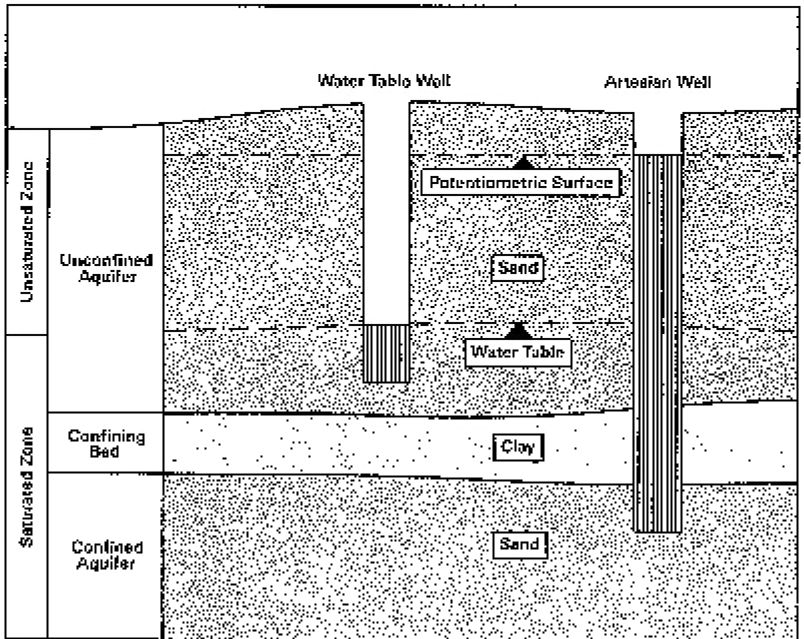


Figure 2.3 Aquifers and Confining Beds

The most productive aquifers, whether confined or unconfined, are generally in sand and gravel deposits. These tend to have large void spaces for holding water. Rocks with large openings such as solution cavities or fractures can also be highly productive aquifers. Generally, the smaller the grain size or the less fracturing, the less water an aquifer will produce. This is because there are fewer void spaces for holding water.

GROUND WATER RECHARGE AND DISCHARGE

Recharge is the process by which ground water is replenished. A **recharge** area is where water from precipitation is transmitted downward to an aquifer.

Most areas, unless composed of solid rock or covered by development, allow a certain percentage of total precipitation to reach the water table. However, in some areas more precipitation will infiltrate than in others. Areas which transmit the most precipitation are often referred to as "**high**" or "**critical**" **recharge areas**.

As described earlier, how much water infiltrates depends on vegetation cover, slope, soil composition, depth to the water table, the presence or absence of confining beds and other factors. Recharge is promoted by natural vegetation cover, flat topography, permeable soils, a deep water table and the absence of confining beds.

Discharge areas are the opposite of recharge areas. They are the locations at which ground water leaves the aquifer and flows to the surface. Ground water discharge occurs where the water table or potentiometric surface intersects the land surface. Where this happens, **springs** or **seeps** are found. Springs and seeps may flow into fresh water bodies, such as lakes or streams, or they may flow into saltwater bodies.

Under the force of gravity, ground water generally flows from high areas to low areas. Consequently, high areas-such as hills or plateaus-are typically where aquifers are recharged and low areas-such as river valleys-are where they discharge. However, in many instances aquifers occur beneath river valleys, so river valleys can also be important recharge areas. Typical recharge and discharge areas are depicted in Figure 2.4.

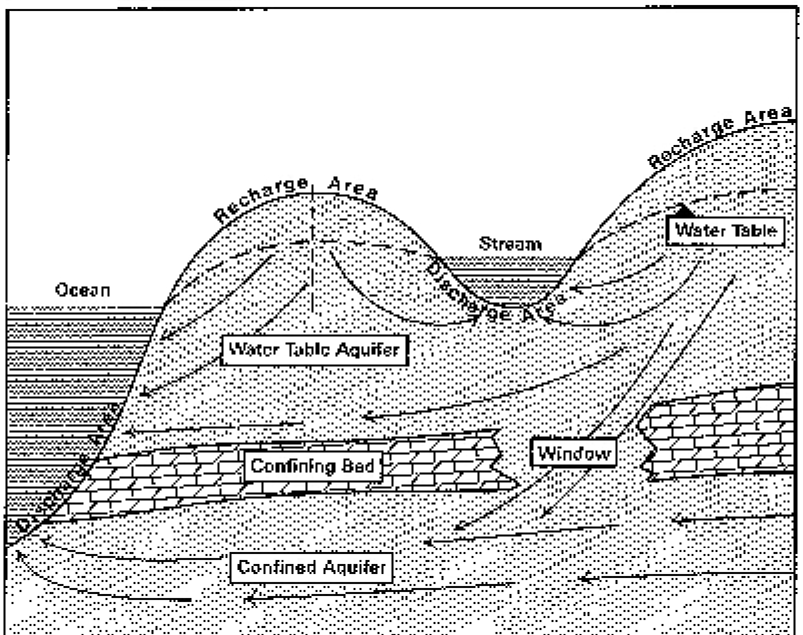


Figure 2.4 Recharge and Discharge Areas

GROUND WATER MOVEMENT

Gravity is the force that moves ground water which generally means it moves downward. However, ground water can also move upwards if the pressure in a deeper aquifer is higher than that of the aquifer above it. This often occurs where pressurized confined aquifers occur beneath unconfined aquifers.

A ground water **divide**, like a surface water divide, indicates distinct ground water flow regions within an aquifer. A divide is defined by a line on the either side of which ground water moves in opposite directions. Ground water divides often occur in highland areas, and in some geologic environments coincide with surface water divides. This is common where aquifers are shallow and strongly influenced by surface water flow. Where there are deep aquifers, surface and ground water flows may have little or no relationship.

As ground water flows downwards in an aquifer, its upper surface slopes in the direction of flow. This slope is known as the **hydraulic gradient** and is determined by measuring the water elevation in wells tapping the aquifer. For confined aquifers, the hydraulic gradient is the slope of the potentiometric surface. For unconfined aquifers, it is the slope of the water table.

The velocity at which ground water moves is a function of three main variables: hydraulic conductivity, (commonly called permeability) porosity, and the hydraulic gradient. The hydraulic conductivity is a measure of the water transmitting capability of an aquifer. High hydraulic conductivity values indicate an aquifer can readily transmit water; low values indicate poor transmitting ability. Because geologic materials vary in their ability to transmit water, hydraulic conductivity values range through 12 orders of magnitude. Some clays, for example, have hydraulic conductivities of .00000001 centimeters per second (cm/sec), whereas gravel hydraulic conductivities can range up to 10,000 cm/sec. Hydraulic conductivity values should not be confused with velocity even though they appear to have similar units. Cm/sec, for example, is not a velocity but is actually a contraction of cubic centimeters per square centimeter per second (cm3/cm2-sec).

In general, course-grained sands and gravels readily transmit water and have high hydraulic conductivities (in the range of 50-1000 m/day). Fine grained silts and clays transmit water poorly and have low hydraulic conductivities (in the range of .001-0.1 m/day).

The porosity of an aquifer also has a bearing on its ability to transmit water. Porosity is a measure of the amount of open space in an aquifer. Both clays and gravels typically have high porosities, while silts, sands, and mixtures of different grain sizes tend to have low porosities.

The velocity at which water travels through an aquifer is proportional to the hydraulic conductivity and hydraulic gradient, and inversely proportional to the porosity. Of these three factors, hydraulic conductivity generally has the most effect on velocity. Thus, aquifers with high hydraulic conductivities, such as sand and gravel deposits, will generally transmit water faster than aquifers with lower hydraulic conductivities, such as silt or clay beds.

Ground water velocities are typically very slow, ranging from around a centimeter per day to almost a meter per day. However, some very rapid flow can occur in rock with solution cavities or in fractured rock. Very high flow rates (more than 15 m/day) are associated, for example, with some parts of the Columbia River basalt in eastern Washington.

The volume of ground water flow is controlled by the hydraulic conductivity and gradient, and in addition is controlled by the volume of the aquifer. A large aquifer will have a greater volume of ground water flow than a smaller aquifer with similar hydraulic properties. But if the cross-sectional area-that is, the height and width-are the same for both aquifers, the aquifer with a greater hydraulic conductivity and hydraulic gradient will produce a greater volume of water.

WATER SUPPLY WELLS

How aquifers respond when water is withdrawn from a well is an important topic in ground water hydrology. It explains how a well gets its water, how it can deplete adjacent wells, or how it can induce contamination.

When water is withdrawn from a well, its water level drops. When the water level falls below the water level of the surrounding aquifer, ground water flows into the well. The rate of inflow increases until it equals the rate of withdrawal.

The movement of water from an aquifer into a well alters the surface of the aquifer around the well. It forms what is called a **cone of depression**. A cone of depression is a funnel-shaped drop in the aquifer's surface. The well itself penetrates the bottom of the cone. Within a cone of depression, all ground water flows to the well. The outer limits of the cone define the well's **area of influence**.

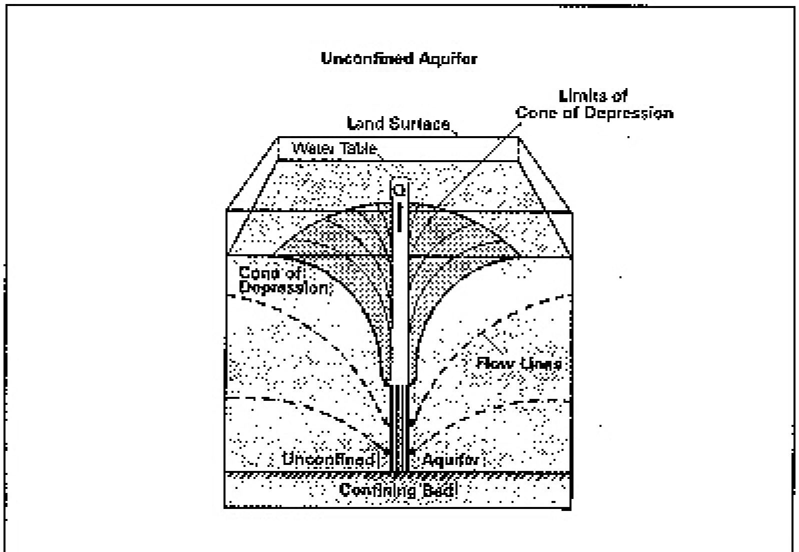


Figure 2.5 Cone of Depression

Great Trinity Forest Management Plan

Wetlands

Streams and Drainage Systems

Prof. Stephen A. Nelson	EENS 111
Tulane University	Physical Geology
Streams and Drainage Systems	

This page last updated on 15-Oct-2003

Streams

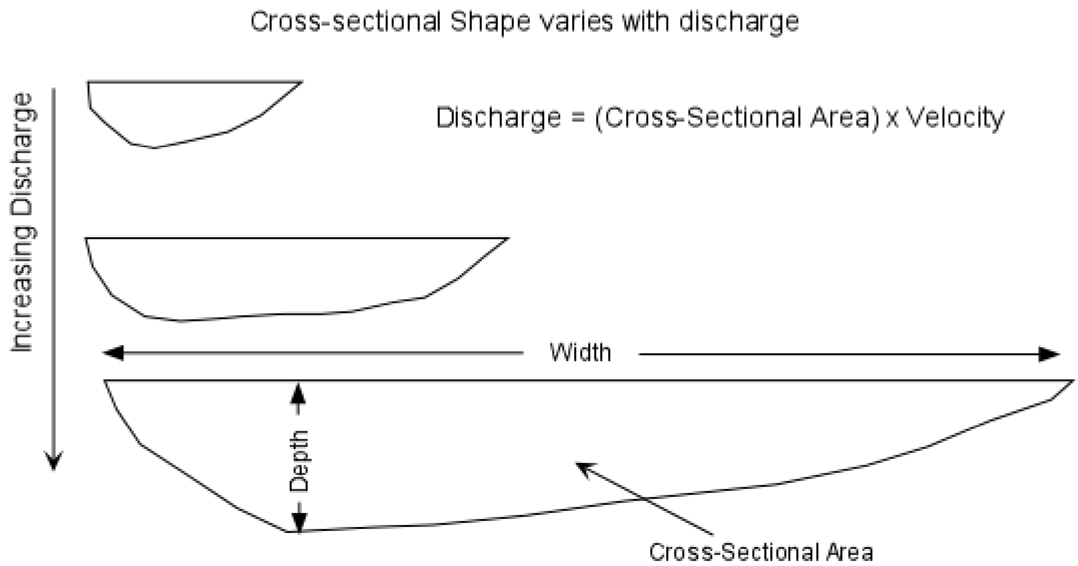
A ***stream*** is a body of water that carries rock particles and dissolved ions and flows down slope along a clearly defined path, called a ***channel***. Thus, streams may vary in width from a few centimeters to several kilometers. Streams are important for several reasons:

- Streams carry most of the water that goes from the land to the sea, and thus are an important part of the water cycle.
- Streams carry billions of tons of sediment to lower elevations, and thus are one of the main transporting mediums in the production of sedimentary rocks.
- Streams carry dissolved ions, the products of chemical weathering, into the oceans and thus make the sea salty.
- Streams are a major part of the erosional process, working in conjunction with weathering and mass wasting. Much of the surface landscape is controlled by stream erosion, evident to anyone looking out of an airplane window.
- Streams are a major source of water and transportation for the world's human population. Most population centers are located next to streams.

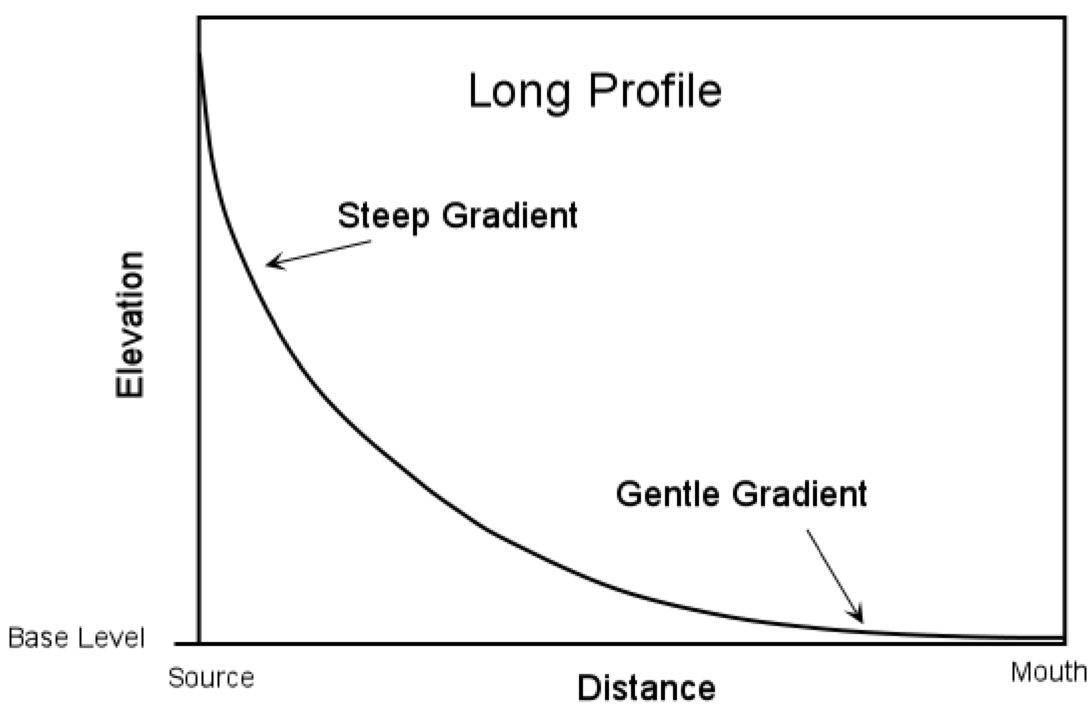
Geometry and Dynamics of Stream Channels

The stream channel is the conduit for water being carried by the stream. The stream can continually adjust its channel shape and path as the amount of water passing through the channel changes. The volume of water passing any point on a stream is called the ***discharge***. Discharge is measured in units of volume/time (m^3/sec).

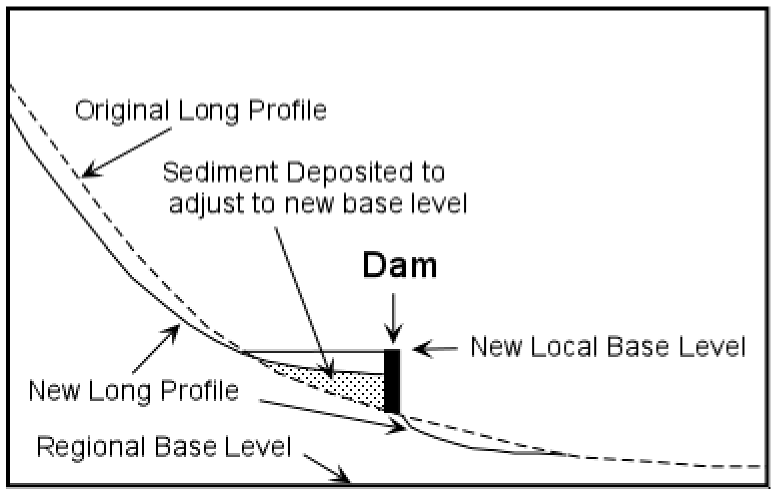
- **Cross Sectional Shape -** varies with position in the stream, and discharge**.** The deepest part of channel occurs where the stream velocity is the highest. Both width and depth increase downstream because discharge increases downstream. As discharge increases the cross sectional shape will change, with the stream becoming deeper and wider.



- **Long Profile -** a plot of elevation versus distance. Usually shows a steep ***gradient*** near the source of the stream and a gentle gradient as the stream approaches its mouth.

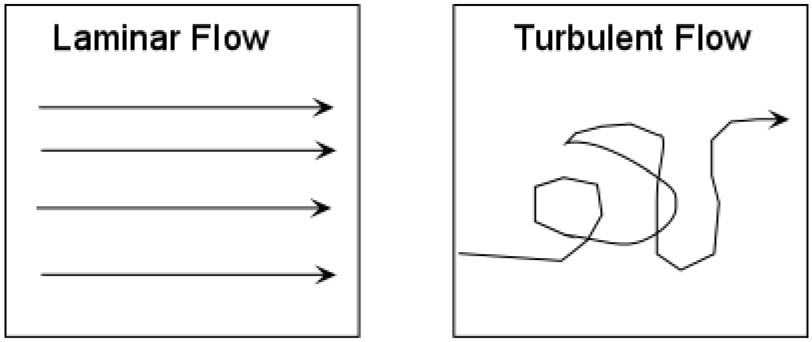


Base Level - base level is defined as the limiting level below which a stream cannot erode its channel. For streams that empty into the oceans, base level is sea level. Local base levels can occur where the stream meets a resistant body of rock, where a natural or artificial dam impedes further channel erosion, or where the stream empties into a lake.



When a natural or artificial dam impedes stream flow, the stream adjusts to the new base level by adjusting its long profile. In the example here, the long profile above and below the dam are adjusted. Erosion takes place downstream from the dam (especially if it is a natural dam and water can flow over the top). Just upstream from the dam the velocity of the stream is lowered so that deposition of sediment occurs causing the gradient to become lower.

- **Velocity -** A stream's velocity depends on position in the stream channel, irregularities in the stream channel caused by resistant rock, and stream gradient. The average velocity is the time it takes a given particle of water to traverse a given distance. Stream flow can be either laminar, in which all water molecules travel along similar parallel paths, or turbulent, in which individual particles take irregular paths. Turbulent flow can keep sediment in suspension longer than laminar flow and aids in erosion of the stream bottom. Average linear velocity is generally greater in laminar flow than in turbulent flow.



- ***Discharge*** **-** The discharge of a stream is the amount of water passing any point in a given time.

$$Q = A \times V$$

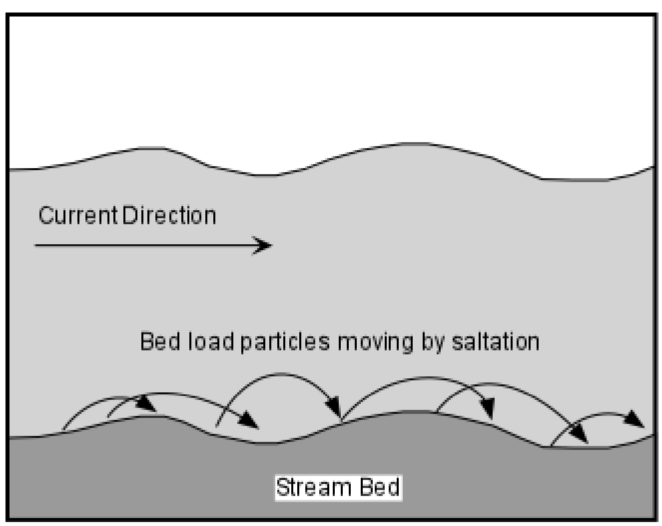
Discharge (m^3/sec) = Cross-sectional Area [width x average depth] (m^2) x Average Velocity (m/sec).

As the amount of water in a stream increases, the stream must adjust its velocity and cross sectional area in order to form a balance. Discharge increases as more water is added through rainfall, tributary streams, or from groundwater seeping into the stream. As discharge increases, generally width, depth, and velocity of the stream also increase.

- ***Load*** - The rock particles and dissolved ions carried by the stream are the called the stream's ***load.*** Stream load is divided into three parts.

    - ***Suspended Load*** - particles that are carried along with the water in the main part of the streams. The size of these particles depends on their density and the velocity of the stream. Higher velocity currents in the stream can carry larger and denser particles.

    - ***Bed Load*** - coarser and denser particles that remain on the bed of the stream most of the time but move by a process of saltation (jumping) as a result of collisions between particles, and turbulent eddies. Note that sediment can move between bed load and suspended load as the velocity of the stream changes.



- *Dissolved Load* - ions that have been introduced into the water by chemical weathering of rocks. This load is invisible because the ions are dissolved in the water. The dissolved load consists mainly of HCO_3^- (bicarbonate ions), Ca^{+2}, SO_4^{-2}, Cl^-, Na^{+2}, Mg^{+2}, and K^+. These ions are eventually carried to the oceans and give the oceans their salty character. Streams that have a deep underground source generally have higher dissolved load than those whose source is on the Earth's surface.

Changes Downstream

As one moves along a stream in the downstream direction:

- Discharge increases, as noted above, because water is added to the stream from tributary streams and groundwater.
- As discharge increases, the width, depth, and average velocity of the stream increase.
- The gradient of the stream, however, will decrease.

It may seem to be counter to your observations that velocity increases in the downstream direction, since when one observes a mountain stream near the headwaters where the gradient is high, it appears to have a higher velocity than a stream flowing along a gentle gradient. But, the water in the mountain stream is likely flowing in a turbulent manner, due to the large boulders and cobbles which make up the streambed. If the flow is turbulent, then it takes longer for the water to travel the same linear distance, and thus the average velocity is lower.

Also as one moves in the downstream direction,

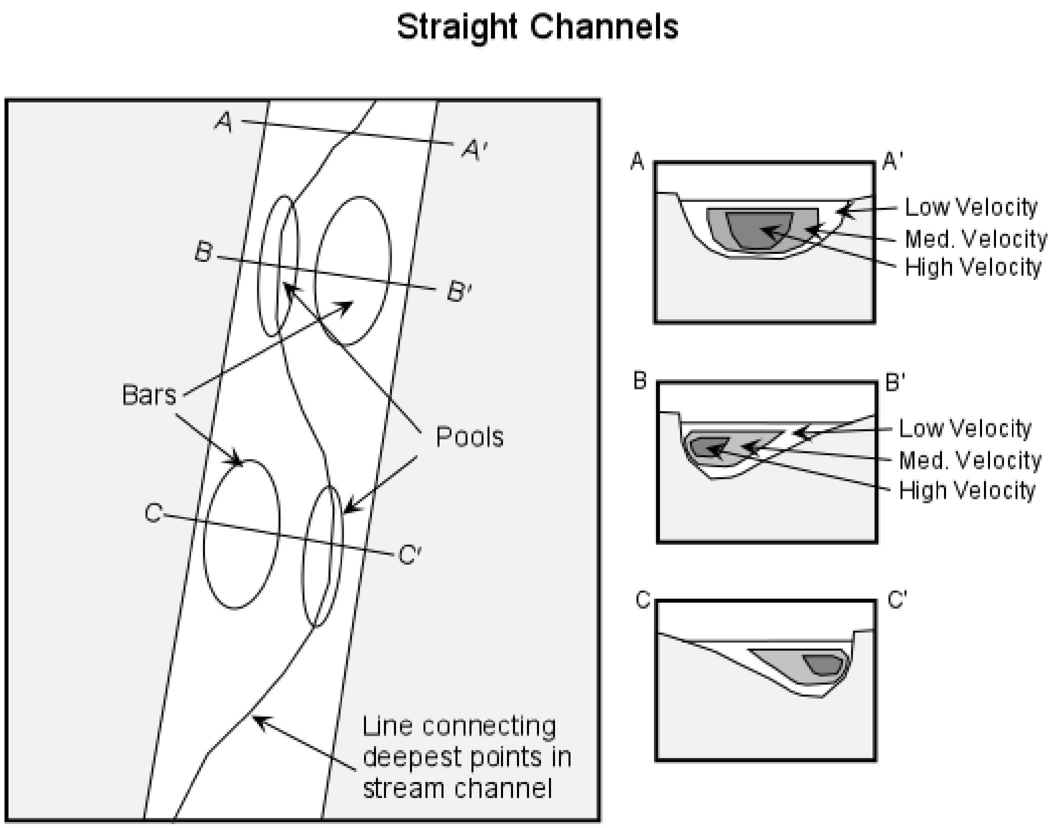
- The size of particles that make up the bed load of the stream tends to decrease. Even though the velocity of the stream increases downstream, the bed load particle size decreases mainly because the larger particles are left in the bed load at higher elevations and abrasion of particles tends to reduce their size.
- The composition of the particles in the bed load tends to change along the stream as different bedrock is eroded and added to the stream's load.

Floods

Floods occur when the discharge of the stream becomes too high to be accommodated in the normal stream channel. When the discharge becomes too high, the stream widens its channel by overtopping its banks and flooding the low-lying areas surrounding the stream. The areas that become flooded are called ***floodplains***.

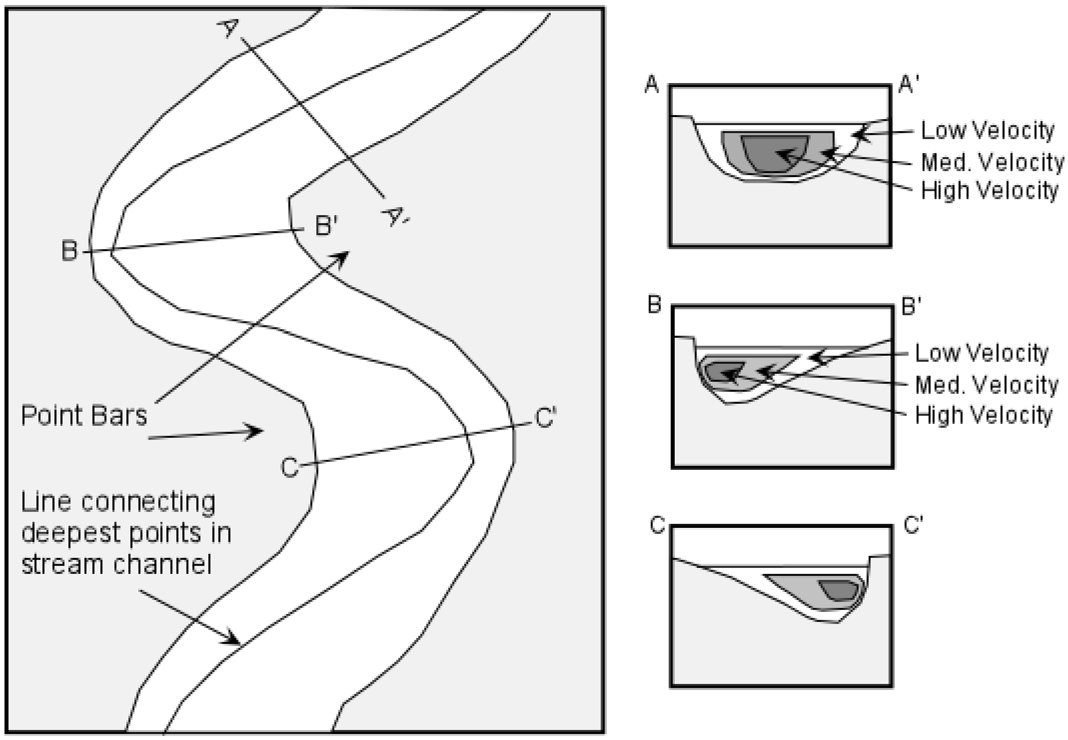
Channel Patterns

- **Straight Channels -** Straight stream channels are rare. Where they do occur, the channel is usually controlled by a linear zone of weakness in the underlying rock, like a fault or joint system. Even in straight channel segments water flows in a sinuous fashion, with the deepest part of the channel changing from near one bank to near the other. Velocity is highest in the zone overlying the deepest part of the stream. In these areas, sediment is transported readily resulting in ***pools***. Where the velocity of the stream is low, sediment is deposited to form ***bars***. The bank closest to the zone of highest velocity is usually eroded and results in a ***cutbank***.

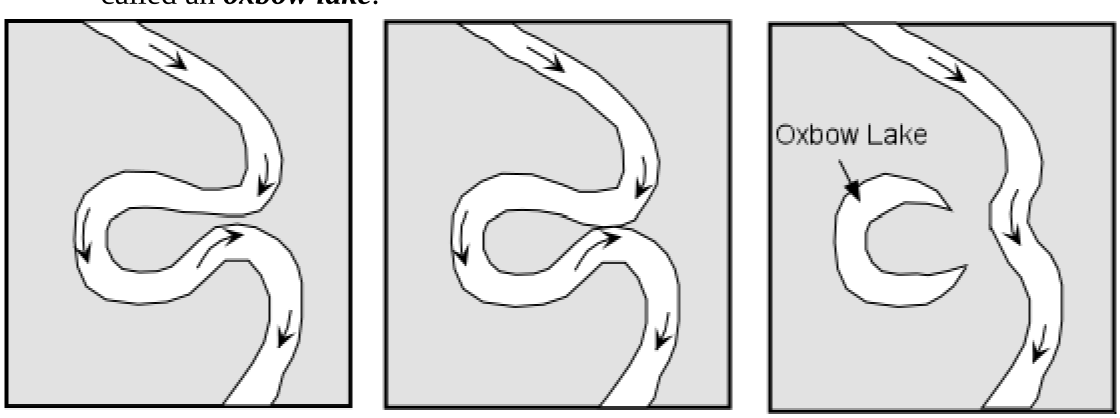


- **Meandering Channels -** Because of the velocity structure of a stream, and especially in streams flowing over low gradients with easily eroded banks, straight channels will eventually erode into ***meandering channels***. Erosion will take place on the outer parts of the meander bends where the velocity of the stream is highest. Sediment deposition will occur along the inner meander bends where the velocity is low. Such deposition of sediment results in exposed bars, called ***point bars***. Because meandering streams are continually eroding on the outer meander bends and depositing sediment along the inner meander bends, meandering stream channels tend to migrate back and forth across their flood plain.

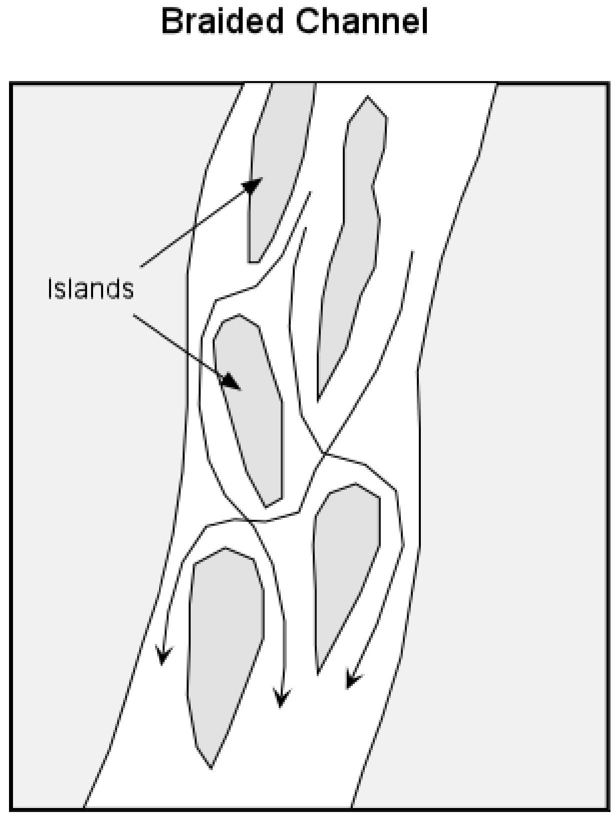
Meandering Channels



If erosion on the outside meander bends continues to take place, eventually a meander bend can become cut off from the rest of the stream. When this occurs, the cutoff meander bend, because it is still a depression, will collect water and form a type of lake called an ***oxbow lake***.



- **Braided Channels** - In streams having highly variable discharge and easily eroded banks, sediment gets deposited to form bars and islands that are exposed during periods of low discharge. In such a stream the water flows in a braided pattern around the islands and bars, dividing and reuniting as it flows downstream. Such a channel is termed a ***braided channel***. During periods of high discharge, the entire stream channel may contain water and the islands are covered to become submerged bars. During such high discharge, some of the islands could erode, but the sediment would be re-deposited as the discharge decreases, forming new islands or submerged bars. Islands may become resistant to erosion if they become inhabited by vegetation



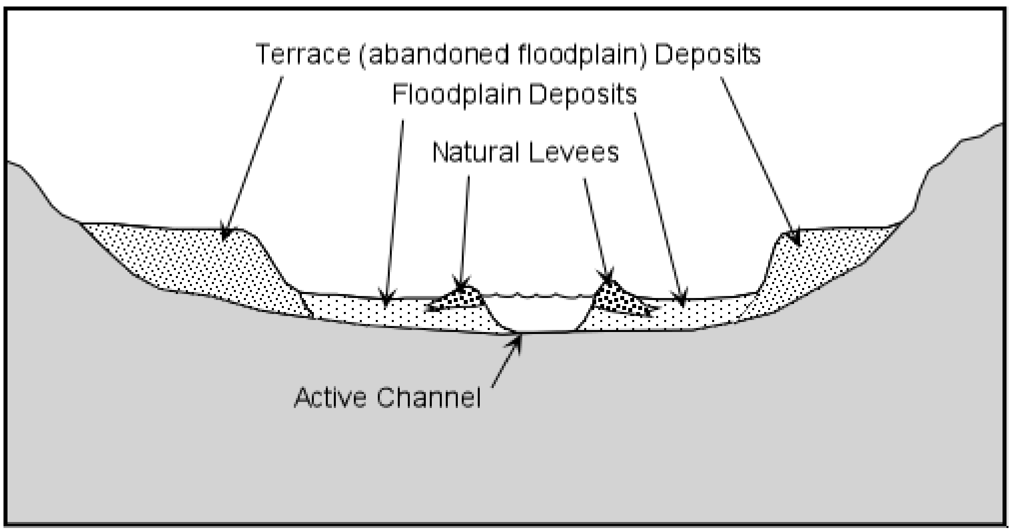
Erosion by Streams

Streams erode because they have the ability to pick up rock fragments and transport them to a new location. The size of the fragments that can be transported depends on the velocity of the stream and whether the flow is laminar or turbulent. Turbulent flow can keep fragments in suspension longer than laminar flow. Streams can also eroded by undercutting their banks resulting in mass-wasting processes like slumps or slides. When the undercut material falls into the stream, the fragments can be transported away by the stream. Streams can cut deeper into their channels if the region is uplifted or if there is a local change in base level. As they cut deeper into their channels the stream removes the material that once made up the channel bottom and sides.

Stream Deposits

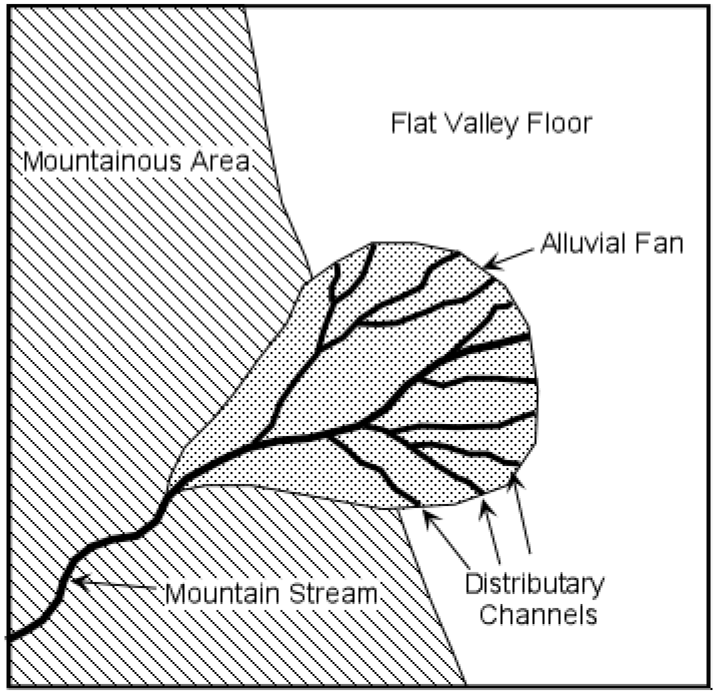
Sudden changes in velocity can result in deposition by streams. Within a stream we have seen that the velocity varies with position, and, if sediment gets moved to the lower velocity part of the stream the sediment will come out of suspension and be deposited. Other sudden changes in velocity that affect the whole stream can also occur. For example if the discharge is suddenly increased, as it might be during a flood, the stream will overtop its banks and flow onto the floodplain where the velocity will then suddenly decrease. This results in deposition of such features as levees and floodplains. If the gradient of the stream suddenly changes by emptying into a flat-floored basin, an ocean basin, or a lake, the velocity of the stream will suddenly decrease resulting in deposition of sediment that can no longer be transported. This can result in deposition of such features as alluvial fans and deltas.

- ***Floodplains and Levees*** **-** As a stream overtops its banks during a flood, the velocity of the flood will first be high, but will suddenly decrease as the water flows out over the gentle gradient of the floodplain. Because of the sudden decrease in velocity, the coarser grained suspended sediment will be deposited along the riverbank, eventually building up a natural levee. Natural levees provide some protection from flooding because with each flood the levee is built higher and therefore discharge must be higher for the next flood to occur. (Note that the levees we see along the Mississippi River here in New Orleans are not natural levees, but man made levees, built to protect the floodplain from floods).

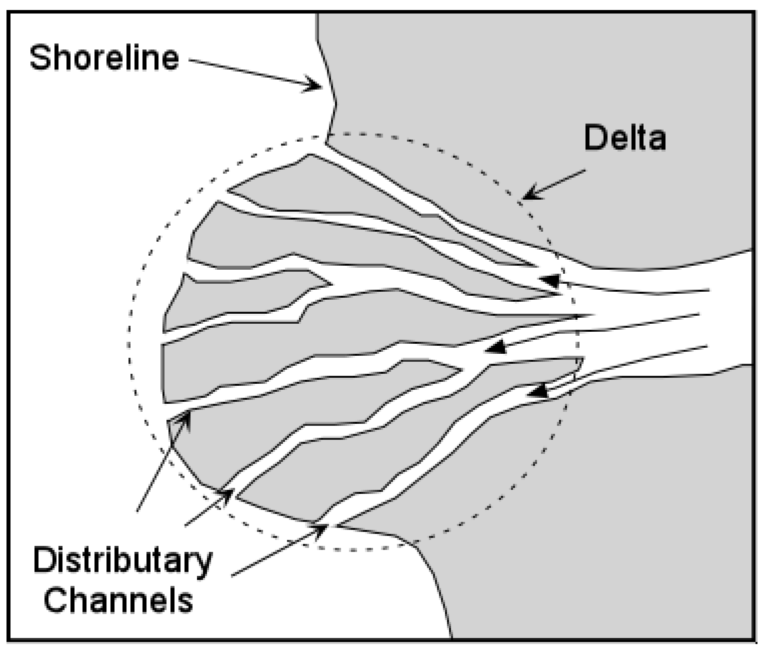


- ***Terraces*** **-** Terraces are exposed former floodplain deposits that result when the stream begins down cutting into its flood plain (this is usually caused by regional uplift or by lowering the regional base level, such as a drop in sea level).

- ***Alluvial Fans*** - When a steep mountain stream enters a flat valley, there is a sudden decrease in gradient and velocity. Sediment transported in the stream will suddenly become deposited along the valley walls in an alluvial fan. As the velocity of the mountain stream slows it becomes choked with sediment and breaks up into numerous distributary channels.



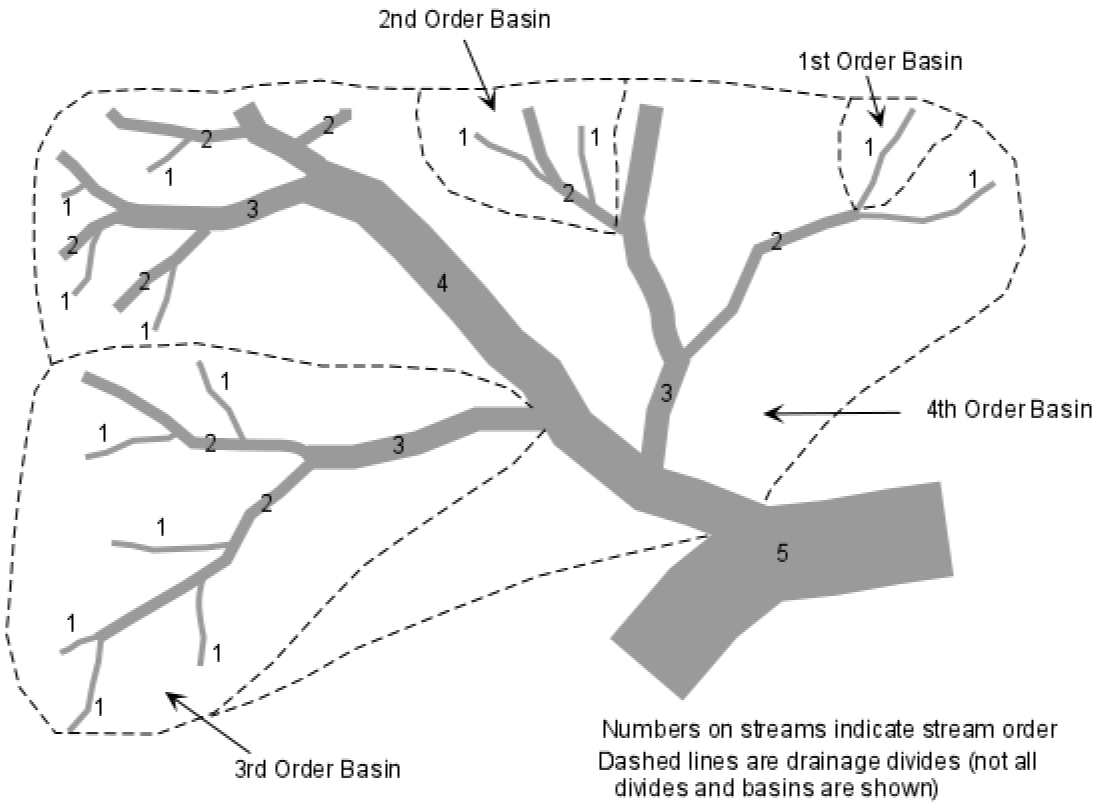
- Deltas - When a stream enters a standing body of water such as a lake or ocean, again there is a sudden decrease in velocity and the stream deposits its sediment in a deposit called a delta. Deltas build outward from the coastline, but will only survive if the ocean currents are not strong enough to remove the sediment. As the velocity of a stream decreases on entering the delta, the stream becomes choked with sediment and conditions become favorable to those of a braided stream channel, but instead of braiding, the stream breaks into many smaller streams called distributary streams.



Drainage Systems

- **Drainage Basins and Divides -** Drainage systems develop in such a way as to efficiently move water off the land. Each stream in a drainage system drains a certain area, called a drainage basin. In a single drainage basin, all water falling in the basin drains into the same stream. Drainage basins can range in size from a few km^2, for small streams, to extremely large areas, such as the Mississippi River drainage basin which covers about 40% of the contiguous United States (see figure 14.29 in your text). A divide separates each drainage basin from other drainage basins.

- **Stream Order** - The smallest streams in a drainage network have no tributary streams. These are called first order streams. Two first order streams unite to form a second order stream. Second order streams only have first-order streams as tributaries. Third order streams only have second and first order streams as tributaries, etc. As the order of the stream increases, the discharge increases, the gradient decreases, the velocity increases, and the channel dimensions (width and depth) increase to accommodate the increased discharge.



- **Drainage Patterns -** Drainages tend to develop along zones where rock type and structure are most easily eroded. Thus various types of drainage patterns develop in a region and these drainage patterns reflect the structure of the rock. You study these drainage patterns in Lab, and examples are shown in figure 14.32 of your text.

- **Continental Divides** - Continents can be divided into large drainage basins that empty into different ocean basins. For example: North America can be divided into several basins west of the Rocky Mountains that empty into the Pacific Ocean. Streams in the northern part of North America empty into the Arctic Ocean, and streams East of the Rocky Mountains empty into the Atlantic Ocean or Gulf of Mexico. Lines separating these major drainage basins are termed Continental Divides. Such divides usually run along high mountain crests that formed recently enough that they have not been eroded. Thus major continental divides and the drainage patterns in the major basins reflect the recent geologic history of the continents.

UNIVERSITY OF FLORIDA
EXTENSION
Institute of Food and Agricultural Sciences

CIR1185

Forests, Hydrology, and Water Quality: Impacts of Silvicultural Practices[1]

Susan E. Moore[2]

This paper explains the potential effects of forest management practices on water quality and hydrology, and presents effective ways to minimize or eliminate these effects, including Best Management Practice (BMP) compliance.

Introduction

The connection between forests and water is complex and varies with topography, geology, climate and vegetation. Forest management practices, even upland forestry activities, while seemingly removed from the wetlands and waterbodies, can impact water quality and hydrology through runoff, erosion, stream flow, infiltration or other means.

Water quality refers to the chemical, physical and biological condition of the water in a water-body, including the stream channel, banks, and stream or lake bottoms, while water pollution refers to the condition with respect to a standard set for water use. Impacts to hydrology involve changes in the amount, distribution and timing of water as it occurs on, or moves through a site. This can include such hydrologic properties as runoff, water table level and storm flow.

Historically, control of water pollution focused on “point” sources—effluents (flows) entering waterbodies through contained structures such as pipes. With the passage of the Federal Clean Water Act in 1972, attention eventually also focused on reducing **“non-point” source (NPS)** pollution—effluent entering a waterbody in a diffuse manner—that was recognized as a major source of water pollution (Figure 1).

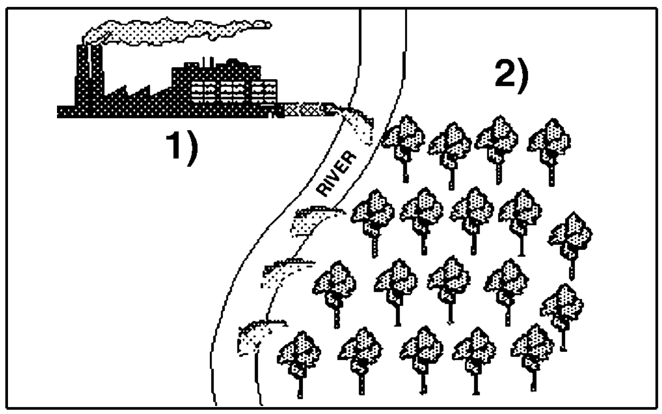


Figure 1. Potential sources of 1) Point and 2) Non-Point Source pollution.

Forestry was designated as one activity with the potential to produce non-point source pollution when carelessly managed.

1. This document is CIR 1185, one of a series of the School of Forest Resources and Conservation, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida. First published: April 1999. Please visit the EDIS Web site at **http://edis.ifas.ufl.edu.**
2. Susan E. Moore is a former Forested Wetlands Extension Specialist, School of Forest Resources and Conservation, Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, 32611.

Despite the potential role of forestry in NPS pollution, an EPA assessment of water quality in 1988 reported that only 3% of the river miles assessed in their study (which included 25% of the nation's miles of rivers and streams) were affected by forestry practices, and NPS problems from forestry activities are relevant in relatively few locations (EPA 1990).

In Florida, degradation of water quality from forestry activities is generally much less than that reported from other land uses such as agriculture, residential, commercial and industrial (Riekerk *et al*. 1985).

Nonetheless, water quality can be affected biologically, chemically or physically, directly or indirectly, through careless forestry operations. With proper care, these impacts can be managed and mitigated.

State **Best Management Practices (BMPs)** are designed to protect water quality, and hydrologic impacts can be moderated with site-specific management plans.

Water Quality

Water quality in relation to forestry practices refers to a few specific attributes including:

- suspended sediment (also called turbidity),
- bedload sediment,
- temperature,
- nutrient levels (such as nitrate and phosphorus), and
- toxins (chemical pesticides, for example).

A significant change in—or addition of—any of these can affect the biology of the system, and so, its health and function. In addition, logging activities can potentially impact stream ecosystems through altered inputs of organic matter such as leaf detritus (leaf and needle fragments and debris) and large woody debris.

These inputs may reduce stream oxygen levels and alter the microhabitat conditions necessary for the survival, breeding, foraging or resting activities of many organisms. In addition, if large woody debris inputs obstruct stream flow, it may reroute the flow resulting in bank erosion and sediment pollution.

Sediment

There are two kinds of sediment, which may be produced from forestry activities—bedload and suspended. bedload **sediments** are heavier particles, which move to the bottom of a stream. A significant increase in bedload sediment can reduce the volume of a waterbody available for water storage.

Suspended sediments are smaller mineral and organic particles, which float in the water and decrease the clarity, in other words, increase turbidity. **Turbidity** is the relative clarity of the water and is measured by light attenuation, in other words the scattering of light in the water column. Increased turbidity decreases the amount of light scattered in the water and can reduce algal photosynthesis levels and decrease the success of sight-feeding fish. Suspended sediment settling out can also interfere with microhabitats in a gravelly stream bottom by filling the gaps between rocks and impeding the flow of water through the gravelly bottom. This can smother fish eggs and in turn reduce dissolved oxygen levels in the bottom of the water column due to a decreased flow of well-aerated water (MacDonald *et al.*1991).

Suspended and bedload sediments may increase following forestry operations if the stream banks are harvested and left bare of vegetation or if forest roads are poorly designed, laid out and maintained. Increased sediment transport into the waterbody will then result as the exposed soil is eroded by flowing water. In addition, mechanical site preparation activities conducted right up the edge of a stream can result in significant sediment loading of the waterbody.

Temperature

Water temperature is critical to the health of aquatic systems. Most aquatic organisms have optimal temperature ranges outside of which their development and survival are hindered. A reduction in tree cover following harvesting of stream banks or shorelines increases the amount of solar radiation reaching the water surface and can cause a significant increase in water temperature by 5°C or more (Brown & Binkley 1994). Because oxygen becomes less soluble at higher temperatures, increased water temperatures reduce oxygen availability, impacting the survival of fish and other aquatic organisms.

Nutrients and Toxins

When fertilizers, pesticides, or herbicides are applied to forests, it is possible for excess amounts (those not taken up by the plants and trees) of certain **elements** or **ions** to enter the water system. The nutrients of major concern to degradation of water quality are nitrate and phosphorus. These are commonly added in forest fertilization on intensively managed industrial pine plantations in the southeastern United States.

Nitrate concentrations in streams draining from forested areas are generally quite low. However, when fertilizers are added, pulses of nutrients may exceed the uptake ability of trees (Brown & Binkley 1994). In this case, the potential exists for fertilizer to enter waterbodies.

Nutrient loading (excessive inputs of nutrients into a waterbody) is a concern because it can potentially increase the rate of a process known as **eutrophication**. Eutrophication occurs when a surplus of essential plant nutrients enters a waterbody, increasing algal growth. As the algae die, the decomposing microorganisms consume dissolved oxygen in the water, reducing the amount available to fish and other aquatic organisms. Ultimately, this can result in a dead lake or pond: a system where no larger aquatic organisms can survive. In general, studies of forest fertilizer applications have shown that careful fertilization (avoiding excessive application and timing the application to avoid periods of heavy runoff such as a rain storm) does not compromise stream water quality (Brown & Binkley 1994).

The water quality concern with toxins is due to chemical runoff or groundwater discharge into stream systems or lakes. High levels of certain chemicals can be toxic to fish and especially degrade filter feeders such as freshwater mussels.

In addition, loading of certain chemicals can alter the pH (acidity) of the stream system affecting the natural chemical processes of the water (Dingman 1994). Truly high levels of toxins can exceed drinking water standards, although this is unlikely to happen with well-managed forestry operations.

When applied in forestry, fertilizers, and pesticides (a general term including herbicides, insecticides and fungicides) can enter streams in two ways:

1. direct hits of open water during application, or
2. by movement from the soil, either on the soil particles (as with erosion) or in groundwater which discharges into a waterbody.

Herbicides are commonly used to control herbaceous plant or hardwood competition on intensively managed pine plantations in the southeastern United States. Unlike annual applications in agriculture, most forests that are treated with herbicides are typically treated only once during a 20- to 100-year rotation.

Because erosion rates are generally lower on forested lands—particularly in Florida with its flat topography—there is less transport of chemicals attached to soil particles into streams as compared to agricultural land uses. Studies of the effects of forest herbicide use (applied under regulatory guidelines) on streamwater element concentrations revealed no levels high enough to warrant concern (Brown & Binkley 1994). Still, applying excess amounts or applying the chemicals right up to the edge of a waterbody is poor practice.

Organic Material

Organic material is produced by microorganisms, plants, and animals. **Large woody debris** is produced when a branch falls off a tree overhanging a stream—or when an entire tree falls in a stream.

Large woody debris is very important in many aquatic ecosystems. It forms pools and traps floating leaves to provide shelter and deep pools for fish and other aquatic organisms. Leaf detritus derives from floating leaves and needles, which fall from the plants, trees and shrubs alongside streams, rivers and lakes. Many organisms feed on leaf detritus as well as use it for shelter in aquatic habitats.

There are two ways stream health may be impacted by inputs of organic material: too many inputs or too few. Natural systems have an optimum range of organic matter inputs to which the stream organisms and the stream function are adapted. Inputs of large woody debris can be substantially increased if harvesting occurs on the bank immediately adjacent to a stream channel, or if logging slash is dropped into a stream. This can interfere with stream channel flow—both velocity and amount—cause stream bank erosion and drastically alter habitat conditions.

Increased organic matter, whether large woody or leaf detritus can also affect dissolved oxygen levels. When these materials are introduced into a stream, increased decomposition by microorganisms requires oxygen. This depletes the oxygen available for a healthy stream habitat.

The other type of impact from organic material also results from logging. When stream banks are harvested and most of the vegetation is removed right up to the stream bank, the source of natural organic matter inputs disappears. This will have a negative impact on stream biological health, eliminating a source of food and shelter for aquatic organisms, as described above.

Hydrology

Trees store some water, but mainly act as pumps, removing water from the soil through their roots, and returning it to the atmosphere through their needles or leaves—a process known as **transpiration.**

In addition, the leaves in a tree canopy intercept water during **precipitation events**. This prevents the water from reaching the soil surface and it evaporates directly back into the atmosphere. The combination of these processes is known as **evapotranspiration**, and it is dependent on solar radiation, air humidity, and wind speed. Forest vegetative ground cover also slows overland flow of water, promoting infiltration into porous surface soils.

Given all this, one can well imagine that removing the trees and other plants, such as during a harvest operation, can have a significant impact on the water relations on a site.

When the transpirational "pump" is removed, there is a resulting temporary rise in the water table—usually in proportion to the amount of canopy removed. Some of this effect may be balanced by increased evaporation from the soil surface now exposed to solar radiation. However, this increase is generally less than the total water table rise—particularly following a clearcut. Slowly, this reduced evapotranspiration returns to normal depending on the rate of new plant growth.

With a full canopy, an average of 20% of the precipitation is intercepted by the needles, leaves and branches where it evaporates, never reaching the soil for infiltration. Following harvesting, the lack of canopy allows more water from rain and other forms of precipitation to reach the soil. When the soil becomes saturated and cannot hold any more water, precipitation becomes surface water. At this time both surface runoff and groundwater flow increase in duration and amount.

On slopes without vegetation, surface runoff can carry topsoil with it, draining into streams and other waterbodies, thus increasing erosion and turbidity. Groundwater flow can discharge dissolved chemicals that plants have not taken up, into the waterbodies.

Increased **storm flow** can be another result of harvesting operations. Storm flow is the additional water that enters streams immediately in response to a rainfall event. Soils with high infiltration rates (the rate at which water enters the soil from the surface) and with high storage capacity will contribute less to storm flow. (Forest soils generally have a very high infiltration rate which minimizes direct runoff into streams until the water table rises to the soil surface.)

Storm flow following harvesting is increased by more intensive harvesting and site preparation practices, which remove more ground cover and vegetation. In addition, where windrows are leading into drainages, runoff and storm flow may be further increased.

Another impact of forest management practices on the water resource is an indirect one resulting from soil compaction. The use of heavy machinery for harvesting and site preparation activities can increase surface runoff by compacting surface soil. This soil compaction reduces **soil pore space** (the openings in the soil which hold water or air), which lowers the internal movement of water, decreases the amount of soil water storage, and decreases infiltration. The excess water which cannot infiltrate the soil will puddle or runoff. Excessive puddling will inhibit vegetation regrowth following harvesting, and increased runoff can contribute to downstream flooding.

The hydrologic impacts following harvesting described here are somewhat temporary in nature. Soon after the harvest, water demand will sharply increase as soil is covered with newly germinating and sprouting vegetation, which demands water for survival and growth.

As vegetative cover develops, more water will evapotranspire, lowering the water table to normal levels and reducing the amount of surface water available for runoff and storm flow. In addition, the abundant regeneration will again dissipate the energy of flowing water and slow it down for infiltration into surface soil pores.

Management Solutions

The impacts on water quality and hydrology described in this document can be minimized or eliminated by carefully managing forest operations.

The best way to ensure that forestry operations will protect water quality is to follow the Silviculture Best Management Practices described in a book published by the Florida Department of Agriculture and Consumer Services, Division of Forestry (1993). These practices were originally designed to prevent water pollution from forestry activities; but were later expanded to protect certain habitat values and ecosystem functions.

The importance of BMP compliance is clear. Many states have studied the effectiveness of BMPs and found their use significantly improved stream water quality. Effectiveness measures included such attributes as protection of nitrate and suspended sediment levels, water temperatures, and aquatic habitat conditions.

In early 1988, the State of Virginia launched a non-regulatory forest water quality program. Within three and a half years, the Virginia Department of Forestry was able to document a 14% statewide reduction in sedimentation from silvicultural and logging operations with 94% of forest operations complying with the BMPs (Shaffer 1995).

In South Carolina a BMP effectiveness study on 27 harvested sites showed that implementation of BMPs during harvesting sufficiently protected the water quality of surrounding streams (Adams *et al.* 1995). A similar BMP effectiveness study is underway in Florida, where compliance rose from 84% in 1985 to 96% in 1995 (Fl. Dept. Ag. & Cons. Serv. 1996).

One BMP, which is effective in mitigating several of the effects discussed in this document, is the **Special Management Zone (SMZ)** —also known as a buffer zone (Figure 2). This is an area along a stream or other waterbody, which may be selectively harvested with certain restrictions and is not subject to mechanical or chemical site preparation activities.

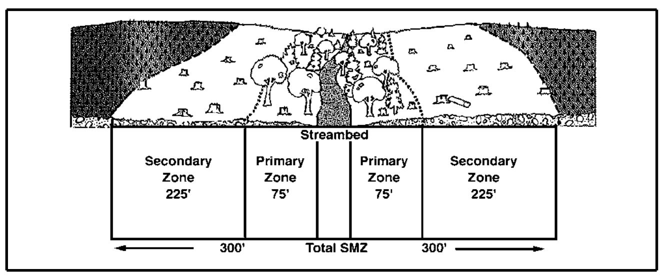


Figure 2. Diagram of an SMZ for a 25-ft. wide perennial stream with moderate soil erodibility and moderate slope. (Fl. Dept. Agric. Cons. Serv. 1993)

This area therefore continues to capture nutrients, provide stream bank stability, shade, large woody debris and leaf detritus, and dissipate the energy of surface water flow into the stream.

The purpose of the SMZ is to reduce or eliminate forestry-related inputs of sediment, chemicals, logging debris, nutrients, and water temperature changes. These buffer zones were found to be particularly effective and important in protecting water quality attributes (Ahtiainen 1992, Shaffer 1995, Wang 1996).

In Florida, the SMZ has three principal components:

- the Primary Zone,
- the Secondary Zone, and
- the Stringer.

The **Primary Zone** applies to perennial waters and varies in width from 35 to 200 feet per side depending on the type and size of waterbody (Figure 2).

There are significant timber harvesting restrictions in this zone. The purpose of the Primary Zone is to maintain streamside shade and reduce disturbance to ground cover and litter. This ensures that surface water will infiltrate into the naturally porous undisturbed forest soil, which acts as a biological filter.

The **Secondary Zone** applies to all intermittent waterbodies and also may serve as an add-on to a Primary Zone in some cases. It is always at least 35 feet wide and may be wider depending on the local soil type and slope percent. This zone has no timber harvesting restrictions, however no mechanical site preparation is permitted. The purpose of the Secondary Zone is to minimize upslope site disturbance.

The **Stringer** applies only to intermittent streams and consists of mature trees left on or near the banks. These trees serve to help minimize heavy equipment operations near the waterbody and reduce the risk of sedimentation and bank damage. The 1993 manual of Silviculture Best Management Practices (listed under References) should be consulted for more detail. You can call your county forester or the Division of Forestry at (850) 488-4090 to get this manual.

BMPs, which specifically pertain to hydrologic impacts of forest management practices, include the BMPs for roads, wetlands, and wet weather operations.

These BMPs address actions, which will avoid impounding or diverting normal water flow, and will help prevent soil compaction. Compaction can be reduced by limiting heavy equipment operations to times when conditions are dry—in other words, suspend logging during wet weather. In wetlands, compaction can be reduced by concentrating designated skid trails to as small an area as possible. Wet soils are much more susceptible to damage from logging equipment than well-aerated dry upland soils.

Forest roads produce most of the sediment from forestry operations, even when well maintained, so the BMPs emphasize their careful placement and management, with broad base dips and roadside ditch turnouts that divert runoff to porous forest lands (Figure 3), and frequent culverts.

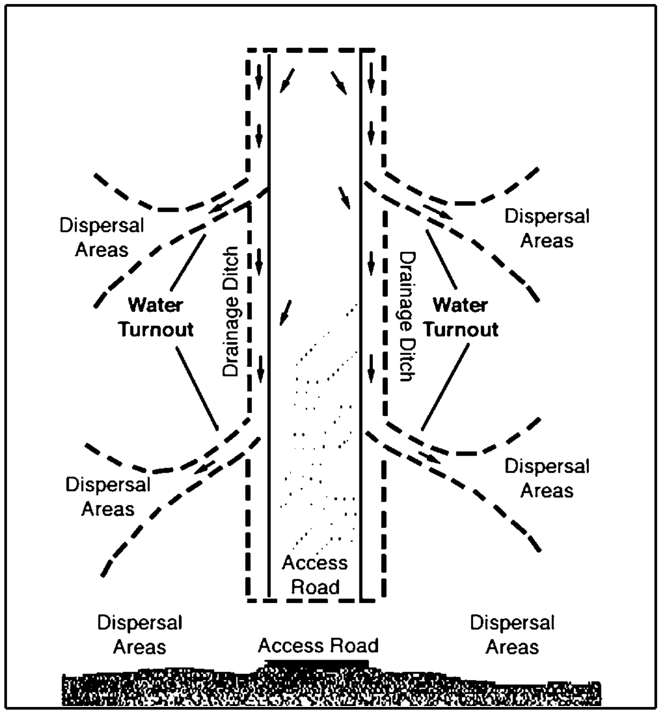


Figure 3. Example of a water turnout that disperses runoff onto vegetable areas. (Fl. Dept. Agric. Cons. Serv. 1993)

Florida's Flatwoods

A Watershed Study

A large watershed study was conducted in north central Florida in the slash pine flatwoods, an ecosystem where much commercial forestry is practiced (Riekerk 1989). This study sought to determine the hydrological and water quality impacts of two harvesting and site preparation methods of varying intensities. The high-intensity system consisted of machine harvesting, including stump removal, followed by slash burning, windrowing, disking, bedding and machine planting without regard to buffer zones. The low-intensity treatment consisted of manual harvesting followed by slash chopping, bedding and machine planting only outside of buffer zones.

The hydrology of these two treatments was compared to that of an undisturbed forest that went unharvested.

The study showed that silvicultural practices significantly affect the hydrology of coastal zone pine flatwoods (Riekerk 1989). Water table levels rose and daily runoff increased in the first year, somewhat in proportion to the size of the clear-cut in each watershed. This was due to the reduction in evapotranspiration following forest harvesting. In addition, the more intensive treatment removed all vegetation, reduced infiltration and increased storm flow. This effect lasted a decade or more after harvesting.

The forest operations resulted in only small and temporary effects on water quality. Due to both the flat ground and the nature of the sandy soils, there was no increase in bedload sediment. Suspended sediment levels increased more with the more intensive harvest and site preparation methods, as did nutrient levels of calcium and potassium. There was no effect on nitrate or phosphate levels in the runoff, and all the water quality attributes returned to normal within two years after treatment (Riekerk 1983).

The increased storm flow, although temporary, is perhaps the biggest hydrologic concern from forestry operations in Florida. Storm flow is critical in downstream flooding. In areas where downstream flooding is a concern, such as in a heavily populated area, the temporary surface water increase can be managed by partial cutting rather than clearcutting, or by clearcutting smaller areas each year within the watershed.

Conclusion

Although the impacts of forest management practices on water quality are small compared to other land uses, poorly managed forestry operations can be detrimental to water quality.

These impacts can be prevented by applying BMPs to your forestry operations, including limiting heavy equipment operations in buffer zones and to dry conditions, taking adequate steps to minimize chemical or nutrient contamination of runoff, and preventing runoff from entering waterways.

By understanding the processes that produce surface runoff and by following these simple, well-designed practices you will help protect water quality on your land. In addition to BMPs, you should consider the hydrologic response of your particular area—which depends in part on degree of slope and the soil type—and design your management plan accordingly to ensure protection of surrounding land uses (for example, prevent downstream flooding).

By practicing responsible forest management, you will minimize detrimental impacts and help maintain water quality. This will support high quality habitat for aquatic organisms and help protect the water resources of Florida.

Glossary

Aquatic environment - areas where the plants and animals live in water.

BMPs - Best Management Practices.

Broad Base Dip - A periodic reversal in the grade of a permanent access road for the purpose of intercepting and diverting surface water flow.

Compaction, soil - The process where soil pedons become firmly packed together, reducing the pore space which in turn reduces the amount of air or water that can be held in the soil, lowers the infiltration rate, and affects the rooting capability of trees and plants.

Detritus - In this instance natural woody debris such as leaves, branches, etc., provided by trees.

Element - A substance that cannot be decomposed into simpler substances.

Eutrophication - The process by which a body of water (such as a lake or pond) with an abundant supply of nutrients and a high rate of organic matter production becomes oxygen depleted.

Evapotranspiration - The combination of the processes of evaporation and transpiration, both of which result in the return of water to the atmosphere.

Groundwater discharge - When groundwater is expelled from the ground and becomes surface water.

Hydrology - The scientific study of the properties, distribution, and effects of water on the earth's surface, in the soil, underlying rocks, and atmosphere.

Impound - To artificially store water.

Infiltration rates - The rate at which water enters the soil from the surface.

Interception - The process by which precipitation falls on tree surfaces where it then may evaporate.

Ion - An atom or group of atoms which has gained (or lost) one or more electrons making it negatively (or positively) charged—a process which occurs widely in nature particularly with the absorption and retention of water soluble fertilizers in the soil.

Large woody debris - Woody material such as branches, stems, and whole trees which accumulates naturally in a forest or is left as residue after logging.

NPS - Non Point Source, refers to water pollution which is not traceable to any discrete source, but which enters the waterbody in a diffuse manner.

Precipitation events - Examples are rain, sleet, snow, and hurricane.

Roadside ditch turnout (Water turnout) - The extension of a roadside ditch into a vegetated area to provide for the dispersion and filtration of stormwater runoff.

Sediment - Soil particles, which have been detached and transported by water during the process of erosion. bedload *sediment* refers to that which moves to the bottom of a stream; *Suspended sediments* are smaller particles which float in the water.

SMZ - Special Management Zone, refers to the area of varying width, which is designated adjacent to a watercourse where management precautions are necessary to protect the natural resource.

Storm flow - Additional water that enters streams immediately in response to a rainfall event.

Transpiration - The process by which plants release water to the atmosphere through their leaves.

Turbidity - A visual measure of the relative clarity of water.

References

Adams, T.O., D.D. Hook, and M.A. Floyd. 1995. Effectiveness monitoring of silvicultural best management practices in South Carolina. *Southern J. App. For.* 19(4): 170–176.

Ahtiainen, M. 1992. The effects of forest clear-cutting and scarification on the water quality of small brooks. *Hydrobiologia* 243/244: 465–473.

Brown, T.C. and D. Binkley. 1994. Effect of management on water quality in North American forests. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. *USDA For. Serv. Gen. Tech. Rpt.* RM–248.

Dingman, S.L. 1994. *Physical Hydrology*. Macmillan College Publishing Company, New York, NY.

EPA. 1990. National water quality inventory: 1988 report to Congress. *EPA 440-4-90-003,* Office of Water, USEPA, Washington, DC.

Florida Dept. Agric. & Consumer Services. 1993. *Silviculture Best Management Practices.* Tallahassee, FL.

Florida Dept. Agric. & Consumer Services. 1996. *Florida's silviculture BMP compliance survey: 1995 report.* Tallahassee, FL.

MacDonald, L., A. Smart, and R. Wismar. 1991. Monitoring guidelines to evaluate effects of forestry activities on streams in the Pacific Northwest and Alaska. USEPA/910/9-91-001, Region 10, Seattle, WA.

Riekerk, H. 1983. Impacts of silviculture on flatwoods runoff, water quality, and nutrient budgets. *Water Resources Bull.* 19(1): 73–79.

Riekerk, H. 1989. Influence of silvicultural practices on the hydrology of pine flatwoods in Florida. *Water Resources Res*. 25(4): 713–719.

Riekerk, H., A.C. Mace, D.G. Neary, and B.F. Swindel. 1985. Hydrologic responses to forest management in pine flatwoods and Florida's water. *Soil Crop Sci. Soc. Fl. Proc.* 45:163–169.

Shaffer, R.M. 1995. Forestry water quality protection in Virginia. *For. Farmer* 54(3):18–21.

Wang, Z. 1996. Effects of harvesting intensity on water quality, nitrogen mineralization, and litter decomposition in a bottomland hardwood floor pain forest in southeast Texas. *Ph.D. Diss.* Mississippi State Univ., Mississippi State, MS.

Great Trinity Forest Management Plan

Wetlands

Forestry Best Management Practices for Water Quality

12/14/2002

Commercially productive forests occupy 11.8 million acres of 43 counties in East Texas. These timberlands make up the western edge of the nation's southern pine timber region. They provide many benefits such as wildlife habitat, recreational opportunities, wood products, and an aesthetically pleasing living environment.

The economy of East Texas depends on its forests and the wood they produce. In 31 of 43 counties, forest industry is the fires or second largest manufacturing employer. Wood-based industry is the ninth largest manufacturing employer in the state, producing $6 billion worth of products each year.

One important product of these forests may be difficult to put a dollar value on. Production of high quality water is a major benefit of forest land that often is taken for granted. Texas form Texarkana to Houston depend on water that originates in the forest of East Texas. Recently, concern has focused on the impact for forest management practiced on water quality.

Nonpoint source (NPS) pollution is water pollution that is created from an activity that has no particular permanent location. Typically, NPS pollution arises from man's activities and is carried over and through the soil by rainfall runoff. Agriculture, urban/suburban development, mining, construction, and silviculture are categories of NPS pollution.

Silviculture is the art and science of growing and tending forest trees. More generally, silviculture includes all activities from planting tree seedlings to transporting the harvested timber from the forest.

Types of Nonpoint Source Pollution
Types of silvicultural nonpoint source pollution include sediment, nutrients, organics, thermal pollution and chemicals.

- Sedimentation is the most significant type of silvicultural NPS pollution. In an undisturbed forest, the tree and understory canopy, forest litter, organic matter, and root systems protect the soil from the erosive action

Sedimentation of streams as a result of forest management activities is a water quality problem that can be solved through the use of Best Management Practices.

for falling raindrops. Silvicultural activities such as timber harvesting, skidding, road building, and mechanical site preparation disrupt this natural erosion protection. As a result, they have the potential to accelerate erosion and increase sedimentation of adjacent streams. Sediment may be harmful to fish and other aquatic organisms that depend on surface water for food or habitat. It also decreases the water's value for recreational and commercial activities, fills in reservoirs, and increases drinking water treatment costs.

- Nutrients such as nitrogen and phosphorus exist naturally in forest soil and some finds its ways into adjacent streams and groundwater. Silvicultural operations, especially timber harvesting, alter the normal nutrient cycle of the forest. This may lead to changes in the nutrient content of discharge water. Excessive nutrient levels in water can stimulate abnormal plant growth, alter levels of dissolved oxygen, and disturb aquatic ecosystems.
- Organic material is a third form of NPS pollution. In forests, this type of pollution may result from logging debris, such as tree tops, logs, and branches, that have fallen or washed into stream channels. Decomposition of this materials reduces oxygen levels in the water and may lead to undesirable changes in the taste, color and odor of the water. Although some organic materials will naturally be deposited in streams, harvesting operations may increase levels if precautions are not taken.
- Thermal pollution is a term that describes the adverse changes in water temperature caused by forest practices that eliminate shading vegetation. Removal of shading forest cover exposes the stream to direct solar radiation. As a result, water temperatures fluctuate more widely and peak temperatures are higher. This affects water quality by impacting the level of dissolved oxygen, rates of chemical processes, and biological oxygen demand.
- Chemicals, including herbicides and other pesticides, entering water bodies can be harmful to aquatic life. Also, petrochemicals from machinery maintenance are hazardous to water quality if not disposed of properly. These chemicals may enter the water in runoff, through leaching, by aerial drift during application, or directly through accidents or carelessness. Trash, garbage, and equipment parts left on the site are also water quality hazards as well as unsightly.

Texas Forestry Best Management Practices

The Texas Forestry Best Management Practices (BMPs) are designed to help landowners, foresters, loggers, and others protect water quality during silvicultural operations. BMPs can prevent, or at least greatly reduce, NPS pollution from forest management activities. Use of BMPs in Texas is voluntary; however, implementing these practices by all involved in forest management will help protect water quality without strict government regulations.

The Texas Forestry BMPs are organized into eight activity areas:

- Planning
- Road Construction and Maintenance
- Road Materials Sites
- Harvesting
- Mechanical Site Preparation/Planting
- Prescribed Fire
- Silvicultural Chemicals
- Streamside Management Zones

Planning
Careful planning of forestry operations can help reduce the potential for nonpoint source pollution. Unit boundaries, road systems, and log sets should be designed so that streams and other water bodies are avoided. Timing activities to avoid seasons when the soil in low areas is wet will help avoid problems.
In planning activities, topographic maps, aerial photographs, and soil surveys in combination with a field reconnaissance and landowner knowledge should be used to determine site condition and pin-point problem areas. Natural drainage channels and topography should be major considerations in determining cutting unit boundaries. The goal is to minimize the number of stream crossings and the length of road and skid trails needed, thus reducing overall soil disturbance.

Road Construction and Maintenance
Several studies have shown that poorly designed orad systems are the major cause of silvicultural NPS pollution. A well-located, constructed and maintained system of forest roads minimizes pollution impacts on forest streams. The road design should be the minimum needed to accommodate expected traffic. Narrower roads requires less soil movement during construction and provide less surface area for potential erosion. A good drainage system is an essential ingredient for preventing roads from eroding and causing NPS pollution. Roads should be crowned and sloped so that water drains from the road surface to the roadside. Water draining down the middle of roads on long slopes will soon cause gullies that make the road both unusable and a potential water quality problem. Ditches, culverts, cross drains, and wing ditches should be installed where needed to direct water off the road and onto the undisturbed forest floor. Stream crossings, where necessary, should be at right angles and should include erosion protection measures. Crossings should be designed to protect the approach to the stream, the stream banks and stream bottom. There are several options for stream crossings including using gravel, a cement slab, or GEOWEB[a] to harden the bottom, installing culverts, or bridges. The choice should depend on the expected use of the crossing and its erodibility. Temporary structures should be removed promptly after use. A well-designed road system will be much less expensive to maintain than a poorly designed, erosion prone, system. Routine maintenance should be conducted to keep drainage systems free of blockage and to rework problem areas before they become unmanageable.

Revegetation of temporary roads should be considered to help protect against surface erosion.

Harvesting

Harvesting trees in an integral part of forest management. The degree to which the forest environment is affected depends largely on the care taken by the logging contractor. The landowner also shares a part of the responsibility in planning a harvest that protects the environmental quality of the site. Tree felling, skidding, loading, and hauling will always disturb the forest floor and expose bare soil to some extent. However, use of BMPs can minimize this impact. Directional tree felling should be used near streams to minimize debris entering the stream. To reduce soil disturbance during skidding, trees should be felled parallel to the skidding direction with butts toward the landing. Skid trails should be laid out to take advantage of topography and minimize disruption of natural drainage patterns. Skid trails on long slopes should have occasional breaks so water does not run straight down the skid trail over long distance. Where stream crossings cannot be avoided, the most direct route should be used, taking advantage of natural fords with firm bottoms, stable banks, and gentle slopes along approaches. Upon completion of use, skid trails should have water bars installed. Seeding should be considered when necessary to prevent erosion. Log sets are ares where harvested trees are collected, temporarily stored, and loaded onto trucks. They can be a source of soil erosion if not well planned. Sets are subject to concentrated traffic of heavy equipment. They are also sites for equipment maintenance. For these reasons, sets should be located on firm ground away from streams. Provision should be made to provide drainage around sets if water will tend to collect on the site. Disposal of logging slash and debris should be done to protect water quality. Debris accidentally deposited in streams should be removed. Erosion prone areas should be mulched or seeded to reestablish vegetative cover.

Mechanical Site Preparation/Planting

Like harvesting, the major problem associated with site preparation and planting involves the potential for soil erosion. Site preparation with heavy equipment exposes bare soil and creates opportunities for erosion.

The primary factors in determining the erosion potential are the percent of the area with exposed soil, the degree of slope, and the type of soil.

Mechanical site preparation should minimize disturbance of areas adjacent to streams or other water bodies. Heavy mechanical site preparation should be avoided on slopes of more than 30 percent, or on highly erosive soils. Operators of equipment should be trained to minimize soil disturbance and compaction.

Prescribed Fire

A major concern of the forest manager is how fires affect surface runoff and soil erosion. However, if the burn is under ta timber stand and much of the forest litter remains, soil movement will be minor on slopes of up to 25 percent. Site preparation burns are the hottest type of burn and can remove the natural erosion protection of the surface organic material.

Water bars should be installed on skid trails to protect against erosion. If necessary, reseeding with grass seed mixtures can provide additional protection.

A significant amount of soil movement can be caused by the construction of the firebreaks rather than the burn itself. To minimize erosion, firebreaks on slopes should have water bars and wing ditches.

Silvicultural Chemicals

The use of silvicultural chemicals can be a potential problem, though less than 1 percent of all pesticides are used in forest management. BMPs for silvicultural chemicals include recommendations for preventing direct or indirect application of forest chemicals to water sources. Precautions should be taken during mixing, application, container handling, and cleanup to prevent the accidental introduction of chemical contaminants into the groundwater or nearby streams.

Streamside Management Zones

One of the most environmentally sensitive areas in the forest is the zone along a stream channel, often called the streamside management zone. Disturbances within the area 50 to 100 feet or more along each side of the stream have the potential to affect water quality. BMP's for streamside management zones are designed to protect these areas.

Generally, these zones should be left relatively undisturbed. Ground cover should be retained as a filter to capture any sediment or other pollutants running towards the channel. Although selective tree cutting is allowable, most trees should be left standing and the ground cover preserved within the streamside management zone to protect the water from solar heating. Both perennial and intermittent streams need well-delineated streamside management zones. management priority should be to protect water quality. If degradation occurs, remedial action should be immediate.

The landowner is responsible for the implementation of practices to control nonpoint source pollution on his/her land. At present, Best Management Practices are voluntary.

However, if voluntary BMPs fail to eliminate NPS pollution problems, the next step could well be regulations and permitting. By implementing BMPs, the forestry community has an opportunity to demonstrate respect for those natural resources including water quality upon which it depends.

For more information

The Texas Forestry Association handbook Texas Forestry Best Management Practices provides a complete listing of the BMPs as well as a more detailed presentation of recommended technical guidelines that provide explanations of when and how to implement specific practices. Copies of the handbook are available by contacting the Texas Forest Service office nearest you or by contacting:

Texas Forestry Association
P.O. Box 1488
Lufkin, Texas 75901

For further information on NPS pollution, contact:

Texas State Soil and Water Conservation Board
P.O. Box 658
Temple, TX 75603

or

Texas Forest Service
Forest Resource Development
College Station, TX 77843-2136

Great Trinity Forest Management Plan

Wetlands

Streamside Management Zones (SMZs)

Streamside Management Zones - SMZs

Protecting Water Quality
Texans in the forestry community currently have the opportunity to protect the quality of East Texas' waters without unnecessary government regulation.

The Texas Forestry Best Management Practices (BMP's) are state-of-the-art, non-regulatory (voluntary) methods designed to prevent erosion and protect water quality during and after forest management activities, including timber harvesting.

Streamside Management Zones (SMZ's) are perhaps the most crucial Best Management Practice. Also called buffer strips, green strips, stringers, or riparian zones. SMZ's are crucial to protecting the waters of East Texas.

What is an SMZ?
A Streamside Management Zone (SMZ) is a forested strip or area next to a creek or stream that is managed with specific attention to instream and downstream water protection. SMZ's should be maintained around both intermittent and perennial streams, lakes, ponds, naturally flowing springs, and reservoirs. Forest management activities within an SMZ should leave the forest floor essentially undisturbed with minimum soil exposure. Mechanical site preparation, logging decks, skid trails, and firelanes are restricted within an SMZ. Similarly, roads should not be constructed within an SMZ, except at designated crossings (see Stream Crossing Alternatives below). Roads should cross the stream at a right angle. Drainage structures such as wing ditches, water bars, and cross drain culverts should vent their runoff before they enter the SMZ.

Why are SMZ's important?
Functioning as buffer strips, SMZ's are very effective in filtering sediment (soil particles) from surface runoff. The water in the runoff can and should reach the stream, but the vegetation in the SMZ filters sediment and other suspended solids resulting from the forest management activity. This filtering process may also lessen any negative effects that pesticides may have on water quality. The trees immediately adjacent to the water provide woody debris to benefit aquatic organisms. The trees also provide shade to the stream, preventing any unnatural changes in water temperature. Direct sunlight can drastically raise water temperatures, which may lower the oxygen content of the water and make it difficult for fish and other aquatic organisms to survive.

When is an SMZ recommended?
As previously states, SMZ’s are recommended on perennial and intermittent streams, as well as on other water bodies. A perennial stream is one that flows throughout the year, except during temporary drought conditions. An intermittent stream usually has a well-defined, continuous channel, although it may be dry for up to eight months of the year. It generally flows throughout the wet season of the year. Ephemeral streams or drains (ephemeral means short-lived) are rain-dependent and carry water only during and for a short time after a rain. Therefore they do not require SMZ protection. However, since these water courses do flow at times, they are sensitive and a SMZ may be prudent.

Determining SMZ width
The Texas Best Management Practices for Silviculture handbook states that SMZ width should be not less than 50 feet on each side of the stream. However, the actual width needed is site specific. A forester or other qualified professional can make a determination based on soil type, slope, vegetative cover, volume of flow, and stream classification. To enhance wildlife habitat, SMZ’s may need to be significantly wider than 50 feet.

Does wildlife benefit?
Streamside Management Zones not only help protect water quality, but also provide excellent habitat for many wildlife species. They function as travel corridors and nesting sites and provide food and cover. Within a young pine plantation, SMZ’s create edge and habitat diversity, two important requirements for wildlife species. As travel corridors, SMZ’s can join otherwise isolated populations of a species. In general, as SMZ width increases, so does use by wildlife species such as squirrels, wild turkey, amphibians, and reptiles. One study on wildlife use of SMZ’s suggests that they should be about 100 feet wide for maximum benefit.

Will SMZ’s affect timber income?
SMZ’s can be thinned for increases timber income without;damaging the integrity or function of the SMZ. The BMP handbook recommends that a minimum of 50 percent of the original canopy be left in the SMZ. Selective logging, when done correctly, will not harm the filtering effects of the SMZ, nor will it significantly damage the remaining trees. Enough cover should be left to provide adequate shade for the stream, lessen erosion caused by raindrop impacts, and filter runoff washing toward the stream. Any logging debris (tree tops or limbs) should be immediately removed from stream channels and other water bodies.
SMZ’s also yield non-monetary benefits such as wildlife, clean water and aesthetics. If a

dollar value were assigned to these benefits, any loss of timber income from selective cutting could easily be offset.

Stream crossing alternatives:

Too often, streams are crossed by simply pushing dirt and other debris into the stream channel. Because this can lead to serious water quality problems, Best Management Practice guidelines recommend avoiding this type of crossing. If used, however, the fill material from the crossing should be removed and stream banks restored immediately to their original condition. Fortunately, alternative crossings, designed to prevent stream sedimentation do exist and are listed on the following pages.

Culverts

Culvert installations are common stream crossing methods that can help prevent harmful impacts to stream quality. When sized to proper diameter and length for the stream drainage area, culverts can provide access across streams without increasing stream sedimentation. It is often necessary to install erosion control measures such as rip-rap or large stone to minimize sedimentation and erosion at culvert inlets and outlets. Different types and sizes of culverts are available for various installations, ranging from 18-inch diameter galvanized steel to 10-foot diameter railroad tank cars (with ends cut out for use as a culvert). For longer culvert life or use in corrosive soil and water, aluminum, plastic, polymer-coated, and other types of culverts may be used. There are also different spiral-types and gauges (thickness) of metal that can affect the strength of the culvert. It may be useful to contact a qualified individual to determine which type of culvert is appropriate.

Bridges

Crossing very large streams may require installations of a bridge. Railroad flat cars, wooden timbers, and iron I-beams are among the materials from which bridges can be constructed. Strength, load-capacity, and safety engineering are important factors when designing and installing bridges. Contacting qualified individuals in recommended for bridge construction.

Geoweb

Geoweb, manufactured by Presto Products, Inc., can provide a permanent, low-water crossing or ford that minimizes stream sedimentation. The plastic material forms a honey-comb mat that is filled with soil or gravel to form a solid road base. Best used in streams with flat approaches to the stream, properly-installed Geoweb allows permanent access across a stream even for fully loaded log trucks. (Use of trade names does not imply endorsement by the Texas Forest Service.)

Timber Mats

Many loggers are now using 4 foot by 20 foot or longer timber mats, or dragline mats, which are portable bridges that consist of rough-cut 8 inch x 8 inch timbers bolted together. Normally two or three mats are placed side by side to span the width of the stream channel. These timber mats are easily transported by loggers on the same trailer used for other equipment transport.

More information is available
SMZ’s should be used in conjunction with other sound land management practices that stress the use of BMP’s for sediment and erosion control. Landowners or land managers who have questions about SMZ’s stream crossings, forestry BMP’s, and possible cost share assistance for implementing these practices should contract their nearest Texas Forest Service office.

Copies of the complete set of non-regulatory BMP’s for water quality protection are available in the handbook entitled Texas Best Management Practices for Silviculture. In addition, Texas Forest Service circulars, Forestry Best Management Practices for Water Quality and Forestry, Wetlands and Water Quality, provide a summary and outline of BMP’s and water quality in non-technical terms. All three publications are available free of charge from any office of the Texas Forest Service.

Riparian Buffers in Forest Management: Establishment, Effectiveness and Recommendations

North Carolina Division of Forest Resources
Forest Management and Development Section
Forestry NPS Unit

Department of Environment and Natural Resources
Raleigh, NC

January 2003

Introduction

Properly established and managed forested riparian buffers, sometimes referred to as Streamside Management Zones (SMZ's) or Riparian Management Zones (RMZ's), are widely recognized as a preferred means to protect water quality. Buffers are commonly established during the planning and operational phases of forest management activities. Examples of these situations include timber harvesting operations, road construction, herbicide/fertilizer applications, practices related to reforestation, and aesthetics enhancement. Buffer effectiveness is a function of width, vegetative composition, and the degree of disturbance within the buffer area.

The North Carolina Division of Forest Resources supports the policy adopted by the National Association of State Foresters regarding forestry's role in managing watersheds. An excerpt states:

> The protection and management of watersheds must consider that forests are dynamic. Wildfire, floods, insects and disease, hurricanes, and windstorms will alter forest conditions at the watershed scale….Management practices can also emulate (but not necessarily duplicate) disturbance events and thus be used to maintain forest and watershed health, while also providing an array of social, economic and environmental services. Increasing the ability….to manage, protect and enhance forests for water supply, water quality and watershed health will be needed to sustain the health of our forests and our watersheds in the future (NASF: October 2, 2002).

Buffer Establishment

Determining the appropriate width of riparian buffers should be fact-based, and identified on the ground using site-specific criteria, such as:

- Purpose of the buffer
- Type and/or size of water body being protected
- Soil type and erodibility potential
- Slope and land-use of adjoining uplands
- Tree age and spatial distribution
- Ground cover type, amount and distribution

The concepts of appropriate buffer establishment are described below by Verry, et al. (pp277-280):

- *Some will argue that the wider the RMZ, the greater the protection given to riparian functions. At some point, increasing the width of the RMZ and imposing more restrictions on management will conflict with economic considerations, the landowner's management objectives, and issues of property rights…*
- *It could be difficult to convince nonindustrial private forest (NIPF) landowners to maintain a wide RMZ with many management restrictions where riparian edge is a significant portion of small tracts…*
- *The bulk of protection for water quality, aquatic habitat, and riparian functions occurs closest to the water body and diminishes with increasing distance from the water body…*
- *Ability to harvest riparian [tree] species with economic value is necessary to encourage continued landowner commitment to maintaining these areas.*

Buffer Effectiveness: Sediment Capture

The USDA-Natural Resources Conservation Service (NRCS) states:

- Most sediment is trapped within the first 25% of a buffer's width (the area furthest out from the water)
- Twenty-five (25) feet is the minimum buffer width necessary to effectively protect water resources.

The National Council for Air and Stream Improvement (NCASI) provides this summary of research that examined the effectiveness of sediment capture by buffer filter strips (p41):

- *90% of sediment flows from roads are trapped within [26 feet] of entering a buffer on nearly level ground, but on 70% slopes sediment flows would require [167 feet] to be trapped.*
- *Buffer width would have to be doubled for domestic water supplies….*
- *Swift Jr. (1986) measured similar distances to trap sediment flows on level and steep slopes in the southern Appalachians.*

Buffer Effectiveness: Nutrient Capture

Effectiveness of forest buffers to capture nitrate as outlined in NCASI (p35):

- *Hubbard and Lowrance (1996) found that most of the nitrate is removed after [23 to 40 feet] movement through a riparian forest…*
- *Peterjohn and Correll (1984) observed that the greatest reductions of [nitrate] occur in the first [56 feet] of a [164 feet] riparian forest buffer in an agricultural watershed in Maryland.*

The effectiveness of forest buffers to capture polluting forms of phosphorus is adequately handled in most cases, since "much of the [phosphorus] is filtered along with sediment in a particulate form" (NCASI, p37).

In addition, younger aged trees typically process and capture more nutrients than older aged trees, as a result of rapid tissue growth exhibited in the stages of new tree growth (Smith, et.al.; Wenger).

Buffer Effectiveness: Water Temperature

Maintaining adequate shading to insure continuity of water temperature while undertaking forest management activities is important in order to achieve proper conditions for the aquatic habitat of the water resources being protected.

- *Clear-cutting effects on temperature of water in streams is variable, depending on volume of streamflow, elevation, shape of the channel, orientation of the watershed, and its latitude….*
- *As a rule of thumb, leaving enough vegetation to fully shade the stream channel at midday will hold water temperature close to levels in the uncut forest….*
- *There is no single width of shade strip that suits all conditions; rather, the watershed manager must adapt to local conditions and owner objectives, doing whatever is necessary to keep temperatures at appropriate levels….*(Patric, p52).

Buffer Effectiveness: Wildlife and Avian Considerations

Riparian areas serve as important wildlife and avian habitat, especially in urban or agriculture settings where the only forest available in a localized area is whatever forest exists along riparian corridors.

- *Although complete protection has been commonly used to "manage" riparian habitats, many riparian areas are amenable to active management…*
- *In fact, optimizing wildlife habitat quality over time requires active vegetation management; more species will occupy managed rather than unmanaged riparian forests…*
- *The vegetation structure of riparian areas largely determines the wildlife habitat values for the avian community….*(Verry et al., p139-143).

Buffer Management Regimes

Once a forested buffer is identified and established, it is essential to manage the buffer to maintain the ecological functions of the riparian area, including the need to harvest trees. Management of riparian buffer areas is especially critical to promote forest health, as it relates to insects, diseases, wildfires, infrequent storm events and control of exotic invasive plant species. As noted:

- ...*No-cut buffers do not accommodate the natural range of variability in riparian forests, including differences in potential composition and productivity.*
- *These buffers ignore the fact that disturbance is a natural part of riparian systems*
- *…And they provide minimal flexibility for meeting diverse management objectives.*
  (Verry, et al. p235-236).

Trends in Buffer Implementation and Management

Appendix I is a matrix summary from a variety of sources across the country describing buffer requirements or recommendations for forestry. There are two important observations to note from this summary:

1: **The width recommendations, even for 'special waters', call for corridors of widths significantly less than 300 feet. The maximum widths noted typically fall in the range of 150 - 200 feet, even on sites of steep slope.**

2: **There are very few cases in which a 'no-cut' buffer is required for forestry activities. More importantly, forestry or silvicultural practices are normally allowed, including timber removal, within the buffer.** However, in most cases, intensive activities within the buffer area are discouraged or not allowed, such as fertilizer application, herbicide use, and tractor-assisted site preparation or tree planting.

Some specific examples of riparian buffer implementation and management practices in other states:

South Carolina's 'Heritage Trust' program allows for timber cutting in order to enhance the ecological integrity of the acquired forestland. Examples may include harvests to re-establish longleaf pine, or other species considered more appropriate for a particular site. <u>Width of riparian buffers during harvesting activities on acquired lands would be considered on a case-by-case basis</u>, though buffers somewhat wider than those recommended by that State's BMP guidelines would likely be established.

Georgia's 'Community Greenspace' land conservation program recognizes the economic, environmental and social benefits of land that is managed for sustainable forestry, and allows managed timberlands to qualify as acceptable 'Greenspace.' A management plan developed by a forester is required, and the timber must be managed in accordance to Georgia's 'Forest Stewardship' guidelines. <u>Implementing BMP's is required when any operations are conducted on the property</u>. Clearcut harvesting is allowed if appropriate aesthetic buffers are retained along all public highway corridors.

In Virginia, lands in the eastern "Tidewater" region fall under the jurisdiction of the Chesapeake Bay Act, which requires a minimum 100-foot wide 'no-cut' vegetative buffer along all perennial waters located within that region. <u>However, ongoing silviculture activities are exempt from this Act, and limited timber harvesting is allowed within the buffer</u> if forestry BMP's are implemented, as outlined by the Virginia Department of Forestry. The Virginia Department of Forestry is required to inspect all operations that claim the exemption, to insure the operation is a justified silvicultural activity, and not related to a land-use change.

In the City of New York watershed, the Watershed Agricultural Council's Watershed Forestry Program provides written management plans for cooperating private landowners whose holdings exist within the watershed for the City's drinking water supply. Riparian buffers are delineated using a field key developed by the USDA-Forest Service, which takes into account the bank structure, floodplain characteristics and accompanying upland slope factors of the individual waterbody being protected. <u>The management plans provide for timber harvesting and forestry activities that are consistent with protecting water quality</u>.

New York State's Division of Lands and Forests requires written management plans on all properties in which the State purchases a conservation easement, and <u>promotes continued management of the property for sustainable forest resources. Riparian buffers are implemented on a "resource-based" approach</u>, taking into account the water resource that is being protected and adjusting buffer recommendations accordingly.

Recommendations

The North Carolina Division of Forest Resources ('DFR') proposes the following recommendations be considered regarding riparian buffer areas on tracts purchased by the North Carolina Clean Water Management Trust Fund ('CWMTF'):

1. **Active forest silvicultural practices, including timber harvesting, should be an allowable practice within the riparian buffer area**. All forest silvicultural activities must comply with the N.C. Forest Practices Guidelines Related to Water Quality. North Carolina Forestry Best Management Practices (BMP's) must be implemented as described in the N.C. Forestry BMP Manual (the most recent edition at the time of the scheduled activity).

2. **The tract must be managed according to a written forest management plan created and executed by a North Carolina Registered Forester**. This plan would specifically outline any work that is proposed to occur within a riparian area. The grant applicant would be responsible for having this plan written or developed, at the applicant's own expense. A copy of the plan would be provided to the CWMTF within six (6) months after a grant award.

3. **Riparian buffer widths would be established to meet or exceed the minimum recommendations detailed in the N.C. Forestry BMP Manual** (the most recent edition at the time of the scheduled activity). Division of Forest Resources personnel would create a written pre-harvest plan prior to any timber harvesting activity, and monitor timber-harvesting operations while work is ongoing and document each visit. Any inconsistencies discovered during the visit would be handled via normal procedures that already exist within the DFR (*ie*: Policy & Procedure 4808). The appropriate CWMTF representative would be notified of any inconsistent practice, with follow up regarding the remedial and/or referral actions undertaken.

4. **Use of the DFR's Self-Audit Program by the responsible party (in lieu of obtaining a site-closure visit by a DFR Forester) would be required** while any forestry operations are undertaken on the tract.

5. **The DFR would assist the CWMTF staff with cooperative on-site inspections of tracts** of land in which any grant application is pending with the CWMTF for either acquisition or conservation easement. The DFR's representative would meet with the CWMTF's representative on a tract to evaluate any site-specific issues relating to the management of forested riparian buffers on the tract, only as it relates to potential future forest management activities, including timber harvesting. Final determination and buffer recommendations would be outlined in the written forest management plan, as described above in Paragraph 2. Dispute resolution regarding the final implementation and activity allowed within the riparian buffers would be resolved by establishing and managing the riparian buffer area of question in accordance to the technical specifications outlined in USDA-Forest Service publication number NA-PR-07-91, *Riparian Forest Buffers: Function and Design for Protection and Enhancement of Water Resources* (1992).

DFR Position Statement

The North Carolina Division of Forest Resources ('DFR') respectfully requests that the North Carolina Clean Water Management Trust Fund (CWMTF) amend its current policy of requiring the establishment of minimum 300-foot preservation riparian buffers upon lands that are acquired by CWMTF grant awards. Prevailing research and practical in-field applications indicate forested buffers of substantially less than 300 feet provide adequate protection of water quality, while achieving sustainable forestry goals, where proper BMP's are employed.

Implementation of mandated buffer widths by the CWMTF may encumber a significant amount of acreage, and limit the ability of natural resource professionals to sustainably manage riparian areas, and associated upland areas. Opportunities to conserve green space and help contribute to the Governor's *One North Carolina Naturally* million acre goal could be lost or compromised when cooperating landowners decide that a resulting loss in income stream outweighs the gains of preserving the land. As a reference note, for every <u>one-quarter mile of horizontal buffer</u> established at a total width of 600 feet (*300 feet on both sides of a waterbody*), <u>eighteen acres</u> are permanently encumbered, or nearly <u>80 acres per mile</u>. In financial terms, this loss could amount to thousands of dollars per acre during a timber sale, which typically occur only once or twice during a private landowner's lifetime.

The DFR, as it continues to expand the Educational State Forest system across the State, must also contend with the CWMTF's requirements of extraordinarily wide, preserved riparian buffers on tracts of land that are purchased with CWMTF funding. Demonstrating sustainable forest management while protecting water quality, facilitating environmental educational programs, and providing recreational opportunities for the citizens of North Carolina are paramount to the management goals of the DFR's assigned forest properties. The DFR remains committed to its part in protecting and enhancing water quality in North Carolina's forests; this commitment dovetails with the CWMTF's strategic directive. However, placing unnecessarily stringent covenants upon property acquired by CWMTF grants can unduly restrict a landowner's options, or the DFR's ability to showcase good forest management practices that can be utilized to sustain properly functioning riparian areas.

Appendix I: Summary of Selected Forested Buffer Recommendations

Agency / Source	Minimum Buffer Width (*feet*) *Normal Waters*	Buffer Width Range (*feet*) *Normal Waters*	Preferred Buffer Width (*feet*) *Special Waters**	Allowable Activities
Alabama	35	Must maintain water quality standards	Must maintain water quality standards	Managed Forest, Selective harvesting
Arkansas	35	35 - 80	80+	Managed Forest, Selective harvesting
Catawba River (Mainstem temp. buffer rule)	50	50+	50+	Managed Forest, selective harvesting of high value trees
City of New York Water Supply watershed plans	Min. NY State BMP w/ Site-specific Adjustments[1]	Min. NY State BMP w/ Site-specific Adjustments[1]	Min. NY State BMP w/ Site-specific Adjustments[1]	Managed Forest captured by a written plan
Florida	35	35 - 200	200	Managed Forest, Selective harvesting
Georgia	20	20 - 100	100 minimum on trout waters	Managed Forest, Selective harvesting
Idaho	30	30 - 75	75+	Managed Forest, Selective harvesting
Kentucky	25	25 - 55	60+	Managed Forest, Selective harvesting
Mississippi	30	30 - 60		Managed Forest, Selective harvesting
N.C. Forestry BMP	50	50 - 100	125+	Managed Forest, Selective harvesting
N.C. Wildlife Resources Comm.	N.C. BMP's	N.C. BMP's	N.C. BMP's	Managed Forest, Selective harvesting
Neuse & Tar/ Pamlico riverbasins buffer rule	50	50+	50+	Managed Forest, selective harvesting of high value trees
New York State	50	50 - 150	150+	Selective Harvesting
South Carolina	40	40 - 120	80+	Managed Forest, Selective harvesting
Tennessee	25	25 - 145	Min. 50	Managed Forest, Selective harvesting
USDA-Forest Service (*unk*)	25	25 - 170	170+	Managed Forest, Selective harvesting
USDA-NRCS	25	50 - 100	200	Managed Forest, Selective harvesting
Virginia	50	50	60 – 200	Managed Forest, Selective harvesting

**Special Waters include drinking water supplies, ONRW, Wild & Scenic, trout-quality waters, or other waterbodies that may warrant additional protection as determined by the governing Agency/Source.*

[1] Riparian buffers are delineated according to a subjective field-key developed by the USDA-Forest Service as described in Figure 2.3 of Verry, et al.

<u>Additional tabular summaries are located in Verry, et al.:</u>
Page 140, Table 8.1 "Guidance for riparian area widths and suggested management practices in northern New England"
Page 237, Table 14.1 "Best management practices for riparian forests in selected eastern states"
Page 275, Table 16.1 "Potential impacts to riparian areas from forest management activities"
Page 278, Table 16.2 "Examples of RMZ widths and harvest restrictions"

References Cited

NASF – National Association of State Foresters (2002). *The Role of Forestry in the Management and Protection of Drinking Water Supply Watersheds*. NASF Resolution No. 2002-10. Washington, D.C. *http://www.stateforesters.org/resolutions/res_02.html*

NCASI - National Council for Air and Stream Improvement, Inc (2000). *Handbook of control and mitigation measures for silvicultural operations*. Unpublished draft Technical Bulletin. Research Triangle Park, N.C. *http://www.ncasi.org/forestry/research/watershed/control.pdf*

Patric, James H. (1995). *Water, Woods, and People: A Primer. Some Effects of human actions on water resources of the eastern forest*. Page 52. Published by Artistic Printers. Greeneville, TN 37745. Phone (615) 639-4316.

Perry, Justin A. *Personal correspondance*. Watershed Forestry Program, Watershed Agricultural Council. 33195 State Highway 10, Walton, NY 13856-9751. Phone: (607) 865-7790. *www.nycwatershed.org*

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M. (1997). *The Practice of Silviculture: Applied Forest Ecology. Ninth Edition*. Published by John Wiley & Sons, New York. Pages 72 – 74.

USDA-Forest Service (1992). *Riparian Forest Buffers: Function and Design for Protection and Enchancement of Water Resources*. State & Private Forestry - Northeastern Area, Forest Resources Management Publication NA-PR-07-91. Radnor, PA. Prepared by David J. Welsch. *http://www.na.fs.fed.us/spfo/pubs/n_resource/buffer/cover.htm*

USDA-Forest Service (1995). *Forested Wetlands*. State & Private Forestry - Northeastern Area, Forest Resources Management Publication PR-NA-195. Radnor, PA. *http://www.na.fs.fed.us/spfo/pubs/n_resource/wetlands/wetlands12_streamsides.htm*

USDA-Natural Resources Conservation Service (NRCS). (unknown date). *Water Related Best Management Practices in the Landscape.* For the Watershed Science Institue of USDA-Natural Resources Conservation Service. Center for Sustainable Design, Mississippi State University. Starkeville, MS. *http://www.wcc.nrcs.usda.gov/watershed/UrbanBMPs/pdf/streams/bank/riparianzone.pdf*

Verry, E.S.; Hornbeck, J.W.; Dolloff, C.A. (2000). *Riparian Management in Forests of the Continental Eastern United States*. Lewis Publishers/CRC Press, LLC. Boca Raton, FL 33431. *http://www.crcpress.com*

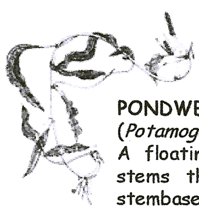
Wenger, Karl F., editor (1984). *Forestry Handbook. Second Edition*. Society of American Foresters. Publication No. SAF 84-01. Published by John Wiley & Sons, New York. Pages 32 – 34.

Texas Aquatic Plant Management Society
201 East Jones, Lewisville, TX 75057

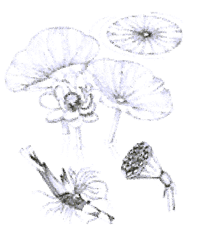
Beneficial Native Aquatic Plants of Texas

Native Aquatic plants are a beneficial component of reservoir and stream ecosystems. They provide structure and improve habitat for fish and other organisms, increase water quality and clarity, stabilize sediments and protect shorelines from erosion. Some of the common native aquatic plants in Texas are shown below.

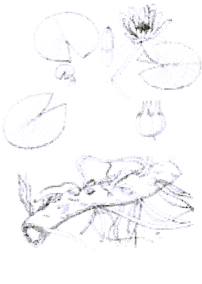
SOUTHERN NAIAD
(*Najas guadalupensis* (Sprengel) Magnus)
A submersed annual aquatic plant, southern naiad is a slender, narrow-leaved plant. Tolerant of many kinds of aquatic systems, southern naiad generally grows in shallow littoral zones. Leaves are opposite and thin, generally less than an inch in length, growing on long slender stems. The flowers are small, yet produce many viable seeds.



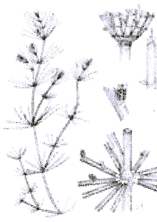
PONDWEED
(*Potamogeton sp.* Poiret.)
A floating-leaved perennial with stems that elongate from the stembase, producing floating and submersed leaves. Submersed leaves are alternate, broad-leafed but tapering, while the floating leaves are shiny, dark green, and oblong. Fruiting spikes are produced singularly in the axils.



AMERICAN LOTUS
(*Nelumbo lutea* (Willd.) Pers)
A perennial aquatic plant, American lotus grows from rhizomes and seeds. Lotus leaves are large, circular, peltate, either floating or emergent. The flowers are extremely large, showy, yellow in color and fragrant. Seeds produced are viable and valuable as waterfowl food. Generally found in slow to nonmoving waters.



WHITE WATER LILY
(*Nymphaea odorata* Aiton)
These perennial aquatic plants produce large leaves and flowers from rhizomes. Leaves of white water lily are circular and v-notched. Leaves are floating and generally reddish on the underside. The flowers are showy white, fragrant and in high demand by the aquatic nursery industry. These aquatic plants are generally found in slow or nonmoving shallow waters.



MUSKGRASS
(*Chara* Linnaeus)
A macroalgae, muskgrass is considered a pioneer species, forming extensive underwater mats similar to vascular plants. The grey-green stems provide habitat in ponds and lakes and have a distinctive odor, hence the common name. The stiff, thin leaves are whorled around a long, slender stem, staying low in the water column. Reproduction occurs through the orange oogonia which are barely visible on the upper leaves.

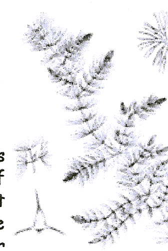

(Stutzenbaker)

WATER STARGRASS
(*Heteranthera dubia* (Jacq.) Small)
A submersed annual, water stargrass can grow efficiently in a variety of habitats, water depths and sediment types. Overwintering by rhizome provides an important food item for waterfowl and habitat for fisheries. A slender, multi-branched stem grows from the buried rhizome. Alternate leaves and a rounded stem can help distinguish from flat-stem pondweed. Distinctive yellow, star-shaped flowers provides basis for it's common name.

ARROWHEAD (*Sagittaria* spp.)
Perennial, generally emergent plants growing from a rhizome with large leaves. Leaf shape can vary from blade to the broad lancelot form. Some underwater rosettes of leaves can be produced. White prominent flowers are produced in whorls of three and can be produced throughout the growing season. Arrowheads generate underground corms or tubers which are highly desirable by waterfowl.

SPATTERDOCK
(*Nuphar luteum* (Small) E.O. Beal)
A perennial, emergent aquatic plant which produces large heart-shaped leaves. The flowers are small and yellow, partially opened, producing a viable seed. Spatterdock can be found in slow to nonmoving water, up to 5 feet in depth.

TAPEGRASS, WILD CELERY
(*Vallisneria americana* Michaux)
This submersed aquatic plant is found in rivers, streams, lakes and ponds. Ribbon-like basal leaves can grow to several feet long from a single rosette. Dioecious staminate flowers are found at the rosette while the pistillate flowers grow to the surface on spiral stalks where pollination occurs. After pollination, the fruit ripens and produces abundant viable seeds.



COONTAIL
(*Ceratophyllum demersum* L.)
This annual submersed aquatic plant is common to quiet streams, ponds, lakes and reservoirs. Generally rootless, mats of coontail can be found free floating . The leaves are in whorls of 5-12, branched, up to 3/4 inch long and can be abrasive to the touch. The entangled stems can reach several feet in length.

PICKERELWEED
(*Pontederia cordata* L.)
An emergent, perennial shoreline plant with heart to lanceolate shaped leaves and erect, showy purple flowers from a single rosette. Pickerelweed grows from rhizomes as well as seeds. Prefers shallow and slow or nonmoving waters.

BULRUSH (*Scirpus validus* Vahl.)
One of the most valuable food sources for waterfowl and mammals. A shoreline plant that grows in clusters, up to several feet in height. Rounded, spongy stems taper at the top with a tuft of dangling flowers on spikelets which produces numerous viable small seeds. Provides excellent shoreline stabilization and spreads by underground rhizomes.

Aquatic plant illustrations provided by the Information Office of the University of Florida, IFAS, Center for Aquatic Plants (Gainesville)

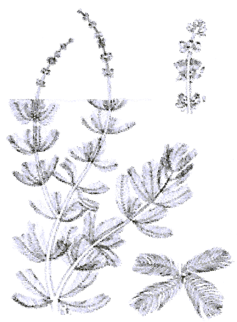
For more information call Texas Aquatic Plant Management Society representatives at 972-436-2215

Texas Aquatic Plant Management Society
201 East Jones, Lewisville, TX 75057

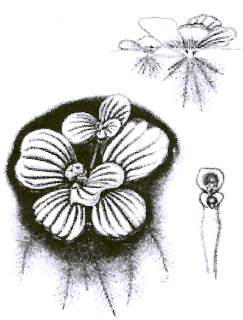
Harmful Non-native Aquatic Weeds in Texas

Aquatic weeds that have been introduced from other parts of the world into Texas waters can create serious environmental, economic, and public health problems. Because of their growth habits and their lack of natural controls, they often create extensive mats of vegetation which block light and gas exchange, degrade aquatic habitat, crowd out native plant populations, and impede human uses.

HYDRILLA- Southeast Asia
(*Hydrilla verticillata* (L.f.) Royle)
This submersed perennial aquatic plant was introduced into the United States in the 1960's and has since spread to 13 states, including Texas. Hydrilla is characterized by oblong whorled leaves (5) with serrated edges at each node. Long stems branch as the plant elongates rapidly to the surface, forming a dense canopy. Due to these growth strategies, hydrilla can shade out desirable native vegetation, impede navigation, affect water quality and habitat. In addition, hydrilla can reproduce sexually (seed) and asexually with tubers, turions, stolons and fragments.

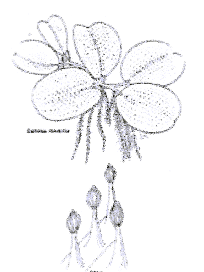


EURASIAN WATERMILFOIL - Europe/Asia
(*Myriophyllum spicatum* L.)
This submersed perennial aquatic plant can be found in 45 states. Stems are long and flexible, generally red when actively growing, with whorled leaves (4) around each node. The leaves are can be more concentrated closer to the surface, with 14+ leaflets per leaf, appearing featherlike. The slender flowering stem has the staminate upper and pistillate positioned lower, producing many viable seeds per plant. Can reproduce asexually by stolons and fragmentation, especially autofragmentation. Through formation of a dense canopy, Eurasian watermilfoil can shade out native vegetation, impede navigation, affect water quality and habitat.

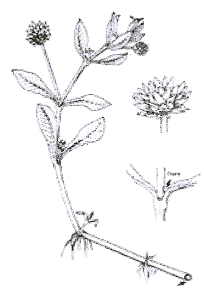


WATERLETTUCE - South America
(*Pistia stratiotes* L.)
A free-floating perennial plant forms a rosette of grey-green leaves about 4 to 8 inches long with long roots extended into the surrounding waters. Intolerant of cold temperatures, waterlettuce is limited to the more sub-tropical regions in Texas. Reproduction is generally asexually through production of daughter plants, forming large dense mats of free-floating plants. These mats can affect habitat and transportation.

WATERHYACINTH - South America
(*Eichhornia crassipes* (Martius) Solms-Laub.)
This floating plant has been called "the world's worst weed", introduced into water gardens because of beautiful purple flowers. Waterhyacinth produces long free-floating dark roots which uptake all required nutrients and release hydrogen ions, acidifying surrounding waters. Numerous broad inflated leafs extend from the stalk, ranging in height from a few inches to several feet. Although waterhyacinth can produce many viable seeds, the main reproductive method is by daughter plants. These interconnected parent to daughter plants form the dense floating mat which can reduce dissolved oxygen levels and effectively block waterways.



GIANT SALVINIA- South America
(*Salvinia molesta*)
This free-floating aquatic fern is larger than the common salvinia, with oblong floating leaves ½ to 1 ½ inch in length. Leaves frequently fold and compress into chains, with white bristles found on the leaf surface. Underwater stalks contain attached spore cases. Giant salvinia forms dense mats, spreading rapidly by buds. These floating mats reduce oxygen exchange and can negatively effect water quality and habitat.



ALLIGATORWEED-South America
(*Alternanthera philoxeroides* (Martius) Grisebach
Aggressive, mat-forming perennial, emergent shoreline plant found in habitats ranging from dry to wetland, lake shore and riverine. Spread can occur from seed or plant fragments. Leaves are opposite, generally lanceolate and about 4 inches long. Small, white flowers are produced on short spikelets, flowering throughout the growing season. Dense mat growth can impede navigation and displace native vegetation.

**It is illegal to import, sell, purchase, transport, propagate, possess, or release into public waters any of these harmful exotic aquatic plants.
(Texas Parks and Wildlife Dept.)**

Please check boat trailers and props when leaving a lake. Don't transport harmful aquatic plants!

For more information call Texas Aquatic Plant Management Society representatives at 972-436-2215

Great Trinity Forest Management Plan

Wetlands

General Prevention Procedures for Stopping Aquatic Hitchhikers

STOP AQUATIC HITCHHIKERS!

Protect Your Waters

Hitchhikers Impacts Prevention Resources News Activities About Us
Contact Us
FAQ

General Prevention Procedures for Stopping Aquatic Hitchhikers: *A must read for all recreational users*

Follow a general set of procedures every time you come in contact with any body of water. By doing so, you can protect your waters from harmful aquatic hitchhikers. Because you never know where a nuisance species has been introduced, but has yet to be discovered.

There are hundreds of different harmful species ranging from plants, fish, amphibians, crustaceans, mollusks, diseases or pathogens. Some organisms are so small, you may not even realize they are hitching a ride with you. So, it is important to follow this general procedure every time you leave any body of water.

Remove all visible mud, plants, fish/animals. Before leaving any body of water, it is important to examine all your equipment, boats, trailers, clothing, boots, buckets etc and:	• Remove any visible plants, fish or animals. • Remove mud and dirt since it too may contain a hitchhiker.* • Remove even plant fragments as they may contain a hitchhiker.* • Do not transport any potential hitchhiker, even back to your home. Remove and leave them at the site you visited. *The larvae (immature form) of an animal can be so tiny that you cannot see it. However, it can live in mud, dirt, sand, and on plant fragments.
Eliminate water from all equipment before transporting anywhere. Much of the recreational equipment used in water contains many spots where water can collect and potentially harbor these aquatic hitchhikers.	• Eliminate all water from every conceivable item before you leave the area you are visiting. • Remove water from motors, jet drives, live wells, boat hulls, scuba tanks and regulators, boots, waders, bait buckets, seaplane floats, swimming floats. • Once water is eliminated, follow the cleaning instructions listed below.

Thus, make sure that you:

Clean and dry anything that came in contact with the water. (boats, trailers, equipment, dogs, boots, clothing, etc.). Basic procedures include:

- Use hot (< 40° C or 104° F) or salt water to clean your equipment.
- Wash your dog with water as warm as possible and brush its coat.
- The following recipes are recommended for cleaning hard-to-treat equipment that cannot be exposed to hot water:
    - Dipping equipment into 100% vinegar for 20 minutes will kill harmful aquatic hitchhiker species.
    - A 1 % table salt solution for 24 hours can replace the vinegar dip. This table provides correct mixtures for the 1 % salt solution in water:

Gallons of Water	Cups of Salt
5	2/3
10	1 ¼
25	3
50	6 1/4
100	12 2/3

- If hot water is not available, **spray** equipment such as boats, motors, trailers, anchors, decoys, floats, nets, **with high-pressure water.**
- **DRY Equipment.** If possible, allow for 5 days of drying time before entering new waters.

Do not release or put plants, fish or animals into a body of water unless they came out of that body of water.
Also, do not release them into storm drains, because most storm drains lead to water bodies or wetlands. This is an important prevention step because many plants and animals can survive even when they appear to be dead. The two categories below describe some common situations where people may feel

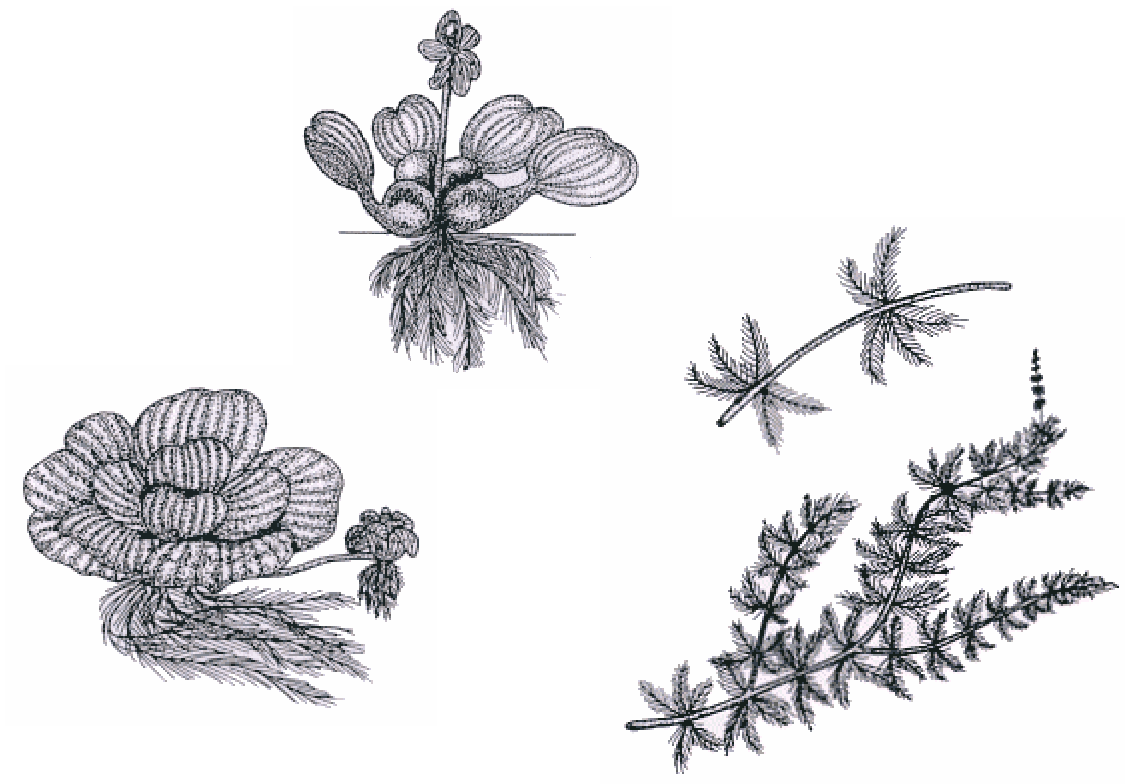
- **Aquarium and Aquatic Pets:** If your family gets tired of its aquarium or aquatic pets, do not release anything from the aquarium (water, plants, fish or animals) into or near a body of water or storm drain. Explain to your children how you could be hurting all of the streams and lakes around the country and killing other fish and animals that already live in the water.

  If you cannot find a home for the critters in you aquarium, bury them. Dump the water into the toilet or yard, far away from storm drains.

- **Bait:** Whether you have obtained bait at a store or from another body of water, do not release unused bait

compelled to release aquatic plants or animals.	into the waters you are fishing. If you do not plan to use the bait in the future, dump the bait in a trashcan or on the land, far enough away from the water that it cannot impact this resource. Also, be aware of any bait regulations, because in some waters, it is illegal to use live bait.

Aquatic Vegetation Management In Texas: A Guidance Document



Texas Parks & Wildlife Department

INLAND FISHERIES

Dr. Earl W. Chilton II
Habitat Enhancement

Philip P. Durocher
Director

Table of Contents

Aquatic Vegetation Management In Texas

I. Background

This is the guidance document described in § 57.932 of the TPWD rules. The rules are in Appendix B of this document. State law directs TPWD to develop a statewide management plan to guide decision making regarding nuisance aquatic vegetation in public water**.** This document describes the best available strategies and alternative treatment methods for preventing and controlling nuisance aquatic vegetation problems, consistent with the principles of Integrated Pest Management (IPM). TPWD rules define IPM as:

> The coordinated use of pest and environmental information and pest control methods to prevent unacceptable levels of pest damage by the most economical means and in a manner that will cause the least possible hazard to persons, property, and the environment. Integrated pest management includes consideration of ecological, biological, chemical, and mechanical strategies for control of nuisance aquatic vegetation.

This document is also intended to assist individuals and organizations in meeting the procedural requirements of state law and rules. The document contains explanatory information, step-by-step procedures, and sample forms.

Aquatic vegetation is an extremely important component of most freshwater systems, providing habitat, refuge, and food for a wide variety of organisms including fish, invertebrates, and waterfowl. It is well documented that aquatic vascular plants serve as habitat for numerous invertebrate species (Muttkowski 1918; Soszka 1975; Biltgen 1981). Habitat complexity increases with plant biomass and is well correlated with increased abundance and diversity of aquatic invertebrates (Heck and Wetstone 1977; Stoner 1980; Wiley et al. 1984; Bell and Westoby 1986). As a result, plant communities often support a large percentage of the total invertebrate biomass in a system. For example, Watkins et al. (1983) found the number of benthic organisms associated with vegetation in one Florida lake was triple that in unvegetated areas, and Wiley et al. (1984) found that macrophytes increased invertebrate abundance by as much as 90% in Illinois ponds. Similarly, Iversen et al. (1985) reported 95% of invertebrates in the River Susa, Denmark, were found in vegetation. Obviously, increased production of invertebrates can have strong implications for fishery productivity since most freshwater fish species consume invertebrates during some portion of their life cycles.

There are also instances when excessive aquatic vegetation growth may detrimentally affect fishery and wildlife resources, or limit access for fishing, hunting, and other recreational activities. Maceina and Reeves (1996) found the lowest average weight of fish caught during largemouth bass fishing tournaments occurred during peak macrophyte coverage. Similarly, Hoyer and Canfield (1996) found a direct relation between macrophytes and young of the year largemouth bass abundance, however, there was an inverse relation between plant abundance and bass growth. A number of researchers have found that dense plant communities may inhibit the feeding efficiency of invertivorous fishes (Crowder and Cooper 1982; Minello and Zimmerman 1983; Heck and Wilson 1987; Russo 1987). In some cases plant species, as well as abundance, can have a strong influence on fish populations. For instance, Dibble and Harrel (1997) found significant differences between largemouth bass feeding in common pondweed *Potamogeton nodosus*, versus those feeding in Eurasian watermilfoil *Myriophyllum spicatum*, despite similar plant densities. Those feeding in pondweed fed heavily on macroinvertebrates, whereas those feeding in watermilfoil fed much more heavily on fish.

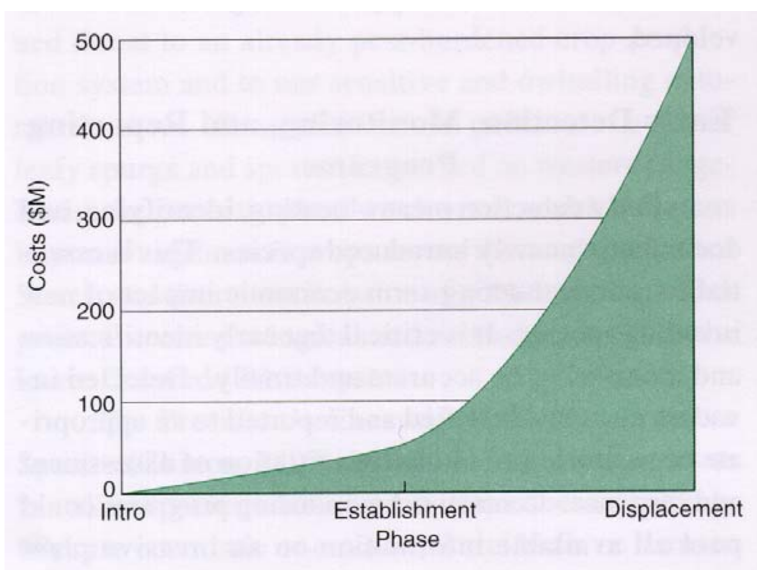
Overabundant aquatic vegetation is typically the result of introduction of exotic species which out-compete native plants, and grow unchecked by natural herbivores or parasites. For example, two of Texas' most problematic aquatic plant species, hydrilla *Hydrilla verticillata* and waterhyacinth *Eichhornia crassipes,* are not native to North America.

Other reasons for aquatic vegetation reaching nuisance proportions may include disturbed habitat and nutrient loading. Construction of reservoirs in Texas dramatically changed the aquatic and terrestrial landscape of the state. These reservoirs have provided flood control, water for agriculture and municipalities, power plant cooling, areas for recreational use, and fish and wildlife habitat that did not exist in Texas. However, like most disturbed habitats, many reservoir ecosystems have not developed stable aquatic plant communities. The fluctuating water levels of many reservoirs make the establishment and spread of native vegetation difficult. Exotic plant species succeed in Texas' reservoirs because these species are adapted to rapidly fill ecological niches created by disturbed or unstable habitats, and because native herbivores may not readily feed on exotic plants. When exotic species are introduced into these systems, growth and spread of these aquatic plants can be quite dramatic. Nutrient-rich water speeds growth and spread of vegetation, including nuisance vegetation. Elevated nutrient input may come from a variety of sources including farm runoff, runoff from fertilized lawns, sewage treatment facilities, septic tanks, etc. Exotic plant species have been introduced and spread through Texas by a variety of mechanisms. Well meaning aquarists and water gardeners are often unaware the plants they are buying are illegal in Texas (and sometimes the United States), and one flood is all it takes to carry unwanted plants from the backyard to the river. Once plants have been introduced they are often spread by waterfowl and wildlife. Boaters may also unknowingly carry plants from one waterbody to another via trailers, live wells, and motor lower units.

II. Prevention

The backbone of every effective program to control nuisance aquatic weeds is prevention. If possible, nuisance exotic aquatic weeds should be prevented from colonizing new waters, and if colonization does occur they should be prevented from spreading. Prevention is the least costly method of controlling aquatic weeds. Figure 1. illustrates the exponential rise in management costs ($ millions) as exotic plants are introduced, become established, and finally may displace native species. In general, prevention strategies fall into five categories, which are discussed below.

Figure 1. Management cost in million dollars and invasion phase relationship show that prevention in the least costly phase, with exponentially rising costs once the invading weed has become established and more costly if it is displacing native species and/or disrupting native habitats (From Mullin et al. 2000).



Root causes

The root causes of nuisance aquatic vegetation - habitat disturbance, nutrient loading, lack of efficient herbivores, transportation and introduction of exotic plant species into previously uncolonized areas (via boats, trailers, wildlife, intentional releases, etc.) - must be addressed if aquatic plant management in Texas is to succeed on a sustainable basis. Although aquatic herbicides, biological controls and mechanical controls can be effective in controlling or managing aquatic vegetation, these are all short-term solutions. Strategies for **preventing** nuisance aquatic vegetation will produce better and longer-lasting results than those directed at managing problematic vegetation. In that regard, managers should seek solutions to the root causes of nuisance aquatic vegetation.

One of the chief causes of nuisance vegetation growth is nutrient enrichment. Nutrient loading (eutrophication) is the process of adding surplus nutrients required for plant photosynthesis and growth (primarily nitrogen and phosphorus) to an ecosystem. The nutrients can either come from point sources (e.g., sewage treatment plants or agri-industrial effluent) or non-point sources (e.g., septic tank field lines or fertilizer runoff from lawns, fields, golf courses, etc.). Although some increase in nutrient inflow can be beneficial by increasing plankton production and native plant growth, an overabundance of nutrients may cause water quality problems and increase the likelihood that hydrilla and other nuisance plants will grow beyond control.

Steps to follow for reduction of nutrient loading include:

a. Contact TCEQ to insure that all point sources for nutrient inflow within the watershed are within permitted limits.

b. Educate property owners in the reservoir's watershed urging that septic systems be checked for proper operation, that turf and field fertilizer be limited to the amount necessary, and that vegetated buffer zones be established between activities that cause nutrient loading (livestock production operations, golf courses, etc.) and the reservoir or its tributaries.

Monitoring and rapid response

If the spread of nuisance aquatic vegetation is to be controlled, the help of all Texans who enjoy fishing, boating and contact recreation on our rivers, streams and reservoirs must be enlisted. Citizens' organizations and advisory groups may be used to aid in early detection of nuisance species infestations, as well as to provide input relative to the most appropriate management techniques for specific waterbodies. When new infestations are discovered and management is deemed appropriate, water managers must be able to respond immediately. TPWD's experience predicts that the short-term costs associated with immediate response are often less than the costs related to "no management" or delayed management. Therefore, programs that enlist the aid of anglers, boaters, and other recreational enthusiasts should be encouraged, since they are often aware of new infestations before biologists. Exotic aquatic plants are here for the foreseeable future and everyone must get involved.

Research

TPWD is committed to ongoing research regarding ecology and management of aquatic vegetation. Over the next few years, TPWD will team with its partners to:

- Evaluate mechanical means of aquatic vegetation management.
- Evaluate the efficacy of reduced concentrations of aquatic

herbicides in aquatic vegetation management.

- Continue research regarding native aquatic vegetation planting and restoration. The advantages of native plant species are understood, but much remains to be learned about the most appropriate species for a body of water, how to produce plants in quantities necessary for replanting, and the best way of maintaining re-vegetated habitats**.**

- Research the safety, efficacy and ecological benefits of biological controls. Biological control has significant potential, particularly when appropriately applied as part of an IPM approach to plant management. While grass carp biology and efficacy have been extensively researched, the use of this biological tool in an IPM plan that stresses establishing or re-establishing native vegetation remains to be carefully researched. Therefore, research into use of other types of biological controls, particularly insects and fungi, will continue.

- Better understand the best management practices necessary for preventing introduction and spread of nuisance aquatic vegetation.

Education

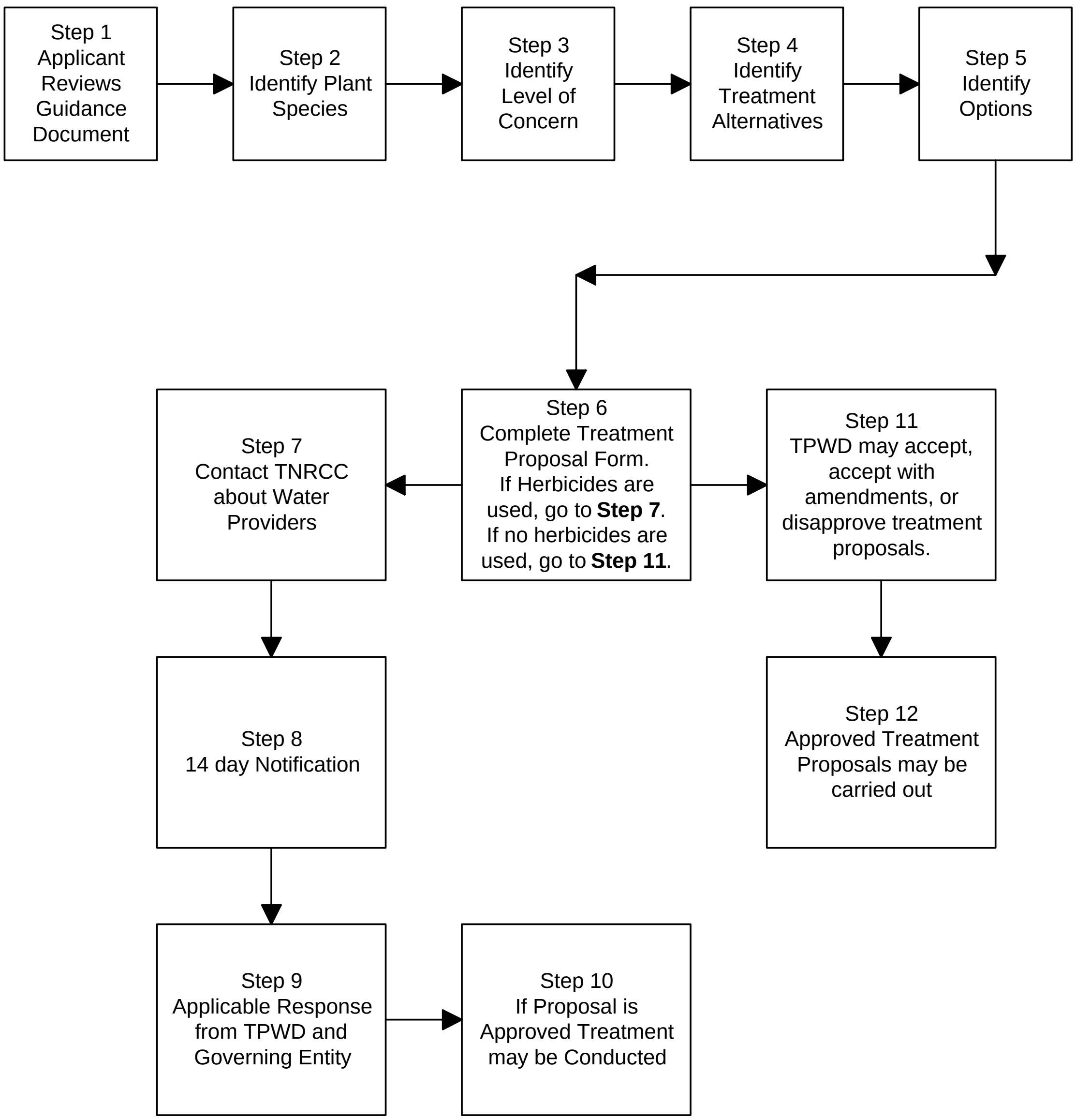
In Texas, where exotic plant distribution is becoming widespread, it is difficult to completely eliminate inadvertent spread of exotic plant species among public waters. However, an aggressive educational program could slow or prevent the distribution of these plants into new areas of the state. The solution may lie in developing and implementing programs to educate water managers, water resource users, and merchants (such as fishing clubs, boaters, aquaculturists, water gardeners, and aquarium hobbyists) about the problems that can arise from the transportation and consequent introduction of exotic aquatic plants. Programs will focus on best management practices necessary to prevent the spread of exotic aquatic plants. Citizens' organizations and advisory groups can play an important role in disseminating valuable information to the public.

Law enforcement

Current statutes and regulations provide penalties for possession, transport and placement of prohibited plant species in public water. Active law enforcement in other states has proved to be a very powerful means of preventing spread of nuisance species and of educating the public about the hazards of transporting and transplanting exotic plants. TPWD will team with its partners to strengthen and coordinate law enforcement activities.

III. How to Develop an Aquatic Vegetation Treatment Proposal

Figure 2. Texas Vegetation Management Plan Process

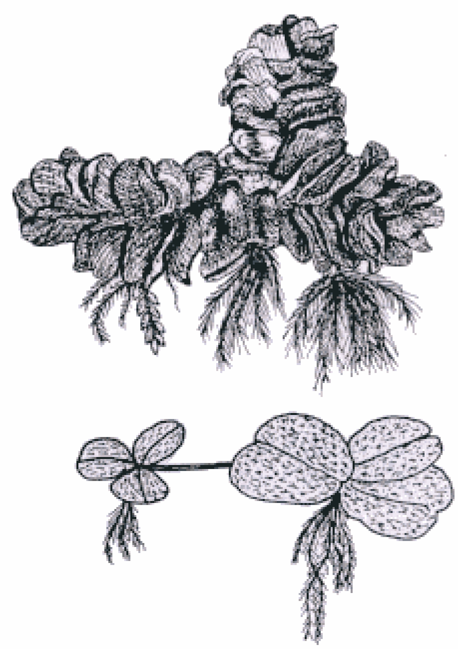


Note: Pages 38-39 describe the steps above in detail.

A. Identifying Vegetation Species

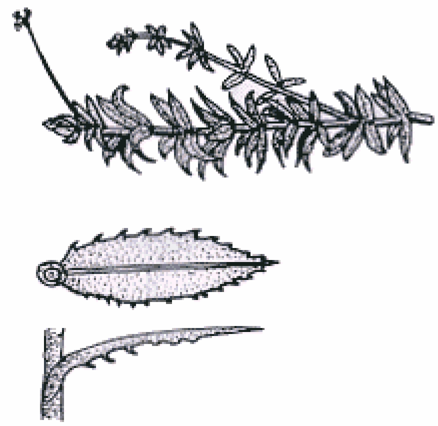
Correctly identifying aquatic vegetation species is critical for understanding what management options are available, and which are most efficacious. Often, vegetation species that are similar in appearance have entirely different management options. Published keys (e.g., Fassett 1957) are useful for identification. Unfortunately, many keys use only line drawings to aid in identification. The University of Florida Center for Aquatic and Invasive Plants maintains an internet site (http://aquatic1.ifas.ufl.edu) that provides color pictures and descriptions of many aquatic vegetation species. If you are not sure what type of vegetation you have please request assistance from a TPWD biologist (Appendix D). Information is provided below for selected nuisance plant species in Texas.

1. Salvinia



Two species of aquatic fern, genus *Salvinia*, have been identified in Texas. Both are small floating plants with oval shaped leaves (fronds) that have tiny hairs on the upper surface. Common salvinia *S. minima* was first identified in Jefferson County (Port Arthur area) in 1992 while the more ecologically threatening Giant salvinia *S. molesta* was first identified in the Houston area in Spring 1998. *S. minima* is the smaller of the two species and is readily distinguished from *S. molesta* by the morphology of its leaf hairs. In *S. minima* the hairs are split four ways near the tip. In *S. molesta* the hairs are also split, but they come together at the tip forming an egg-beater type structure. Typically, mature leaves of *S. molesta* are quarter to half-dollar sized, about twice the size of *S. minima*. All salvinia species are on the state's "Harmful or Potentially Harmful Exotic Fish, Shellfish, and Aquatic Plants" list, which means they are prohibited in the State of Texas. Giant salvinia, also known as Kariba Weed, has spread from its native habitat in southern Brazil to many other countries around the world including Australia, New Guinea, New Zealand, Zambia, Zimbabwe, and now to the United States (Mitchell 1976). It ranks second behind waterhyacinth on the nuisance aquatic weed list where it was placed in 1984 (Barrett 1989). Giant salvinia damages aquatic ecosystems by outgrowing and replacing native plants that provide food and habitat for native animals and waterfowl. Additionally, salvinia blocks out sunlight and decreases oxygen concentration to the detriment of fish and other aquatic species. When plant masses die, decomposition lowers dissolved oxygen still further. Blockage of waterways to traffic is common. Giant salvinia infestations often expand very rapidly. Doubling times as low as two days have been observed in the laboratory, and under field conditions doubling times of approximately a week are not unusual.

2. Hydrilla



One of Texas' most problematic aquatic plant species, hydrilla, is not native to North America. Hydrilla, which has small (0.5-1.0 inches) leaves arranged in whorls around the stem, was introduced into Florida in the early 1950's through the aquarium trade, and initially marketed as Indian star-vine (Schmitz 1990). Since then the plant has spread throughout Florida, also becoming established widely throughout eastern seaboard states as well as California and Washington (Netherland 1997). As a result of its rapid growth and competitive ability, hydrilla populations often exceed beneficial levels. Bowes et al. (1979) reported dense surface mats of hydrilla may cause wide fluctuations in dissolved oxygen levels, pH, and temperature. Overabundant hydrilla may also reduce plant and animal diversity (Barnett and Schneider 1974), as well as stunt sport-fish populations (Colle and Shireman 1980). Flow rates in canals and rivers may be restricted (TPWD staff observations), and access may become limited, precluding water recreation, as well asthe economic benefits of recreational activities (Colle et al. 1987).

Two characteristics that are most problematic include its rapid growth rate under a wide range of environmental conditions, and its ability to reproduce in a variety of ways. Hydrilla can grow up to one inch per day until it nears the surface of the water. Once near the surface it forms a thick mat of branches and leaves that intercept sunlight, often preventing native plants from growing underneath. Hydrilla commonly occurs in reservoirs ranging from oligotrophic (low in nutrients) to eutrophic (high in nutrients) conditions. Although hydrilla prefers a pH of 6-8 (Langeland 1990), it can grow under a wide range of pH conditions. Hydrilla can also tolerate relatively high salinity but perhaps its greatest advantage is the ability to grow and photosynthesize in less than 1% of full sunlight (Haller 1978). The ability to grow and photosynthesize at light levels below those required for native submersed plants allows hydrilla to colonize deeper water, frequently growing in water 3 yds deep with instances of establishment in very clear water up to 15 yds deep. It is this ability to grow in deeper depths that allows hydrilla to cover such a large portion of relatively shallow Texas reservoirs.

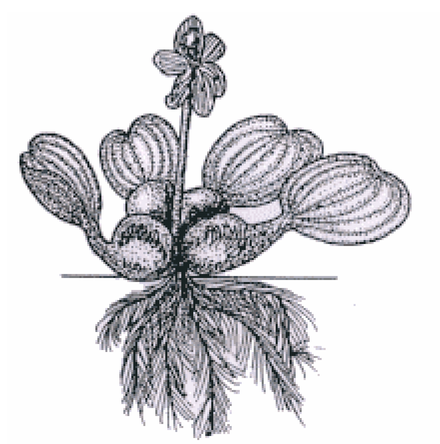
Hydrilla can reproduce in a variety of ways including fragmentation, tubers, turions, and seeds (Langeland 1990). The ability of hydrilla to reproduce from fragments causes its rapid spread within reservoirs and from one reservoir to another. Nearly 50% of fragments with a single leaf whorl can sprout a new plant (and subsequently a new population). For fragments with three or more leaf whorls, the success rate is over 50%. With success rates so high, it is easy to see why hydrilla is spread easily by boats, boat trailers, wildlife, and from aquariums.

Tubers are actually subterranean (underground) turions. Tubers can remain dry for several days and still remain viable. They can be buried in undisturbed wet sediment for over four years and survive. They can also survive herbicide treatment and ingestion and regurgitation by waterfowl. It is largely the tubers that allow hydrilla to remain established even during an aggressive treatment program. A single tuber can potentially produce approximately 6,000 new tubers per yd^2 .

Turions that form in leaf axils are another potential means of hydrilla expansion. A single turion can potentially produce over 2,800 additional turions per yd^2.

Although hydrilla can reproduce sexually, seed viability is low and the overall importance of seed production is unknown. So far in Texas only dioecious populations of female plants have been found, so seed production in Texas is unknown.

3. Waterhyacinth



Waterhyacinth~~,~~ is a large floating plant, native to South America, which has been called the world's worst aquatic weed (Cook 1990). It is believed to have been introduced into the United States at the World's Industrial and Cotton Centennial Exposition of 1884-1885 in New Orleans, Louisiana, and may have been cultivated in the U.S. as early as the 1860's (Tabita and Woods 1962). By the late 1890's, waterhyacinth had become such a problem for navigation that Congress was prompted to pass The Rivers and Harbors Act of 1899 which authorized the U.S. Army Corps of Engineers (ACOE) to begin major aquatic plant control programs (North American Lake Management Society and Aquatic Plant Management Society 1997). Waterhyacinth reproduce~~d~~s by budding daughter plants, or by producing seeds when its distinctive purple flower is in bloom. Populations may double in size every 6-18 days (Mitchell 1976). Perhaps due to its rapid growth rate, efforts by the ACOE were unable to control waterhyacinth, and populations expanded to over 125,000 acres in Florida by the late 1950's (United States Congress 1965). Light and oxygen diffusion (Gopal 1987), as well as water movement (Bogart 1949) can be severely reduced by the presence of over abundant waterhyacinth. Waterhyacinth can smother beds of submersed vegetation and eliminate plants that are important to waterfowl (Tabita and Woods 1962; Chesnut and Barman 1974). Similarly, low oxygen concentrations underneath waterhyacinth mats can cause fish kills (Timmer and Weldon 1967). Waterhyacinth has completely eliminated resident fish populations in some small Louisiana lakes (Gowanloch 1945). The combination of large leaves and hanging roots can produce evapotranspiration rates in excess of twice normal evaporation. Waterhyacinth induced water loss can be significant in West Texas water supply systems where drought conditions often occur. Waterhyacinth infestations are often associated with reduced boating, fishing, hunting, and swimming access.

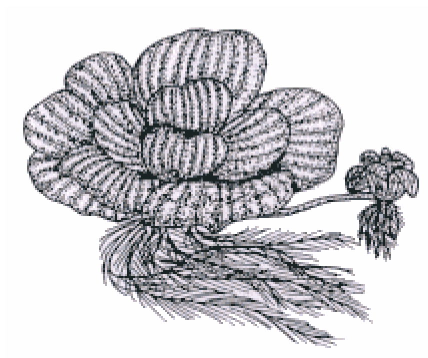
4. Eurasian watermilfoil

Eurasian watermilfoil *Myriophyllum spicatum* is an aquatic plant native to Europe and Asia which was first introduced into North America in the late 19th century (Reed 1977). In recent years it has gained a reputation as a nuisance plant species (Nichols and Shaw 1986). Although it is quite similar to the North American native watermilfoil *M. exalbescens*, the species can usually be distinguished on the basis of leaf morphology. In general, *M. spicatum* produces 5-24 pairs of leaflets per leaf, whereas *M. exalbescens* produces 4-14 (Aiken and McNeill 1980). About 70% accuracy can be obtained by characterizing everything with 14 or more pairs of leaflets as M.spicatum (Nichols 1975).

Eurasian watermilfoil flowers in mid-June through late summer. In addition to flowering, the plant may reproduce asexually by producing vegetative buds, and by fragmentation (Nichols 1975*). M. spicatum* may survive winter seasons as a whole plant, as a root mass, or by producing turions or winter buds.(Stuckey et al. 1978; Titus and Adams 1979).

Eurasian watermilfoil is a very good competitor capable of displacing native submerged plant species, reducing both habitat diversity and plant species diversity. When overabundant this species can create many of the same problems as hydrilla, including reduced boat access, reduced access to other recreational opportunities such as swimming and skiing, and low dissolved oxygen levels.

5. Waterlettuce



Waterlettuce *Pistia stratiodes* is one of the most cosmopolitan aquatic plants in the world. It is a floating plant (although it is capable of rooting in wet soil for prolonged periods of time), and is easily recognizable by its lettuce-like leaves, which are broadly rounded at the upper end and covered by tiny hairs. This plant is found on every continent except Europe and Antarctica (Gillett et al. 1968, Stoddard 1989). Origins of the plant are unclear, but based on the abundance of associated insects it is believed waterlettuce may have come from South America (Cordo et al. 1981).

As a large floating plant, waterlettuce may cause many of the same problems associated with waterhyacinth, including reduced boating, fishing, hunting, and swimming access.

6. Alligatorweed

Alligatorweed *Alternanthera philoxeroides* has been described as an amphibious plant because is grows in a wide range of habitat types including both terrestrial and aquatic (Vogt et al. 1979). It may be found as either a floating plant or a rooted plant. The aquatic form usually has hollow stems, whereas, the terrestrial form does not. The plant originated in the Parana River region of South America (Maddox 1968, Vogt et al. 1979), but has since spread to other areas of South America, as well as North America, Asia, and Australia (Julien et al. 1995). Flowering stems are upright. Leaves are usually elliptic and may be up to 4 inches long. Flowers bloom from April through October if conditions are favorable.

Similar to waterhyacinth and waterlettuce, excessive alligatorweed growth can clog waterways, and limit boating, fishing, hunting, and swimming access. Low oxygen problems may also result where waterbodies are completely covered.

B. Identifying Your Level of Concern

Each body of water in Texas is unique. The native flora and fauna, primary and secondary uses, water quality parameters and recreational use of reservoirs (in particular) underscore the need for aquatic plant management that is tailored to each water body. As shown on the treatment proposal form (Appendix C), the person submitting the treatment proposal should try to classify each aquatic vegetation problem on each body of water into one of three "management response categories". Which response category should be chosen depends on several factors, including (but not limited to) primary use of the water body, recreational uses, drinking water uses, agricultural uses, species of plant, surface coverage, ecological significance, history of infestation, and possibility of expansion. A multi-tier system provides a sound method of classifying reservoirs with nuisance aquatic vegetation to allow a consistent and reasonable approach to meeting the challenges brought about by invasive aquatic plants. This system is set up with general guidelines; placement of a particular reservoir situation into a specific tier will be based on all the attributes and uses of the reservoir, not strictly on the amount of nuisance vegetation present.

It is possible that a water body will face nuisance aquatic vegetation problems from more than one species of plant. For example, a reservoir could have both giant salvinia and hydrilla. In that case, each nuisance plant species should be classified into a response category. The giant salvinia infestation will probably be Tier I, while the hydrilla might be Tier I, II or III. Each nuisance plant species on each water body should be addressed on a different treatment proposal form. If the choice of category is not easily ascertained, consultation with TPWD is readily available and encouraged (Appendix D).

Immediate Response - Tier I

Tier I response is a management option for bodies of water experiencing limited, controllable stands of nuisance aquatic vegetation, or areas of special ecological concern. Tier I situations will be addressed by executing as quickly as possible an appropriate management strategy designed to eliminate the nuisance vegetation and reduce or preclude chances of spread or reoccurrence.

Presence of nuisance aquatic plant species, primary water use requirements and the water body's physical and biological attributes (e.g., submerged contour, hydrology, and nutrient loading) should determine Tier I response. For example, if the uses of the reservoir are not affected and there is little potential for expansion over 30% surface coverage the decision may be to implement a different tier response. Conversely, in bodies of water with characteristics conducive to establishing stands of nuisance plant species (for example, stable water levels, shoreline development and an absence of native vegetation), an immediate Tier I response could be the most effective and least harmful long-term solution. The goals of any Tier I response will include the continuation or improvement of fishery and/or other recreational benefits.

Maintenance - Tier II

Tier II response situations are those that have substantial occurrences of nuisance aquatic vegetation such that complete control is virtually impossible or at the very least impractical. Tier II situations are to be monitored closely and managed, in conjunction with the governing entity, to provide fishing and boating access or to meet ecological needs. Mechanical, biological and chemical plant control methods may be used, consistent with IPM, to help limit adverse impacts of vegetation on fishing and boating access.

Watch Status - Tier III

Tier III response situations are those where control of nuisance aquatic plants could be achieved given adequate resources; however, the plants are stable or declining, and there is little chance of the infestation being spread to a nearby water body. These reservoirs should be monitored for expansion of the exotic plant populations with a plan in place to control plants if such control becomes necessary.

C. Identifying Possible Prevention and Treatment Techniques

The tools commonly available to control nuisance vegetation can be grouped into three major categories: **Biological controls** use living organisms capable of controlling particular plant species; **Mechanical/physical controls** incorporate a wide variety of techniques, usually shredding or cutting and removing nuisance vegetation directly or exposing plants to unfavorable environmental conditions; and **Chemical controls** eliminate vegetation by utilizing herbicides toxic to specific plants, or in some cases making use of plant hormones. Using an IPM approach, any one of a variety of techniques, or combinations thereof, may be used to effectively manage nuisance aquatic vegetation in the most economic and environmentally sound way possible.

1. Mechanical/Physical Control

i. Mechanical harvesters (Includes traditional barge type harvesters with both vertical and horizontal cutting blades and a conveyor belt that gathers cut material for later offloading or for shredding.)

Target Species: All aquatic vegetation found in water greater than 2.0 feet in depth.

Pros:

- No chemicals introduced into the water, and no effect on drinking water.
- Plant biomass/nutrients can be removed from the system.
- No new organisms are introduced.
- High level of treatment precision; targeted plants can be removed within a well-defined area.

Cons:

- Very slow removal (typically 1-2 acres/day under ideal conditions).
- Fragmentation may accelerate spread of aquatic plant species.
- Small fish and other wildlife mortality may occur during the process of vegetation removal, but may not affect overall fish community health.
- Short-term control method, repeated cutting during the growing season typically required.
- Only cuts to a maximum depth of 5-5.5 feet.
- Requires 2.0-3.0 feet of water (depending on harvester size) with no submerged obstacles (stumps, rocks, etc.).

Applicability: May be used in areas greater than 2.0 feet deep, where there are few submerged obstacles, and where fragmentation and re-growth will not significantly increase a plant's ability to spread.

ii. Mechanical shredders (Includes floating barge type machines that shred vegetation near the water surface rather than cutting and harvesting it.)

Target Species: All aquatic vegetation found in the upper 1-2 feet of water greater than 2.0 feet in depth that do not reproduce by fragmentation.

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- 80% or more of the plants that are shredded usually die.
- Up to 32 times faster than traditional harvesters.
- Potentially much lower cost per acre than traditional harvesters.

Cons:

- Fragmentation may accelerate spread of aquatic plant species.
- Requires a minimum of 2.0-3 feet of water with no submerged obstacles (stumps, rocks, etc.).
- May require multiple use during each growing season.
- May temporarily depress dissolved oxygen levels.
- May be dangerous to fish and other wildlife associated with plants.

Applicability: Areas greater than 2.0 feet deep with few submerged obstacles, and where fragmentation will not significantly increase a plants ability to spread.

iii. Water level manipulations - The purpose of drawdowns is to strand plants on the shoreline for a sufficient period to cause mortality by dessication or freezing. Water level is usually manipulated by the reservoir's governing entity. Specific strategies vary depending on the reservoir situation, but generally holding the water level at several feet above normal pool in the spring can reduce light transmission to established vegetation thereby reducing its growth. Dropping the water level several feet through the fall and winter dries vegetation killing some of the plants outright. Drawdowns are quite effective on most submerged plants such as Eurasian watermilfoil. However, although hydrilla on dry ground is more likely to be damaged by cold weather than hydrilla insulated by water, in general, water level manipulations seem to be somewhat less effective on hydrilla than on many other plants. Because of hydrilla's adaptability, water level manipulation could give hydrilla a survival advantage over desirable native plants. Raising the water level in the spring may cut light penetration enough to limit native plant growth while hydrilla continues to grow unabated, especially in relatively clear water. Lowering water level in the fall may kill both hydrilla and native plants, but the hydrilla, because of its ability to produce numerous tubers, may return more quickly than many native plants when the water level rises. Further, some drying seems to act as a trigger to cause increased hydrilla tuber sprouting. For these reasons, specific circumstances have to be examined carefully before water level manipulation is used as a hydrilla control strategy. For example, if hydrilla already maintains a monospecific plant community, water level manipulations may be a viable means of controlling its growth, especially if two drawdowns are used as suggested in some literature; one to germinate tubers, and a second to kill germinated tubers.

Target Species: All floating or submergent nearshore aquatic vegetation

Pros:

- Can provide substantial control if water levels can be adjusted.
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Can provide selective control if level manipulations are properly timed with the life history of target species.
- No new organisms are introduced.

Cons:

- May have significant detrimental impacts to ecosystem, particularly fisheries, if drawdowns are not appropriately timed.
- Drawdowns may be restricted by water rights and/or reservoir obligations.
- May impact various uses of the water body (e.g. boat access, sale of water, power plant cooling, etc.).
- Individual floating plants (species such as salvinia or waterhyacinth) may remain viable.

Applicability: Use of drawdowns is limited to water bodies with water control structures.

iv. Booms - The use of floating booms can be useful in a floating plant control program. They can be deployed to prevent floating plants from clogging water intakes, marinas, swimming areas, or other susceptible sites. Booms can also be used to collect or contain plants in an otherwise open setting. Booms placed around a boat launch may prevent plants from interfering with ingress or egress of boats, and prevent plants that have been accidentally introduced at a boat launch from escaping into the open water body. Floating booms can also be used to collect floating plants being moved by currents within a water body, or prevent plants from entering the main course of the reservoir from feeder embayments. Plants collected in such manner can be more efficiently removed with other control methods.

Target Species: All floating plant species

Pros:

- After deployment, operation of booms is fairly passive.
- No new organisms are introduced.
- Can achieve high level of site-specific control.
- Simple technology.
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Few off-target impacts.
- No water use restrictions.
- Can help prevent spread of floating nuisance plant species.

Cons:

- Does not provide “active” control of existing infestations.
- Effectiveness limited spatially, except when considered as a preventative measure.
- May restrict navigation, or become a navigation hazard.
- Requires a high level of maintenance; booms must be cleaned regularly.
- Built up material may be carried over or under a boom by current.
- Easily vandalized.
- Short-term solution.

Applicability: Mainly for protection of fixed structures and facilities. Also for containing infestations for control by other methods and for helping prevent new introductions.

v. Bottom Barriers - Physical barriers have been used with various degrees of success to prevent weed growth in specific applications. Usually these consist of various types of dark polyethelene plastic which are spread across the bottom of the area to be kept weed-free and then staked in place. Barriers are fairly expensive and labor-intensive to install. These systems are generally used only around boat docks, swimming areas, etc. due to their expense. Barriers are susceptible to damage by propellers, storm damage, and dredging. Problems have also been encountered in the past with gases (i.e. oxygen and CO_2) building up under the film and buoying the barrier up from the bottom; however more modern gas permeable fabrics are designed to avoid this.

Target Species: All submerged plant species.

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- Growth of submerged plant species is inhibited.
- No fragmentation problems.

- No water use restrictions.

Cons:
- Not plant specific, all submerged plants are affected.
- Expensive and labor intensive.
- Not effective on floating species.
- Difficulties keeping the barrier submerged.
- Sediment may accumulate on top of the barrier.
- Plants may grow in sediment on top of the barrier.
- Limited to small areas.

Applicability: Primarily useful in small pond, and still water situations.

vi. **Shading -** A number of dyes are on the market that are used to shade plants growing up from the bottom of a water body. Shading is an artificial means of controlling unwanted submersed aquatic vegetation. Chemicals are employed to inhibit light penetration and thus shade out the problem plant species. Shading is best employed in small lakes or ponds. Commercially available chemical dyes are sometimes used to color the water (usually a deep blue) to inhibit light penetration and thus shade out existing or potential weeds. These products are generally used in maintaining immaculate landscape ponds.

Target Species: All submerged plant species.

Pros:
- No use restrictions in drinking water sources.
- Growth of submerged plant species as well as phytoplankton is inhibited.
- No new organisms are introduced.
- No fragmentation problems.
- No water use restrictions.

Cons:
- Not plant specific, all submerged plants are affected.
- Not effective on floating species.
- Inhibition of phytoplankton may affect fish production.
- Not effective in flowing water situations.
- Artificial looking water color.

Applicability: Primarily useful in small pond, and still water situations.

vii. **Weed Rollers** – Microchip controlled cylinders roll in an arc (up to 270°) continually, disturbing vegetation and inhibiting growth

Target Species: Submerged plant species

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms introduced.
- Can be used on any submerged plant species.
- Site specific.
- No water use restrictions.
- May be effective in 2 days to 2 weeks.

Cons:
- Limited to a radius of 7-21 feet.

- May disturb benthic (bottom dwelling) organisms.
- May cause fragmentation.

Applicability: Useful on small areas with no stumps or other underwater obstructions.

viii. Removal by hand

Target Species: All plant species.

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- No new organisms are introduced.
- Can be used on any plant species.
- Can be highly species and site specific.
- No water use restrictions.

Cons:
- Very labor intensive.
- May significantly alter substrate and disturb resident organisms.
- Very time consuming.
- Only effective on small infestations.
- Re-growth may occur in as little as 30 days unless roots and tubers are removed.
- Fragmentation can be a significant problem with submerged species.

Applicability: Primarily useful with new or small infestations.

2. Biological Control

The following list includes non-experimental control methods considered acceptable under the statewide plan. For procedures relative to the use of triploid grass carp in public water see Appendix F.

i. Triploid grass carp *Ctenopharyngodon idella*

Grass carp, or white amur, are plant-eating fish native to Asia. They are capable of surviving at temperatures ranging from below freezing to over 100ºF. Grass carp grow rapidly. In their native habitat they may typically grow 80-100 pounds. Fingerlings, juveniles and adults feed almost exclusively on plant material. Depending on temperature, water quality, and plant quality they may eat up to three times their body weight per day. Typically, submerged plants such as hydrilla are preferred food items, whereas floating plants (with the exception of duckweed) are among the last species consumed. Triploid grass carp are sterile. In Texas, only triploid grass carp may be stocked, and only by TPWD permit. In general, recommended stocking rates are 5-10 fish per acre of waterbody.

Target Species: Hydrilla and other species

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Usually long-term control
- Plant biomass can be removed from the system.
- Triploid grass carp will not reproduce.

Cons:

- If not confined, grass carp will typically leave target treatment area. In some cases they have been found over 200 miles from target treatment areas.
- Grass carp may consume non-target plant species when available.
- Grass carp may consume vegetation in non-target areas.
- It is difficult to achieve partial control.
- Grass carp are not readily susceptible to conventional capture techniques and are not easily removed from waterbodies if overstocked.
- Grass carp have been captured in brackish water up to 17 ppt (~50% sea water) and can even survive for short periods of time in hypersaline water. Escapees may be capable of feeding in some estuary situations.

Applicability: Waterbodies where confinement is possible and potential elimination of all aquatic vegetation is preferable to the nuisance plant infestation.

ii. Alligatorweed flea beetles *Agasicles hygrophila*

Alligatorweed flea beetles are native to Argentina. Adults are 0.2-0.3 inches long. Their head and thorax are black, while their wing covers have yellow and black stripes. Larvae burrow into the hollow stem of the aquatic form of alligator weed. Larvae often feed on the plant stem, but both larvae and adults feed primarily on the leaves. Since they were first used in the U.S. in the early 60's alligatorweed flea beetles have proven to be very effective are controlling alligatorweed. Rarely are other control measures now necessary. However, they are only effective on the aquatic form of the plant.

Target Species: Alligatorweed *Alternanthera philoxeroides*

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects may reduce plant biomass significantly.
- Alligatorweed flea beetles are plant specific (feeding only on alligatorweed).

Cons:

- Significant amounts of alligatorweed may remain in the system because the beetles are more effective on the aquatic rather than the terrestrial growth form of the plant.
- Insect populations should be monitored to ensure continued stability.
- Severe winter conditions may negatively impact insect populations.

Applicability: Any waterway with alligatorweed. Herbicide use may inhibit effectiveness of insects.

iii. Waterhyacinth weevils *Neochetina spp.* (*N. eichhorniae* and *N. bruchii)*

Waterhyacinth weevils are native to Central and South America. The chevroned waterhyacinth weevil *N. bruchii* and the mottled waterhyacinth weevil *N. eichhoniae* were introduced into the U.S. in the 1970's to help control waterhyacinth. The two species are very similar in appearance, both are usually gray to dark brownish red. However, grooves on the wing covers are coarse on the mottled weevil and fine on the chevroned weevil. Larvae may grow up to about 0.3 inches. Adults and larvae of both species feed exclusively on waterhyacinth. Circular to rectangular scars are often evident on the leaves as a result of waterhyacinth weevil feeding activity. However, rather than quickly killing waterhyacinth plants, weevil herbivory often results in stunted plant growth, less flowering (and hence less seeds production), and reduced competitive ability against native plants.

Target Species: Waterhyacinth

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects may reduce plant biomass significantly.
- Insects may reduce the number of flowers present and the number of seeds produced.
- No problems with low oxygen levels.
- Weevils are species specific (feeding only on waterhyacinth).

Cons:

- Weevils will not eliminate waterhyacinth.
- Weevils will probably not reduce the area covered to below nuisance levels.
- In some cases efficiency may be reduced if chemical treatments are conducted.
- Severe winter conditions may negatively impact insect populations.
- Limited commercial availability.

Applicability: Any waterway with waterhyacinth.

iv. Waterlettuce weevils *Neohydronomous affinis*

Waterlettuce weevils are native to Central and South America. They were first introduced into the U.S. in the 1980's to help control waterlettuce in Florida. Adult weevils are very small ranging in size from 0.06 to 0.09 inches. They vary in color from nearly white to blue-gray to brown. Larvae cause extensive damage to waterlettuce by tunneling through leaves, whereas adults cut circular holes on both the underside and the top (primarily) of leaves. Waterlettuce weevils have proven to be very effective at waterlettuce control. Where they have become established nearly complete control is usually achieved in 18-24 months.

Target Species: Waterlettuce

Pros:

- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Insects reduce plant biomass significantly.
- No problems with low oxygen levels.
- Weevils are species specific (feeding only on waterlettuce).

Cons:

- Efficiency may be reduced if chemical treatments are conducted.
- Severe winter conditions may negatively impact insect populations. Herbicide use may inhibit effectiveness of insects.
- Limited commercial availability.

Applicability: Any waterway with waterlettuce.

3. Chemical Control

Many herbicides are quick acting and show results within a matter of days. Others are systemic and kill plants over longer periods of time. Appendix G lists commonly used herbicides available today. Use of federally approved chemicals for the purposes of nuisance aquatic plant removal is acceptable under the plan within the limitations of the rules (the rules are in Appendix B).

Because human health and safety are always a concern when aquatic herbicides are applied to vegetation in water supplies (particularly drinking water) and areas of contact recreation, TPWD staff conducted a review of the scientific literature relative to three of the most commonly used aquatic herbicides in Texas (Luedke and Cantu 2000). Before labeling herbicides for use in aquatic systems, the United States Environmental Protection Agency (EPA) evaluates appropriate data and determines that at the approved rate, these chemicals should not adversely affect human or ecosystem health.

In many instances surfactants may have to be used with herbicides to help increase their effectiveness. Depending on the morphology of the plant species in question both a wetting agent and a penetrant may be used. Surfactants can increase costs by as much as 10-15 percent.

TPWD rules (57.932(b)(2)(D)) prohibit aquatic herbicide use unless the individual proposing to apply the herbicide use includes, with the notice of proposed herbicide use," information demonstrating that the proposed application will not result in exceeding: (i) the maximum contaminant level of the herbicide in finished drinking water as set by the TCEQ and the EPA; or ii) if the aquatic herbicide does not have an MCL established by the TCEQ and the EPA, the maximum label rate".

Regarding all of the herbicides discussed below, MCL's either have not been set, or have been waived by TCEQ as long as instructions on each specimen label are followed correctly. In order to demonstrate compliance with the specimen label, the notice should provide water depth, area treated, and amount of herbicide proposed for use. This information will be sufficient to make the demonstration required in this provision of the rules. Below is detailed information about the herbicides listed in Appendix G.

i. **2,4-D -** In Texas 2,4-D compounds have a restricted use and are regulated by TDA. Applicators must be certified by TDA and must follow strict use restrictions based on the county of a proposed application. In areas where 2,4-D use is limited, and at times of the year where its use is restricted, diquat, endothall, trichlopyr, and glyphosate products can be used.

Active ingredient: 2,4-D (2,4-dichlorophenoxy acetic acid, dimethylamine salt) (Due to lower volatility n-alkylamine salts are recommended over ester formulations).

Target Species: Waterhyacinth (2,4-D can also be used on Eurasian watermilfoil, but it is rarely done in Texas), pickerelweed, waterlily, waterwillow, bladderwort, coontail, water stargrass.

Pros:
- Requires short contact time with target plant.
- Very quick acting, results evident in a few days.
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.
- Low cost relative to other herbicides.

Cons:
- Low oxygen can be a problem if large areas are controlled at once.
- Treated water cannot be used for livestock or as municipal water source for 21 days after application or until tests indicate concentration levels are below 0.1 ppm.
- Surviving plants may re-establish population levels within 1-2 months; therefore, maintenance spraying may be required later in the growing season.
- Not species specific.
- Volatility may be a problem, particularly in hot weather or where an atmospheric inversion may develop.
- Problems with the interpretation of terms such as "treated water" and "treated area" on the specimen labels of several herbicides, including 2,4-D compounds, must be worked out with TDA, and U.S. Environmental Protection Agency. A final interpretation of these terms may affect post treatment water uses.
- Can only be purchased and applied by an applicator licensed by TDA.

Applicability: Can be used on waterhyacinth growing in both lotic (river-like) and lentic (lake-like) habitats.

ii. Chelated Copper (Copper sulfate is sometimes used instead. However, chelated copper is generally recommended because it typically remains in suspension longer and provides similar or better results with less copper.)

Active ingredient: Copper chelates

Target Species: Hydrilla, chara, nitella, filamentous algae

Pros:
- Requires a short contact time on the order of hours with target plant species.
- Quick acting, results evident in a few days.
- No water use restrictions after application.
- No new organisms are introduced.

Cons:
- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Surviving plants may re-establish population levels within 1-2 months.
- May have to be used more than once per growing season.
- Does not affect hydrilla tubers buried in the soil, which may remain dormant for 4-5 years or more before germinating.
- In flowing water special slow release herbicide delivery equipment is required.

Applicability: May be used in still water. May also be used on plants in flowing water, however, a special delivery system may be required in high flow situations.

iii. Diquat

Active ingredient: Diquat (6,7-dihyrodipyrido (1,2-α:2',1'-c) pyrazinediium bromide)

Target Species: Waterhyacinth, hydrilla, salvinia spp., waterlettuce, water pennywort, bushy pondweed, coontail, elodea, parrot feather, pondweeds, Eurasian watermilfoil, duckweed, cattail, Brazilian elodea.

Pros:
- Requires short contact time with target plant (minutes).
- Quick acting, results evident in a few days (in some cases the same day).
- When sprayed on floating plants, very little enters the water column (although it can be injected into the water for use on submerged vegetation).
- No new organisms are introduced.
- No swimming or fishing restrictions when using diquat at labeled rates.
- Controls floating, marginal, and submerged weeds.

Cons:
- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Treated water cannot be used for livestock, or as public water source for 0-5 days after application depending on application rate and how the water will be used.
- Surviving plants may re-establish population levels within weeks.
- May have to be used more than once per growing season to control surviving plants (depending on plant species).
- Does not affect hydrilla tubers buried in the soil that may remain dormant for 4-5 years or more before germinating.

Applicability: May be used on floating, marginal, or submerged plants in either still or flowing water.

iv. Endothall

Active ingredient: Dipotassium salt of endothall (7-oxabicyclo [2,2,1]heptane-2,3-dicarboxylic acid)

Target Species: Hydrilla, Eurasian watermilfoil, Brazilian elodea, bushy pondweed, coontail, parrot feather, pondweeds, Eurasian watermilfoil, water stargrass, chara, nitella, filamentous algae.

Pros:
- Requires very short contact time (~2 hrs) with target plant to be effective.
- Quick acting. Results may be seen in 7-10 days.
- Remains in the water column only a matter of minutes.
- No new organisms are introduced.

Cons:
- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Treated water cannot be used for livestock or as a public water source for 7 days after application.
- Surviving plants may re-establish population levels within 30 days.
- May have to be used more than once per growing season.
- Does not affect hydrilla tubers buried in the soil that may remain dormant for 4-5 years or more before germinating.
- In flowing water, special slow release herbicide delivery equipment would be required.
- Problems with the interpretation of terms such as “treated water” and “treated area” on the specimen labels of several herbicides, including endothall compounds, must be worked out with TDA, and U.S. Environmental Protection Agency. A final interpretation of these terms may affect post treatment water uses.

Applicability: Can be used in moderate flow situations where immediate use of the water for drinking or livestock is unnecessary. As with fluridone, experimental drip delivery systems which expose target plants to low concentrations over extended periods of time have shown promise.

v. Fluridone

Active ingredient: Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)phenyl]-4(1H)-pyridinone)

Target Species: Hydrilla, Salvinia spp., Eurasian watermilfoil, variable-leaf milfoil, alligatorweed, American lotus, smartweed, waterlily, water primrose, Yellow cow-lily, bladderwort, Brazilian Elodea, bushy pondweed, coontail, elodea, fanwort, parrot’s feather, pondweeds, duckweed, watermeal, cattail, torpedograss.

Pros:
- Fluridone is a systemic herbicide and hydrilla populations are slow to recover after treatment. All parts of the plant are affected, with the exception of dormant tubers which have become separated from parent plants. In some reservoirs 2-4 years of control are achieved.
- Low dissolved oxygen typically not a problem because plants die slowly.
- May kill newly germinated hydrilla tubers.
- No new organisms are introduced.

Cons:

- Requires very long contact time. In some cases the treatment may be spread out over several weeks to provide the necessary contact time (under normal treatment conditions in still water).
- Takes up to 100 days for full results.
- Cannot be used within ¼ mile of a potable water intake at concentrations greater than 20 ppb.
- Treated water should not be used for irrigation for 7-30 days depending on the crop.
- Does not affect dormant hydrilla tubers buried in the soil and separated from parent plants. Tubers may remain dormant for 4-5 years or more before germinating.

Applicability: Fluridone is most applicable in water with little flow, and where the treatment area is greater than 10 acres in size. There is little applicability in flowing water such as main channels using conventional delivery systems. However, experimental drip delivery, which exposes target plants to low herbicide concentrations over an extended period of time, has shown promise. The use of pelleted formulations allows treatment in areas with some flow. Pellets are also often used on submerged plants. Liquid fluridone is usually used on floating vegetation such as salvinia.

vi. Glyphosate

Active ingredient: Glyphosate (N-(phosphonomethyl) glycine)

Target Species: Waterhyacinth, Salvinia, Alligatorweed, American lotus, smartweed, waterlily, water primrose, yellow cow-lily, waterlettuce, black willow, bulrush, cattail, giant reed, torpedograss.

Pros:

- Requires short contact time with target plant (4-6 hours).
- Very quick acting, results evident in 1-2 weeks.
- No need to post signs prior to application.
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.

Cons:

- Low dissolved oxygen can be a problem if large areas are controlled at once.
- Clean water needed for mixing if large mats are treated.
- Plant populations may recover and grow back quickly; therefore periodic re-treatment is often necessary.
- May have to be used more than once per growing season.
- Floating and marginal plants only.

Applicability: Can be used even in flowing water.

vii. Imazapyr

Active ingredient: Isopropylamine salt of Imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-imiazol-2-ly]-3-pyridinecarboxylic acid)

Target Species: Waterhyacinth, salvinia, alligatorweed, smartweed, waterlily, parrot feather, pickerelweed, water pennywort, water primrose, waterwillow, yellow cow-lily, duckweed, black willow, bulrush, cattail, giant reed, torpedograss.

Pros:
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.

Cons:
- May not be used within one mile upstream of an active potable water intake in flowing water, or within one mile of an active potable water intake in a standing body of water (lake or pond).

Applicability: Can be used in flowing or quiescent water.

viii. Triclopyr

Active ingredient: Triclopyr: 3,5,6-trichloro-2-pyridinyloxyacetic acid, triethylamine salt.

Target Species: Waterhyacinth, Alligatorweed, American lotus, smartweed, waterlily, parrot's feather, pickerelweed, water pennywort, water primrose, waterwillow, yellow cow-lily, Eurasian watermilfoil, variable-leaf milfoil, frog's-bit, Chinese Tallow, black willow, bulrush.

Pros:
- When sprayed on floating plants very little enters water column.
- No new organisms are introduced.

Cons:
- May not be used within one mile upstream of an active potable water intake in flowing water, or within one mile of an active potable water intake in a standing body of water (lake or pond).

Applicability: Can be used in flowing or quiescent water.

4. Experimental Options and Procedures

Experimental procedures are not recommended for general use at this time. Consistent control of target species has not been fully demonstrated and further research and documentation is currently underway. Additionally, insects listed below are not generally available for sale. They are, however, used in conjunction with research activities and use may be approved.

a. Experimental Biological Controls

i. Hydrilla flies *Hydrellia pakistanae*

Target Species: Hydrilla

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Preliminary evidence suggests insects may reduce plant biomass significantly in some instances.
- Flies are plant specific (feeding only on hydrilla).
- No problems with low oxygen levels.

Cons:
- Effectiveness is variable and difficult to document.
- Severe winter conditions may negatively impact insect populations.

- Significant amounts of hydrilla remain in the system.
- Hydrilla must be at the surface for insects to lay their eggs.
- Insect populations must be monitored to ensure continued stability.
- Herbicide use may inhibit effectiveness of insects.
- Limited commercial availability.

Applicability: Any waterway where hydrilla has grown to the surface.

ii. Salvinia weevils *Cyrtobagous salviniae*

Target Species: Salvinia, Giant salvinia

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.
- Has been highly effective in other countries. They are the most frequently used biological control for salvinia in the world.
- Could be fairly fast acting for insect controls.
- In the tropics results are obtained in months rather than years.
- Well documented host specificity
- Highly cost effective if experience in the U.S. proves to be similar to that in other areas of the world.

Cons:
- Effectiveness may vary depending on a number of abiotic, as well as biotic, factors including temperature, nutritional status of the plants, predators, etc.
- Conditions for effectiveness are not totally understood.
- Does not totally eradicate salvinia.
- Severe winter conditions may negatively impact insect populations.
- Efficacy of the weevil is not proven in Texas or in other parts of the U.S.
- Limited commercial availability.

Applicability: Biological control techniques can be used in areas where long-term suppression can be tolerated and where plant populations are large and require reduction before other management techniques can be employed economically and effectively.

b. Experimental Ecological Intervention

i. Native Vegetation Establishment

Reservoirs are disturbed ecosystems that often do not contain a propagule bank for native plants and therefore often remain un-vegetated until weedy species such as hydrilla are accidentally introduced. Most reservoirs capable of supporting hydrilla can also support some species of native aquatic vegetation. Filling the empty niches in un-vegetated areas of reservoirs with native vegetation may act as a deterrent to hydrilla establishment or further spread. For information regarding current research efforts and possibility of partnerships in further research dealing with the establishment of native aquatic vegetation, contact TPWD representatives listed in Appendix D.

Pros:
- No chemicals introduced into the water and no restrictions on the use of water for drinking.

- Some native species, if established, may slow (but not eliminate) the spread of introduced exotics.
- Native vegetation adds needed habitat diversity for invertebrate and fish production.

Cons:

- Native plant establishment is long-term, and quick results are usually not seen.
- Native plants are sometimes susceptible to damage due to water level fluctuations and herbivory.
- Does not totally eradicate already established introduced exotic plants.
- Experimental results have been inconsistent and the controlling mechanisms are not well understood.

Applicability: Nearly all Central and East Texas reservoirs. West Texas reservoirs may experience drastic water level fluctuations, which reduce the effectiveness of many native littoral zone plant species that require a more stable environment.

D. Choosing the Appropriate Management Options

Following is a list of selected vegetation species that are included on Texas' "Harmful or Potentially Harmful Exotic Fish, Shellfish, and Aquatic Plants" list. It is illegal to "release into public waters, import, sell, purchase, transport, propagate, or possess any species, hybrid of a species, subspecies, eggs, seeds, or any part of any species" included on the list. Recommended general management options are provided for each plant species. General management options are the currently accepted procedures for controlling aquatic vegetation. If you cannot locate a species of interest, or have questions, contact a TPWD biologist (Appendix D).

1. Giant Salvinia

Giant salvinia has previously been intercepted and eradicated at nurseries and botanical gardens in Florida, Virginia, Texas and Missouri and at a private pond in South Carolina (NPAG 1998). Its introduction to Toledo Bend Reservoir, a 186,000 acre body of water that forms a large portion of the boundary between Texas and Louisiana, poses a serious threat to interstate spread. The plant was found by the Sabine River Authority (SRA) of Louisiana on September 24, 1998, and identified by TPWD personnel, in the central portion of the reservoir, where it has become widespread (Hyde and Temple 1998). Since then it has been found in a number of waterbodies, both public and private.

Because of its extreme growth rate and highly invasive tendencies, any infestation of giant salvinia warrants a **Tier I Management Response**. Infestations of giant salvinia should be reported immediately to the TPWD Inland Fisheries Division. TPWD personnel familiar with both common and giant salvinia should verify all identifications. The following management options will be applicable to both species; however, infestations of giant salvinia will have preference if resources are limited.

Recommendations:

Mechanical-Physical Control - Various physical methods may be used to control or restrict spread of salvinia. These include mechanical and manual removal, devices for blocking entrance to or exit from an area, and inducing changes in the environment.

Booms and other barriers - Booms and other barriers may be useful in confining infestations or restricting entry into sensitive areas. However, in areas with significant current or wind action their utility is limited without frequent clearing and maintenance since plants will accumulate against barriers until pressure forces them over or under the barrier.

Water Level Manipulation – Water level is usually controlled by the reservoir's controlling authority. Dropping the water level several feet has proven effective at helping control salvinia. Since salvinia is a small floating plant it is often blown into shallow water nearshore areas, and is therefore susceptible to being stranded on dry ground under falling water conditions. In 1999, a rise and subsequent drop in water level on Toledo Bend Reservoir significantly reduced the salvinia population on the lake. However, in order to be effective, water levels must remain low long enough to allow for the desiccation or freezing of stranded plants.

Biological Control - No biological control agents are currently available for general use on salvinia in Texas. Research is being conducted on the salvinia weevil *Cyrtobagous* sp. Although experimental in Texas, the weevil has proven to be very effective in other parts of the world.

Chemical Control – Although Cyrtobagous sp. shows great promise, herbicide treatment is currently the most efficient method of salvinia control in Tier I situations. However, small floating plants such as salvinia can be difficult to eradicate with herbicides. Due to the extremely large number of individual plants present, applying herbicide to <u>each</u> plant is difficult. In addition, the dense hair or pubescence on the leaf surface, characteristic of all salvinia species, can negatively impact the effectiveness of certain types of herbicide applications. These thick hairs can impede herbicide penetration when using any type of foliar spray application. This is especially true when attempting to control giant salvinia.

Because application techniques and herbicides of choice are subject to change, contact TPWD Inland Fisheries Division before attempting a herbicide application for the control of either species of salvinia. With the recent introduction and expansion of giant salvinia into the U.S., renewed effort and research into the available herbicides, surfactants, and their combinations are ongoing.

Currently, there are three primary options for herbicide use. The effectiveness of all three is inhibited when salvinia has formed a thick mat before application.

> <u>Reward, Weedtrine D</u> – Diquat is the active ingredient in Reward, which is a fast acting contact herbicide. Reward is most effective for spot treatments and when there is moving water. Surfactants are spray additives used to enhance adherence to and penetration through the dense covering of hairs on the plant leaf surface. These additives are especially critical to achieving desirable efficacy levels when using diquat for salvinia control. A combination of two surfactants, one silicone-based and the other petroleum based, is used to properly penetrate the dense covering of hairs on the leaf surface.
>
> <u>Sonar AS, Sonar PR, Sonar, Q, Sonar SRP, Avast</u> – Fluridone is the active ingredient in Sonar, which is a slow acting systemic herbicide best used in still water. Sonar is probably most effective in small pond applications where the entire waterbody is treated. Sonar requires a long contact time and desired results may take up to 90 days.
>
> <u>Aquamaster, Aqua Star, Rodeo, Aquaneat, AquaPro, Eagre, Eraser, and Touchdown Pro,</u> – Glyphosate, a systemic herbicide, is the active ingredient in these products. These products are used as topical sprays on salvinia, and as with Reward they require a combination of two surfactants, one silicone-based and the other petroleum based, to properly penetrate the dense covering of hairs on the leaf surface.

Recommended Salvinia Treatment Options

Treatment Methods	Tier I
Booms	Yes[1]
Herbicide	Diquat, Fluridone, Glyphosate
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of salvinia while other methods are used for actual eradication.

2. Hydrilla

Like other rooted submersed aquatic plants, hydrilla can provide benefits in an aquatic ecosystem. However, hydrilla is considered a nuisance aquatic plant because of its 1) rapid growth, 2) ability to colonize deeper water, 3) ability to spread easily, 4) ability to form dense surface mats that block sunlight, inhibit surface oxygen exchange, and increase biological oxygen demand in the mat area, 5) ability to inhibit navigation and other water uses, 6) resistance to control methods, and 7) its ability to outcompete native plants and form a monoculture (single species community) and thereby decrease plant community diversity.

Recommendations:

Mechanical-Physical Control – Because of the likelihood of hydrilla spread due to fragmentation by conventional harvesters, the only appropriate mechanical control in a Tier I situation is complete removal with shovels or other implements designed to carefully avoid fragmentation and remove the entire plant including the root system below ground. If this type of mechanical removal is attempted, it should be accomplished as soon after discovery of the infestation as possible to lessen the chance of fragmentation or tuber or turion production. Infested area(s) should be frequently monitored and plant re-growth removed or treated appropriately. Since the spread of hydrilla is not usually a concern in Tier II situations, both mechanical harvesters and shredders may be used effectively. Small cutters such as those mounted on a jon boat may be useful around individual docks but most areas will require large boats equipped to cut and move through dense hydrilla mats. Cutting should begin in early spring. Since hydrilla can grow an inch a day, areas cut to a depth of five feet will need to be re-cut at least every 60 days during the growing season. Other physical control techniques are listed below. Because of the potential for hydrilla spread from fragmentation, the only appropriate use of mechanical control in a Tier III situation would be to open areas within a large mat to allow angler/boater access, greater oxygen exchange, and increased edge effect. Great care should be taken to insure fragments stay bound within the mat and do not float free in open water.

Water level manipulation - In general, the effectiveness of drawdowns to control hydrilla is unclear. Survival of plant material found at the bottom of drying hydrilla mats, as well as germination of tubers, may facilitate rapid population recovery.

Biological Control - Because of the lack of proven effectiveness of hydrilla flies and the lack of feeding selectivity by grass carp, biological control is problematic in Tier I situations for hydrilla. However, triploid grass carp can be used in situations where complete vegetation removal is not considered a problem. Steps to follow for using grass carp as a biological control in public water are found in Appendix F.

Chemical Control - Chemical control is likely the most effective means of hydrilla control in a Tier I situation where complete removal of all vegetation species is not desired. For continuous areas of less than 10 acres, or in moderately flowing water, endothall products such as Aquathol K (liquid) or Aquathol Super K (granular), and Reward are appropriate. For continuous infestations of 10 acres or more, and with little to no water flow, fluridone products such as Sonar SRP, Sonar AS, Sonar PR, and Sonar Q are probably most appropriate. With either chemical, treatment should be conducted as soon as possible after the infestation is discovered to decrease fragmentation and turion or tuber production. However, fluridone products will only work when water temperatures are warm enough for active growth and photosynthesis (usually 60-65° F). Treated areas should be surveyed often to determine effectiveness of treatment and possible plant re-growth. Chelated copper compounds are also acceptable, and early studies suggest efficacy of chelated copper may be enhanced when used in combination with other herbicides such as diquat. . A program using both contact (diquat or endothall) and systemics such as fluridone has been demonstrated to be highly effective.

Recommended Hydrilla Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	No	Yes
Shredders	No	Yes
Shading	Yes	Yes
Herbicide	Fluridone, Endothall, Diquat, Copper	Fluridone, Endothall, Diquat, Copper
Triploid Grass Carp	Yes	Yes[1]
Water level manipulation	Yes	Yes

[1]Grass carp may be used at low stocking rates in Tier II situations to help put added stress on hydrilla populations.

3. Waterhyacinth

Like a number of other exotic floating plants, waterhyacinth is considered a nuisance aquatic plant because of its 1) rapid growth, 2) ability to spread easily by floating into previously uncolonized areas, 3) ability to form dense surface mats that block sunlight and inhibit surface oxygen exchange, 4) ability to inhibit navigation and other water uses, and 5) its ability to outcompete native plants and decrease plant community diversity.

Recommendations:

Mechanical/Physical Control – Mechanical removal may be a viable and economically feasible method of waterhyacinth control. For moderately large infestations (on the order of approximately 100 acres or less) in water more than 2 feet deep with few stumps or other obstructions, shredding may be used effectively. For larger infestations, shredding quickly becomes logistically difficult with current technology. Harvesting may be used on small infestations in water greater than 2 feet deep with few stumps and other obstructions.

Water Level Manipulation – Specific strategies vary depending on the reservoir situation, but dropping the water level several feet through the fall and winter can strand plants on the bank. Waterhyacinth can survive for long periods on moist damp soil so stranding plants during cold weather when there is a chance of freezing is most effective.

Biological Control – Waterhyacinth weevils may be used to slow the growth of waterhyacinth populations and reduce their ability to flower and produce seeds. In some cases, waterhyacinth populations have also been significantly reduced by weevil introductions. In general, triploid grass carp are not a viable biological control option for waterhyacinth since they rarely eat the plant unless all other vegetation is removed.

Chemical Control – In Tier I situations, herbicide use may be the most efficacious means of waterhyacinth control in areas with many stumps or other obstructions, or in areas with water depths less than two feet. Similarly, in Tier II situations herbicides are probably the most efficient control method in areas with extremely large infestations where aerial application is required. In general, the cheapest and most efficacious herbicide for waterhyacinth is 2,4-D. , although both diquat and glyphosate products are very effective as well. Diquat works best when used as a spot treatment or boat application in areas where drift may be of concern with other products.

Recommended Waterhyacinth Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	Yes	Yes
Shredders	Yes	Yes
Booms	Yes[1]	Yes
Herbicide	2,4-D, diquat, Glyphosate, Imazapyr, Triclopyr	2,4-D, diquat, Glyphosate, Imazapyr, Triclopyr
Waterhyacinth Weevils	Yes	Yes
Water level manipulation	Yes	Yes

[1]Booms may be used to help prevent the spread of waterhyacinth while other methods are used for actual eradication.

4. Eurasian watermilfoil

Eurasian watermilfoil can out-compete native plant species and create a mono-specific plant community. Because it can grow to be very dense at the surface, Eurasian watermilfoil stands can inhibit angling, boating, swimming, and other forms of aquatic recreation if not controlled.

Recommendations:

Typically, Eurasian watermilfoil causes few problems in Texas waters. TPWD has conducted no herbicide treatments for Eurasian watermilfoil for at least 10 years. Therefore, **Eurasian watermilfoil infestations usually will be considered Tier III situations.**

Mechanical/Physical Control – Due to the likelihood of Eurasian watermilfoil spread due to fragmentation, the only appropriate mechanical control in a Tier I situation is complete removal of small patches with shovels or other implements designed to carefully avoid fragmentation. If mechanical removal is attempted in this manner it should be accomplished as soon after discovery of the infestation as possible to lessen the chance of fragmentation or turion production. Infested area(s) should be frequently monitored and plant re-growth removed or treated appropriately. In Tier II situations mechanical harvesters may be effectively used to remove Eurasian watermilfoil in areas where water depth is greater than 2.0 ft.

Water Level Manipulation –Specific strategies vary depending on the reservoir situation but dropping the water level several feet through the fall and winter dries the vegetation killing much of the plant outright. This strategy has proven effective for Eurasian watermilfoil control. However, care should be exercised if hydrilla or some other extremely invasive species is also present. Since drawdowns have very limited efficacy on hydrilla, removal of Eurasian watermilfoil by this method may simply open new areas for colonization by hydrilla.

Biological Control – Triploid grass carp are the only effective biological control agent currently available for Eurasian watermilfoil. However, since Eurasian watermilfoil is typically low on their dietary preference list, they are rarely recommended for its control in Texas. Grass carp should only be considered if watermilfoil populations grow beyond the point at which they can be controlled with herbicides or drawdowns, and complete eradication of all vegetation becomes preferable to the milfoil infestation.

Chemical Control – In Tier I situations herbicide use may be the most efficient means of Eurasian watermilfoil control in non-potable water lakes and in waterbodies that also have hydrilla. In general, the cheapest and most efficient herbicide is 2,4-D. In areas where 2,4-D use is limited and at times of the year where its use is restricted, diquat, endothall, and fluridone products can be used effectively.

Recommended Eurasian watermilfoil Treatment Options

Treatment Methods	Tier I	Tier II
Harvesters	No	Yes

Herbicide	2,4-D, Diquat, Endothall, Fluridone, Triclopyr	2,4-D, Diquat, Endothall, Fluridone, Triclopyr
Water level manipulation	Yes	Yes

5. Waterlettuce

The floating growth characteristic and fast reproductive rate of waterlettuce cause environmental problems similar to those encountered with waterhyacinth. Waterways can be clogged and access to fishing, swimming, and boating may be reduced or eliminated. Dense mats of waterlettuce may cause oxygen depletion (Attionu 1976) and increase siltation, which effectively reduce the suitability of the underlying substrate for nesting fish (Beumer 1980) and invertebrates (Roback 1974). The seeds, which may remain dormant for months, are resistant to both drought and freezing.

Recommendations:

New infestations of waterlettuce or recurrence in areas where it has previously been problematic should be considered a Tier I situation. Because of the extreme nature of the problems encountered with overabundant waterlettuce most occurrences of waterlettuce will be considered Tier I situations.

Mechanical/Physical Control – Mechanical removal may be a viable method of waterlettuce control. Shredding may be used effectively for removal of moderately large infestations (100 acres or less), in water more than 2 feet deep, in areas with few stumps or other obstructions, and where (if) biological control has proven ineffective.

Water Level Manipulation – Specific strategies vary depending on the reservoir situation but generally lowering the water level several feet through the fall and winter can strand plants on the bank. Waterlettuce can survive for long periods on moist damp soil so stranding plants during cold weather when there is a chance of freezing is most effective.

Biological Control – Waterlettuce weevils are currently the only viable option, although research into other biological controls is now underway.

Waterlettuce weevils – Waterlettuce weevils have proven effective so far at every location they have been tried in Texas. Within a year or two waterlettuce populations have usually been eliminated.

Waterlettuce infestations should be surveyed by a qualified person(s) to determine if waterlettuce weevils are already present, and if so at what density. Waterlettuce weevils are stocked at densities of 500 – 1,000 per site. Stocking sites should be surveyed to determine if either or both species of waterlettuce weevils is established and additional weevils should be stocked as necessary to insure the population remains at optimum density.

Chemical Control – Herbicide use is a viable means of waterlettuce control in areas with many stumps or other obstructions, in areas with water depths less than two feet, in the case of extremely large infestations where aerial application is required, and in areas where biological control may prove ineffective. Currently, there are three primary options for herbicide use.

Reward, Weedtrine D – Diquat, the active ingredient in Reward, is a fast acting contact herbicide, generally considered the best for waterlettuce control. Surfactants are spray additives used to enhance adherence to and penetration through the plant leaf surface. These additives are especially critical to achieving desirable efficacy levels when using diquat for waterlettuce control. A combination of two surfactants, one silicone-based, and the other petroleum based, are used to properly penetrate the dense covering of hairs on the leaf surface.

Aquathol k, Aquathol Super k – Endothall is the active ingredient in Aquathol. Aquathol is applied into the water and quickly absorbed up by plants. Results may take days to become apparent.

Aquamaster, Aqua Star, Aquaneat, AquaPro, Eagre, Eraser, Rodeo, and Touchdown Pro, – Glyphosate, a fast acting herbicide, is the active ingredient in these products. There herbicides are used as a topical spray on waterlettuce, and as with Reward should be used with a combination of two surfactants, one silicone-based and the other petroleum based, to properly penetrate the dense covering of hairs on the leaf surface.

Recommended Waterlettuce Treatment Options

Treatment Methods	Tier I
Harvesters	Yes
Shredders	Yes
Booms	Yes[1]
Herbicide	Diquat, Fluridone, Imazapyr
Waterlettuce Weevils	Waterlettuce Weevils
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of waterlettuce while other methods are used for actual eradication.

6. Alligatorweed

Alligatorweed can cause a variety of problems. Free floating plants can choke waterways, and rooted plants can even invade moist pastoral and agricultural land (Coulson 1977, Julien and Bourne 1988, Julien and Broadbent 1980).

Recommendations:

In general, alligatorweed causes very little problem in Texas. Since the release of the alligatorweed flea beetle, very few areas have required active control efforts. Therefore, alligatorweed infestations will usually be considered Tier III "wait and see" situations.

Mechanical/Physical Control – Mechanical removal may be a viable method of alligatorweed control. Costs for shredding floating alligatorweed plants are equivalent to herbicide treatments. However, in order to use machinery, infestations must occur in water more than 2 feet deep, and in areas with few stumps or other obstructions.

Biological Control – Alligatorweed flea beetles have effectively controlled alligatorweed in a number of areas of Texas. Alligatorweed infestations should be surveyed by qualified person(s) to determine if alligatorweed flea beetles are already present and if so at what density. Flea beetles should be stocked at densities of 500-1000 per stocking site. Stocking sites should be surveyed to determine if the flea beetles are established and additional flea beetles should be stocked as necessary to insure optimum densities.

Chemical Control - Herbicides are an effective means of alligatorweed control for rooted infestations that are apparently less susceptible to control by the flea beetle. Fluridone, glyphosate, imazapyr, and triclopyr products may be used when the flea beetle is ineffective.

Recommended Alligatorweed Treatment Options

Treatment Methods	Tier II
Harvesters	Yes
Shredders	Yes
Booms[1]	Yes
Herbicide	Fluridone, Glyphosate, Imazapyr, Triclopyr
Alligatorweed Flea beetle	Yes
Water level manipulation	Yes

[1]Booms may be used to help prevent the spread of alligatorweed while other methods are used for actual eradication.

7. Other exotic species

Responses to infestations of other exotic species will depend on which species are involved and information regarding potential threat. New infestations by species for which there is evidence of environmental or economic damage or for which no information is available will generally be considered Tier I situations. However, if evidence suggests the species will not grow to overabundance and become problematic it will be treated as Tier III.

8. Native plant species

Since native species rarely become overabundant and create environmental difficulties they will nearly always be classified in the Tier III response category. See Fassett (1957) for descriptions of native species.

E. Develop and Submit Your Treatment Proposal

A Treatment Proposal details what will be done to manage nuisance vegetation in Texas' public water. Although there is latitude in how vegetation can be managed, the Treatment Proposal formalizes those actions and provides a basis for future efforts. A Treatment Proposal, accompanied by a map of the proposed treatment site, must be submitted to the TPWD 14 days before anticipated implementation. Failure to provide a map may slow the review process. A blank Treatment Proposal Form is found in Appendix C. A separate treatment proposal should be filled out for each plant species treated. Below is a step-by-step guide to development and submittal of a Treatment Proposal. Individuals who are planning to conduct vegetation control activities on a public body of water should follow these steps:

STEP 1 – Obtain a copy of "Aquatic Vegetation Management in Texas: a Guidance Document" (Guidance Document) from TPWD staff or from the TPWD web page at:

http://www.tpwd.state.tx.us/fish/infish/vegetation/guiddoc.pdf

STEP 2 - Using the Guidance Document and/or other materials identify what plant species are causing a problem. If necessary, contact a professional pond manager or aquaculturist, a botanist, the local governing entity, local water authority, or TPWD staff. A list of TPWD staff is available in Appendix D.

STEP 3-5 Consult "Aquatic Vegetation Management in Texas: a Guidance Document" as well as the governing entity to determine the level of concern (Steps 3) for managing the species in question, appropriate treatment methods (Step 4), and appropriate management options (Step 5). In many cases a variety of control techniques may be used in concert. At this step, the individual should assess which management response tier (I, II, or III) is appropriate.

STEP 6 - Complete the Treatment Proposal form (found in "Aquatic Vegetation Management in Texas: a Guidance Document" or available from TPWD Inland Fisheries Division staff). If herbicide use is proposed, go to Step 7. If herbicide use is not proposed, go to Step 11.

STEP 7 - Contact TCEQ's Public Drinking Water Section (512-239-6020) to obtain a list of public potable water intakes on the waterbody in question, and their locations.

STEP 8 - Assure that at least 14 calendar days prior to the proposed herbicide use, the treatment proposal, map, and notice letter are provided to the governing entity, TPWD (Documents should be sent to the District Supervisor in your area of the state. Contact information is found in Appendix D), all drinking water providers that have an intake within two river miles of a site at which an application of aquatic herbicide is proposed to occur, and all persons who have requested notice. The list of persons who have requested notice is available from TPWD District Supervisors. The 14-day notice period runs from the date notice is received by TPWD. The notice letter must include: all label information for the aquatic herbicide to be applied (This requirement may be fulfilled by providing the URL of an internet site with the specimen label, and may be waived if the same herbicide has been used under an approved proposal for that water body within the previous year); a statement that the guidance document has been reviewed and the proposed herbicide application is consistent with the principles of integrated pest management, § 57.932(a)(2) of TPW rules, and the guidance document; information demonstrating that the proposed application will not result in exceeding the maximum contaminant level of the herbicide in finished drinking water as set by the TCEQ and the EPA, or if the aquatic herbicide does not have an MCL established by the TCEQ and the EPA, the maximum label rate; and the TDA applicator license number, if any. A sample "Proposed Herbicide Use Notice" is provided with this guidance document on page 41.

STEP 9 - The governing entity must also notify the individual in writing that it is a violation of state law to apply aquatic herbicides in a public body of water in a manner inconsistent with the state plan. A sample “Notice From Governing Entity in Response to Proposed Herbicide Use” is provided with this guidance document.

STEP 10 - TPWD and the governing entity will respond to the treatment proposal, map and notice no later than the day before the herbicide application is to occur. Both TPWD and the governing entity must approve herbicide applications. Note that if the individual proposing to apply the herbicides is not a licensed applicator, the herbicide application may not proceed in the absence of an affirmative finding by the governing entity and TPWD that the application will be consistent with the state plan (or an approved local plan if one has been adopted for the particular public body of surface water in question). In a case where the herbicide application would be done by a licensed applicator, however, the application may proceed if the governing entity or TPWD do not disapprove the application no later than the day before it is scheduled to occur.

STEP 11 - If approved, the herbicide use called for in the treatment proposal may be carried out.

STEP 12 - In a case where the treatment proposal does not include herbicide use, TPWD will review and may disapprove or amend the treatment proposal no later than the day before the proposed control measures are to begin.

STEP 13 - If approved, the measures called for in the treatment proposal may be carried out.

Aquatic Vegetation Treatment Proposal

A **map of the water body** with proposed treatment sites indicated should be **attached.**
A **separate form** should be filled out for **each plant species treated.**

Water Body Name: Lake Dunlap______________ ***Submission Date:**__5/5/99_________

Date Surveyed: 5/3/99______________ Proposed Treatment Date:__6/1/99_________

Target Plant Species: Salvinia Estimated Acres:___2.3________

Recommended Treatment: Mechanical ( ), Biological ( ), Chemical (X).

Tier _____

Method of Treatment: Reward herbicide, Boat and Backpack__________

Applicator Name: _Jane Smith________________________________

TDA Applicator License Number: (If applicable)___950762_____________________

Floating or Emergent Vegetation:

Treatment Location	**Relative Surface Coverage**	**Treatment Area (acres)**	**Treatment Rate/type (organisms, gals, lbs./acre, harvested or shredded)**	**Total (organisms, gals., lbs, acres harvested or shredded)**	**Mean water depth**
0.25 East of I 35 Bridge	Heavy	2.0	0.75 gal.	1.5 gal.	2.0 m
	Heavy	0.3	0.75 gal	0.23 gal.	2.0 m
Total		2.3		1.73 gal.	

Submerged Vegetation:

Treatment Location	**Relative Surface Coverage**	**Treatment Area (acres)**	**Treatment Rate/type (organisms, gals, lbs./acre, harvested or shredded)**	**Total (organisms, gals., lbs, acres harvested or shredded)**	**Mean water depth**
Total					

Comments:____
____

***Proposals are good for six months from the date of submission, unless application plans change.**

PROPOSED HERBICIDE USE NOTICE

TO: TPWD; Governing Entity; Public Drinking Water Providers With an Intake Within Two River Miles of the Proposed Herbicide Application; All Persons Who Have Requested Notice

This is a notice of proposed herbicide use on [water body], as described in the enclosed treatment proposal. Following is the label information for [the herbicide to be applied] [a copy of the label is adequate]. [Name of person proposing herbicide use] has reviewed TPWD's guidance document and determined that the proposed herbicide application is consistent with the principles of integrated pest management, § 57.932(a)(2) of TPWD rules, and the guidance document.

The information demonstrating that the proposed application will not result in exceeding the maximum contaminant level of the herbicide in finished drinking water as set by TCEQ and EPA, or if there is no MCL, the maximum label rate, is [see section III.B.3 of guidance document for discussion of how this information is developed]:

The TDA license number for the herbicide applicator is:

NOTICE FROM GOVERNING ENTITY IN RESPONSE TO PROPOSED HERBICIDE USE

To: [Person(s) proposing herbicide use]

[Name of Governing Entity] has received your Proposed Herbicide Use Notice, Treatment Proposal, and map. As state law requires, [governing entity] is providing you, as an attachment to this letter, a copy of the state aquatic vegetation plan. It is a violation of state law to apply aquatic herbicides in a public body of water in a manner inconsistent with the state plan.

Literature Cited:

Aiken, S.G., and J. McNeill. 1980. The discovery of *Myriophyllum exalbescens* Fernald (Haloragacea) in Europe and the typification of *M. spicatum* and *M. verticillatum* L Botanical Journal of the Linnean Society 8:213-222.

Attionu, R. H. 1976. Some effects of water lettuce (*Pistia stratiotes*, L.) on its habitat. Hydrobiologia 50:245-254.

Barnett, B. S., and R. W. Schneider. 1974. Fish populations in dense, submersed plant communities. Hyacinth Control Journal 12:12-14.

Barrett, S.C.H. 1989. Waterweed invasions. Scientific American 261:90-97.

Bell, J.D. and M. Westoby. 1986. Abundance of macrofauna in dense seagrass is due to habitat preference, not predation. Oecologia 68:205-209.

Biltgen, B.A. 1981. Aufwuchs and benthic macroinvertebrate community Structure associated with three species of rooted aquatic macrophytes in Lake Onalaska, 1976-1977. M.S. Thesis. University of Wisconsin, LaCrosse, Wisconsin. 112 pp.

Bogart, D. B. 1949. The effects of aquatic weeds on flow in Everglades canals. Proceedings of the Soil Science Society of Florida 9:32-52.

Bowes, G., A. S. Holaday, and W. T. Haller. 1979. Seasonal variation in the biomass, tuber density and photosynthetic metabolism of hydrilla in three Florida lakes. Journal of Aquatic Plant Management 15:32-35.

Beumer, J. P. 1980. Hydrology and fish diversity of a North Queensland tropical stream. Australian Journal of Ecology 5:159-186.

Chesnut, T. L., and E. H. Barman, Jr. 1974. Aquatic vascular plants of Lake Apopka, Florida. Florida Science 37:60-64.

Colle, D. E., and J. V. Shireman. 1980. Coefficients of condition for largemouth bass, bluegill, and redear sunfish in hydrilla infested lakes. Transactions of the American Fisheries Society 109:521-531.

Colle, D. E., J. V. Shireman, W. T. Haller, J. C. Joyce, and D. E. Canfield, Jr. 1987. Influence of hydrilla on harvestable sport-fish populations, angler expenditures at Orange Lake, Florida. North American Journal of Fisheries Management 7:410-417.

Cook, C. D. K. 1990. Origin, autecology, and spread of some of the world's most troublesome aquatic weeds. Pages 31-73 in A. H. Pieterse and K. J. Murphy, editors. Aquatic weeds. Oxford University Press. Cary, North Carolina.

Cordo, H. A., J. C. DeLoach, and R. Ferrer. 1981. Biological studies on two weevils, *Ochatina bruchi* and *Onychylis cretatus*, collected from *Pistia* and other aquatic plants in Argentina. Annals of the Entomology Society of America 74:363-369.

Coulson, J.R. 1977. Biological control of alligatorweed, 1959-1972. A review and evaluation. USDA Technical Bulletin 1547, 98 p.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. Ecology 63:1802-1813.

Dibble, E.D. and S.L. Harrel. 1997. Largemouth bass diets in two aquatic plant communities. Journal of Aquatic Plant Management 35:74-78.

Fassett, N.C. 1957. A manual of aquatic plants. The University of Wisconsin Press. Madison, Wisconsin.

Gillett, J. D., C. R. Dunlop, and I. L. Miller. 1968. Occurrence, origin, weed status and control of waterlettuce (*Pistia stratiotes* L.) in the northern territory. Plant Protection Quarterly 3(4):144-148.

Gopal, B. 1987. Water hyacinth. Elsevier Science Publishers, Amsterdam.

Gowanloch, J. N. 1945. Economic importance of the waterhyacinth, *Eichhornia crassipes*, in management of water areas. Transactions of the 10th North American Wildlife Conference 10:339-345.

Haller, W.T. 1978. Hydrilla: a new and rapidly spreading aquatic weed problem. University of Florida Circular S-245.

Heck, K.L., Jr., and G.S. Wetstone. 1977. Habitat complexity and invertebrate species richness and abundance in tropical seagrass meadows. Journal of Biogeography 4:135-142.

Heck, K.L. and K.A. Wilson. 1987. Predation rates on decapod crustaceans in latitudinally separated seagrass communities: a study of spacial and temporal variation using tethering techniques. Journal of Experimental Marine Biology and Ecology 107:87-100.

Hoyer, M.V. and D.E. Canfield Jr. 1996. Largemouth bass abundance and aquatic vegetation in Florida lakes: an empirical analysis. Journal of Aquatic Plant Management 34:33-38.

Iversen, T.M., J. Thorup, T. Hansen, J. Lodal, and J. Olsen. 1985. Quantitative estimates and community structure on invertebrates in a macrophytes rich stream. Archives fur Hydrobiologie 102:291-301.

Julien, M.H. and A.S. Borne. 1988. Alligatorweed is spreading in Australia. Plant Protection Quarterly 3:91-96.

Julien, M.H. and J.E. Broadbent. 1980. The biology of Australian weeds 3. Alternanthera philoxeroides(Mart.) Griseb. The Journal for the Australian Institute of Agricultural Science 46:150-155.

Julien, M.H., B. Skarratt, and G.F. Maywald. 1995. Potential geographical distribution of alligator weed and its biological control by *Agasicles hygrophila*. Journal of the Aquatic Plant Management Society 33:55-60.

Langeland, K.A. 1990. Hydrilla (Hydrilla verticillata (L.F.) Royle): a continuing problem in Florida waters. University of Florida Circular No. 884.

Luedke, M. and R. Cantu. 2000. The environmental fate and effects of diquat, fluridone, and 2,4-D. Texas Parks and Wildlife Department FCTS-2000-001.

Maceina, M. J. and W.C. Reeves. 1996. Relations between submerged macrophyte abundance and largemouth bass tournament success on two Tennessee River impoundments. Journal of Aquatic Plant Management 34:33-38.

Maddox, D.M. 1968. Bionomics of an alligator weed flea beetle, *Agasicles* sp. In Argentina. Annals of the Entomological Society of America 61:1300-1305.

Minello, T.J. and R.J. Zimmerman. 1983. Fish predation on juvenile brown shrimp, *Penaeus aztecus* Ives: the effects on simulated Spartina structure on predation rates. Journal of experimental Marine Biology and Ecology 72:211-231.

Mitchell, D. S. 1976. The growth and management of *Eichhornia crassipes* and Salvinia spp. In their native environment and in alien situations. Pages 167-175 in C. K. Varshney and J. Rzoska, editors. Aquatic weeds in southeast Asia. Dr. W. Junk Publisher. The Haque, Netherlands.

Mullin, B.H., L.W.J Anderson, J.M. DiTomaso, R.E. Eplee, and K.D. Getsinger. 2000. Invasive plant species. Council for Agricultural Science and Technology, Issue Paper Number 13.

Muttkowski, R.A. 1918. The fauna of Lake Mendota: A qualitative and quantitative survey with special reference to the insects. Transactions of the Wisconsin Academy of Sciences, Arts, and Letters 19:374-482.

Netherland, M.D. 1997. Turion ecology of hydrilla. Journal of Aquatic Plant Management 35:1-10.

Nichols, S.A. 1975. Identification and management of Eurasian watermilfoil in Wisconsin. Wisconsin Academy of Science, Arts, and Letters 63:116-128.

Nichols, S.A. and B.H. Shaw. 1986. Ecological life histories of the three aquatic nuisance plants, *Myriophyllum spicatum*, *Potamogeton crispus*, and *Elodea canadensis*. Hydrobiologia 131:3-21.

North American Lake Management Society and Aquatic Plant Management Society. 1997. Aquatic plant management in lakes and reservoirs. M.V. Hoyer and D.E. Canfield, editors. University of Florida, Center for Aquatic Plants.

Reed, C.F. 1977. History and distribution of Eurasian water-milfoil in the United States and Canada. Phytologia 36:417-436.

Roback, S. S. 1974. Insects (Arthropoda: Insecta). Pages 313-376 in C. W. Hart, Jr. and S. L. H. Fuller, editors. Pollution ecology of freshwater invertebrates. Academic Press, New York.

Russo, A.R. 1987. Role of complexity and mediating predation by the gray damselfish Abudeduf sordidus on epiphytal amphipods. Marine Ecology-Progress Series 36:101-105.

Schmitz, D. C. 1990. The invasion of exotic aquatic and wetland plants into Florida: history and efforts to prevent new introductions. Aquatics 12(2):6-24.

Soszka, G.J. 1975. The invertebrates on submerged macrophytes in three Masurian Lakes. Ekologia Polska 23:371-391.

Stoddard, A. A. 1989. The phytogeography and paleofloistics of *Pistia stratiotes* L. Aquatics 11:21-24.

Stoner, A.W. 1980. The role of seagrass biomass in the organization of benthic macrofaunal assemblages. Bulletin of Marine Science 30:537-551.

Stuckey, R.L, J.R. Wehrmeister, and R.J. Bartolotta. 1978. Submersed aquatic vascular plants in ice covered ponds of Central Ohio. Rhodora 80:575-580.

Tabita, A., and J. W. Woods. 1962. History of waterhyacinth control in Florida. Hyacinth Control Journal 1:19-23.

Timmer, C. E., and L. W. Weldon. 1967. Evapotranspiration and pollution of water by water hyacinth. Hyacinth Control Journal 6:34-37.

Titus, J.E., and M.S. Adams. 1979. Comparative carbohydrate storage and utilization patterns in the submersed macrophytes, Myriophyllum spicatum and Vallisneria americana. American Midland Naturalist 102:263-272.

U.S. Congress. 1965. Expanded project for aquatic plant control: letter from the Secretary of the Army. Unpublished report, House document 251(89-1).

Vogt, G.B., J.U. McGurie, Jr., and A.D. Cushman. 1979. Probable evolution and morphological variation in South American Disonychine flea beetles (Coleoptera: Chrysomelidae) and their Amaranthaceous hosts. USDA Technical Bulletin 1593, 148 p.

Watkins, C.E., II, J.V. Shireman, and W.T. Haller. 1983. The influence of aquatic vegetation upon zooplankton and benthic macroinvertebrates in Orange Lake, Florida. Journal of Aquatic Plant Management 21:78-83,

Wiley, M.J., R.W. Gorden, S.W. Waite, T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: a simple model. North American Journal of Fisheries Management 4:111-119.

Appendix A. Parks and Wildlife Code subchapter G, Aquatic Vegetation Management (§§ 11.081-11.086)

§ 11.081. Definitions

In this subchapter:

(1) "Governing entity" means the state agency or other political subdivision with jurisdiction over a public body of surface water.

(2) "Integrated pest management" means the coordinated use of pest and environmental information and pest control methods to prevent unacceptable levels of pest damage by the most economical means and in a manner that will cause the least possible hazard to persons, property, and the environment.

(3) "Local plan" means a local aquatic vegetation management plan authorized by Section 11.083.

(4) "Public body of surface water" means any body of surface water that is not used exclusively for an agricultural purpose. The term does not include impounded water on private property.

(5) "State plan" means the state aquatic vegetation management plan authorized by Section 11.082 and developed and implemented under this subchapter.

(6) "Water district" means a conservation and reclamation district or an authority created under authority of Section 52(b)(1) or (2), Article III, or Section 59, Article XVI, Texas Constitution, that has jurisdiction over a public body of surface water. The term does not include a navigation district or a port authority.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

§ 11.082. State Aquatic Vegetation Management Plan

(a) The department shall develop and by rule adopt a state aquatic vegetation management plan following the generally accepted principles of integrated pest management. The state plan shall apply throughout the state unless a governmental entity has adopted an approved local plan.

(b) The department shall develop the state plan in coordination with the Texas Natural Resource Conservation Commission*****, the Department of Agriculture, water districts and other political subdivisions of the state with jurisdiction over public bodies of surface water, and public drinking water providers.

(c) The state plan must:

(1) establish minimum standards for a governing entity that regulates a public body of surface water;

(2) require that any application of aquatic herbicide complies with label rates approved by the United States Environmental Protection Agency;

(3) ensure that any public drinking water provider that has an intake within two river miles of a site at which an application of aquatic herbicide is proposed to occur receives notice of the proposed application not later than the 14th day before the date the application is to occur;

(4) provide for the coordination, oversight, public notification, and enforcement of all aquatic herbicide use to protect state fish and wildlife resources and habitat and to prevent unreasonable risk from the use of any aquatic herbicide; and

(5) require that the written notice of a proposed application of herbicide include information demonstrating that the proposed application of herbicide under a plan will not result in exceeding:

(A) the maximum contaminant level of the herbicide in finished drinking water as set by the Texas Natural Resource Conservation Commission***** and the United States Environmental Protection Agency; or

(B) the maximum label rate, if the aquatic herbicide does not have a maximum contaminant level established by the Texas Natural Resource Conservation Commission***** and the United States Environmental Protection Agency.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

§ 11.083. Local Aquatic Vegetation Management Plan

Text of section effective upon notice of adoption of aquatic vegetation management plan

(a) A governing entity may develop and adopt a local aquatic vegetation management plan. A local plan must be approved by the department, the Texas Natural Resource Conservation Commission*****, and the Department of Agriculture.

(b) A local plan may take into account the particular needs and uses of the public bodies of surface water to which it will apply, but the plan may not be approved unless the plan meets the minimum standards set by the state plan. The local plan may allow herbicide use if the person proposing to apply the herbicide notifies the governing entity not later than the 14th day before the proposed date of application.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

§ 11.084. Application of Aquatic Herbicide in Public Body of Surface Water

Text of section effective upon notice of adoption of aquatic vegetation management plan

(a) No person may apply aquatic herbicide in a public body of surface water unless the herbicide is applied in a manner consistent with the plan adopted by the governing entity.

(b) State money may not be used to pay for treatment of a public body of surface water with a chemical herbicide unless the application of the herbicide is performed by an applicator licensed for aquatic herbicide application by the Department of Agriculture.

(c) An individual who does not hold an applicator's license and who desires to apply an aquatic herbicide on a public body of surface water shall give written notice not later than the 14th day before the date the application of the aquatic herbicide is to occur to the governing entity with jurisdiction over the body of water on which the application of the herbicide is proposed. The governing entity shall respond to the individual's application not later than the day before the date the application of the aquatic herbicide is to occur. The individual may not apply the aquatic herbicide unless the governing entity finds that the application will be consistent with the state or local plan adopted by the entity.

(d) The state plan may provide for use of an aquatic herbicide consistent with the plan if:

(1) the individual who desires to apply the aquatic herbicide gives notice to the appropriate governing entity in the same manner as provided by Subsection (c) for an unlicensed applicator; and

(2) the governing entity does not disapprove the application.

(e) After receiving notice of a proposed application of aquatic herbicide, the governing entity shall:

(1) provide the individual proposing the application with a copy of the state or local plan, as appropriate;

(2) notify the individual in writing that it is a violation of state law to apply aquatic herbicides in that body of water in a manner inconsistent with the plan; and

(3) determine whether the proposed application is consistent with the plan.

(f) The governing entity shall:

(1) prohibit a proposed application of aquatic herbicide if the governing entity finds that the proposed application is inconsistent with the appropriate plan; or

(2) notify the individual proposing the application of the herbicide that the proposed application is not inconsistent with the appropriate plan if the governing entity finds that the proposed application is not inconsistent with the plan.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

§ 11.085. Liability

Text of section effective upon notice of adoption of aquatic vegetation management plan

(a) The liability under other law of a governing entity that receives notice of a proposed application of aquatic herbicide is not affected by the requirements of this subchapter.

(b) Notice by a governing entity to an individual under Section 11.084(f)(2) does not constitute authorization by that entity for the application of the herbicide.

(c) This subchapter does not relieve an individual who applies aquatic herbicide to a public body of surface water of the obligation to comply with all applicable federal, state, or local laws, rules, ordinances, or orders relating to the application of the herbicide in the body of water.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

§ 11.086. Records

Text of section effective upon notice of adoption of aquatic vegetation management plan

A governing entity shall maintain for not less than five years all records relating to notifications received under Section 11.084 and any other information relevant to a particular individual request for shoreline treatment.

Added by Acts 1999, 76th Leg., ch. 1461, § 1.

***TNRCC is now Texas Commission for Environmental Quality (TCEQ)**

Appendix B. 31 Texas Administrative Code subchapter K, Aquatic Vegetation Management Rules, §§ 57.930-57.934 and 57.936 (includes the State Plan as § 57.932).

§57.930. Definitions. The following words and terms, when used in this subchapter, shall have the following meanings, unless the context clearly indicates otherwise. All other words and terms in this subchapter shall have the meanings assigned in the Texas Parks and Wildlife Code.

(1) Canal – an artificial waterway used for the transportation of water for agricultural and/or industrial purposes but for no other purpose.

(2) EPA - the United States Environmental Protection Agency.

(3) Governing entity - the state agency or other political subdivision with jurisdiction over a public body of surface water.

(4) Integrated pest management - the coordinated use of pest and environmental information and pest control methods to prevent unacceptable levels of pest damage by the most economical means and in a manner that will cause the least possible hazard to persons, property, and the environment. Integrated pest management includes consideration of ecological, biological, chemical, and mechanical strategies for control of nuisance aquatic vegetation.

(5) Licensed Applicator - a person who holds a valid license for aquatic herbicide application from the Texas Department of Agriculture.

(6) Local plan - a local aquatic vegetation management plan authorized by Parks and Wildlife Code, §11.083 and meeting the requirements in §57.933 of this title (relating to Adoption and Applicability of Local Aquatic Vegetation Plans) and §57.934 of this title (relating to Local Aquatic Vegetation Plan).

(7) MCL - maximum contaminant level.

(8) Nuisance aquatic vegetation - any non-native or native vascular plant species that is determined, in consideration of TPWD guidance, to have the potential to substantially interfere with the uses of a public body of surface water.

(9) Public body of surface water - any body of surface water that is not used exclusively for an agricultural purpose. The term does not include impounded water on private property or water being transported in a canal.

(10) Public drinking water provider - any person who owns or operates a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such system has at least fifteen service connections or regularly serves at least twenty-five individuals at least 60 days out of the year.

(11) State plan - the state aquatic vegetation management plan authorized by Parks & Wildlife Code, §11.082, and described in §57.931 of this title (relating to State Aquatic Vegetation Plan Applicability) and §57.932 of this title (relating to State Aquatic Vegetation Plan).

(12) TDA - the Texas Department of Agriculture.

(13) TNRCC* - the Texas Natural Resource Conservation Commission.

(14) TPWD - the Texas Parks and Wildlife Department.

(15) Treatment proposal – a submission to TPWD on a TPWD-approved form that describes intended measures to control nuisance aquatic

vegetation.

(16) Water district - a conservation and reclamation district or an authority created under authority of Section 52(b)(1) or (2), Article III, or Section 59, Article XVI, Texas Constitution, that has jurisdiction over a public body of surface water. The term does not include a navigation district or a port authority.

§57.931. State Aquatic Vegetation Plan Applicability. The state plan governs throughout the state except where a governing entity has adopted an approved local plan.

§57.932. State Aquatic Vegetation Plan.

(a) Requirements Applicable to All Measures to Control Nuisance Aquatic Vegetation.

(1) Purpose. The purpose of the state aquatic vegetation plan is to provide for the coordination, oversight, guidance and where applicable public notice and enforcement of all activities related to the management of nuisance aquatic vegetation on public bodies of surface water. This includes, but is not limited to, coordination, oversight, public notification and enforcement of all aquatic herbicide use to protect state fish and wildlife resources and habitat and to prevent unreasonable risk from the use of any aquatic herbicide.

(2) Standards. All measures that a person undertakes to control nuisance aquatic vegetation shall be consistent with the principles of integrated pest management as defined in §57.930 of this title (relating to Definitions). A guidance document prepared by TPWD will describe measures to control nuisance aquatic vegetation, and the minimum standards applicable to governing entities that regulate a public body of surface water and persons who propose to treat nuisance aquatic vegetation. The guidance document will include:

(A) Encouragement of the growth and, where lacking, establishment of native aquatic vegetation that provides habitat for fish, the food chain that supports desirable fish populations, other desirable aquatic organisms and wildlife without interfering with reasonable recreational use, navigation, drinking water supply, flow of water to power plants, industrial use, irrigation, or other beneficial uses;

(B) Encouragement of efforts to address the root causes supporting the overgrowth of nuisance aquatic vegetation;

(C) Support for continued monitoring and assessment activities to identify new nuisance aquatic vegetation species and act appropriately to eliminate or minimize ecological impacts;

(D) Support for continued research and evaluation of vegetation control methods that will cause the least possible hazard to persons, property and the environment as required by application of integrated pest management principles;

(E) Encouragement of public input in decision-making processes;

(F) Encouragement of ongoing education and outreach efforts as to the importance of managing aquatic vegetation to assure the ecological health of public waters;

(G) Information to guide individuals wishing to treat nuisance aquatic vegetation; and

(H) Criteria for choosing management responses to nuisance aquatic vegetation problems based on the uses of the water body and the nature of the problem. These criteria may take the form of a three-tier system: Tier I, which calls for immediate response and eradication; Tier II, which calls for ongoing control where nuisance aquatic vegetation is well-established; and Tier III, which calls for monitoring and a contingency plan in case the problem worsens. The three-tier system is subject to change as provided in paragraph (3) of this subsection.

(3)Modification of Guidance. TPWD will publish notice in the Texas Register and seek input from interested parties when it proposes to modify the guidance document. TPWD will also mail notice to persons who so request. Notice shall be provided at least 60 days prior to the effective date of any changes to the guidance document. The notice shall describe the proposed modifications and the reasons for the modifications, and how comments on the proposed modifications may be made to TPWD.

(4) Review by TPWD. Prior to undertaking any measures to control nuisance aquatic vegetation, a person operating under the state plan shall provide to TPWD a treatment proposal, on a form included in the guidance document, no later than the 14th day before the measures are to begin. TPWD will review and may disapprove or amend any treatment proposal and will respond no later than the day before the proposed control measures are to begin. Where appropriate, TPWD will provide technical advice and recommendations regarding prevention of nuisance aquatic vegetation problems. The person submitting the treatment proposal shall have the burden of demonstrating compliance with the state plan. Where a local plan governs, treatment proposals are not subject to TPWD review, approval, and amendment, but are to be submitted to TPWD (pursuant to §57.934(b) of this title, relating to Local Aquatic Vegetation Plan)) for informational purposes.

(b) Additional Requirements Applicable to the Use of Aquatic Herbicides to Control Nuisance Aquatic Vegetation.

(1) No person shall apply aquatic herbicide in a public body of surface water where the state plan governs unless the herbicide is applied in a manner consistent with the state plan. No person shall apply aquatic herbicide in a public body of surface water where a local plan governs unless the herbicide is applied in a manner consistent with the local plan. Where a local plan has been adopted and approved, the requirements of the local plan supersede the requirements of this subsection.

(2) All persons intending to apply an aquatic herbicide shall provide written notice to the governing entity, TPWD, all public drinking water providers that have an intake within two river miles of a site at which an application of aquatic herbicide is proposed to occur, and all persons who have requested notice (TPWD will maintain a list) no later than the 14th day before the application is to occur. The notice shall include:

(A) the dates of the proposed application;

(B) all label information for the aquatic herbicide to be applied;

(C) a statement that TPWD's guidance document has been reviewed and the proposed herbicide application is consistent with the principles of integrated pest management as set forth in subsection (a)(2) of this section and that document;

(D) information demonstrating that the proposed application will not result in exceeding:

(i) the maximum contaminant level of the herbicide in finished drinking water as set by the TNRCC* and the EPA; or

(ii) if the aquatic herbicide does not have an MCL established by the TNRCC* and the EPA, the maximum label rate; and

(E) TDA applicator license number, if any.

(3) An individual who is not a licensed applicator may not apply aquatic herbicides unless the governing entity affirmatively finds, after receiving the proper notice as provided in subsection (b)(2) of this section, that the application will be consistent with the state plan. The governing entity shall respond to the notice given by an individual who is not a licensed applicator no later than the day before the date the application is scheduled to occur.

(4) An individual who is a licensed applicator may apply aquatic herbicide after notice consistent with subsection (b)(2) of this section if the governing entity finds that the application would be consistent with the state plan or does not disapprove the application no later than the day before the application is to occur.

(5) After receiving notice of a proposed application of aquatic herbicide, a governing entity, or TPWD in the absence of such an entity, shall:

(A) provide the individual proposing the application with the state plan;

(B) notify the individual in writing that it is a violation of state law to apply aquatic herbicides in a public body of water in a manner inconsistent with the state plan; and

(C) determine whether the proposed application is consistent with the state plan.

(6) The governing entity shall prohibit the proposed application of aquatic herbicide if the governing entity finds that the proposed application is inconsistent with the state plan, or, if the proposed application is consistent with the state plan, so notify the person.

(7) State money shall not be used to pay for treatment of a public body of surface water with an aquatic herbicide unless the application of the herbicide is performed by an applicator licensed for aquatic herbicide application by the TDA.

(8) Any application of aquatic herbicide shall comply with label rates approved by the EPA.

§57.933. Adoption and Applicability of Local Aquatic Vegetation Plans. A local aquatic vegetation plan may be adopted and shall apply to particular public bodies of surface water as provided in Texas Parks and Wildlife Code, §11.083. A governing entity intending to operate under a local aquatic vegetation plan shall seek approval of its proposed local aquatic vegetation plan under §57.934

of this title (relating to Local Aquatic Vegetation Plan).

§57.934. Local Aquatic Vegetation Plan.

(a) To be approvable by TNRCC*, TPWD, and TDA, a local plan must meet the minimum standards set forth in §57.932 of this title (relating to State Aquatic Vegetation Plan). Additional or more specific requirements are approvable.

(b) A local plan may take into account the particular needs and uses of the public body or bodies of surface water to which it will apply. The local plan may allow herbicide use if the person proposing to apply the herbicide notifies the governing entity not later than the 14th day before the proposed date of application. The local plan shall provide that treatment proposals shall be submitted concurrently to TPWD and the governing entity (on the form provided in the guidance document) no later than the 14th day before the measures are to begin and that the governing entity will review and may disapprove or amend any treatment proposal and will respond no later than the day before the proposed control measures are to begin. The person submitting the treatment proposal shall have the burden of demonstrating compliance with the local plan.

(c) Proposed local plans should be developed in cooperation with TPWD, TDA, and TNRCC*, and shall be submitted to TPWD on a form prepared by TPWD. TPWD will coordinate review of the plan by TNRCC* and TDA.

(d) Governing entities shall seek and encourage public participation in the creation and review of local plans. At a minimum, TPWD, TNRCC*, or TDA will hold at least one public meeting in the area affected by the local plan. Public comment will be received by TPWD, TNRCC*, and TDA for 30 days after the local plan is submitted for agency approval. TPWD, TNRCC*, and TDA will review and respond to local plan submittals within 60 days of receipt.

§57.936. Recordkeeping. Governing entities shall retain copies of the following documents generated under this subchapter for a minimum of five years from generation: all local plan submissions and approvals, all treatment proposals submitted to TPWD, all notices received and provided, all control measures taken by the governing entity (including records of date, place, location, type, and amount of all aquatic herbicide applications), and any other information relevant to a particular individual request for shoreline treatment.

***TNRCC is now Texas Commission for Environmental Quality (TCEQ)**

APPENDIX C

Aquatic Vegetation Treatment Proposal Form

A **map of the water body** with proposed treatment sites indicated should be **attached.**
A **separate form** should be filled out for **each plant species treated.**

Water Body Name: ______________________ ***Submission Date:**__________________

Date Surveyed: _________________ Proposed Treatment Date:__________________

Target Plant Species: _________________ Estimated Acres: _________________________

Recommended Treatment: Mechanical ( ), Biological ( ), Chemical ( ).

Tier ____

Method of Treatment: ____________________________________

Applicator Name: ____________________________________

TDA Applicator License Number: (If applicable)_________________________

Floating or Emergent Vegetation:

Treatment Location	Relative Surface Coverage	Treatment Area (acres)	Treatment Rate/type (organisms, gals, lbs./acre, harvested or shredded)	Total (organisms, gals., lbs, acres harvested or shredded)	Mean water depth
Total					

Submerged Vegetation:

Treatment Location	Relative Surface Coverage	Treatment Area (acres)	Treatment Rate/type (organisms, gals, lbs./acre, harvested or shredded)	Total (organisms, gals., lbs, acres harvested or shredded)	Mean water depth
Total					

Comments:

____

***Proposals are good for six months from the date of submission, unless application plans change.**

Appendix D. TPWD Contacts

Inland Fisheries Division Personnel Involved in Aquatic Vegetation Management

Austin Headquarters
4200 Smith School Road, Austin Texas 78744

Philip P. Durocher, Division Director	512-389-4643
Dr. Gary Saul, Deputy Director	512-389-8082
Bill Provine, Chief, Management & Research	512-389-4855
Dr. Earl Chilton, Aquatic Habitat Enhancement	512-389-4652

Regions – Inland Management

I	Bobby Farquhar	3407-B S. Chadbourne, San Angelo 76903	325-651-4846
II	Brian Van Zee	1601 E. Crest Dr., Waco 76705	254-867-7974
III	Dave Terre	11810 FM 848, Tyler 75707	903-566-1615

Districts – District Management Supervisors

1-A	Charles Munger	P. O. Box 835, Canyon 79015	806-655-4341
1-B	Spencer Dumont	5325 N. 3rd, Abilene 79603	325-692-0921
1-C	Craig Bonds	3407-A S. Chadbourne, San Angelo 76903	325-651-5556
1-D	Randy Myers	134 Braniff Dr., San Antonio 78216-3392	210-348-6355
1-E	John Findeisen	P. O. Box 116, Mathis 78368-0116	361-547-9712
2-A	Bruce Hysmith	P. O. Box 1446, Pottsboro 75076-1446	903-786-2389
2-B	John Tibbs	8684 LaVillage Ave, Waco 76712	254-666-5190
2-C	Steve Magnelia	505 Staples Road, San Marcos 78666	512-353-0072
2-D	Rafe Brock	6200 Hatchery Rd., Ft. Worth 76114	817-732-0761
2-E	Mark Howell	409 Chester, Wichita Falls 76301	940-766-2383
3-A	Tim Bister	3802 East End Blvd. So., Marshall 75672	903-938-1007
3-B	Kevin Storey	2122 Old Henderson Hwy, Tyler 75702	903-593-5077
3-C	Rick Ott	11942 FM 848, Tyler 75707	903-566-2161
3-D	Todd Driscoll	Rt.2, Box 535, Jasper 75951	409-384-9572
3-E	Mark Webb	1004 E. 26th St., Bryan 77803	979-822-5067

Aquatic Vegetation Control

Howard Elder	Rt. 2, Box 535, Jasper 75951	409-384-9965

Heart of the Hills Science Center

Dr. Robert Betsill, Supervisor	5103 Junction Hwy, Ingram 78025	830-866-3356

Appendix E. How to Develop a Local Management Plan

1. Consistency with State Plan

Local plans may take into account particular local needs and uses of the water bodies and/or systems for which they are written; needs which may not be addressed in the broader statewide plan. In order to address local issues individual lake management plans may be more restrictive than the statewide plan. However, all individual lake management plans must meet the minimum standards set by the statewide plan.

2. How a Local Plan Differs from a Treatment Proposal.

The purpose of a local plan is to transfer to a governing entity TPWD's authority to oversee nuisance aquatic vegetation control on the public bodies of surface water that the local plan covers. Local plans must be approved by TCEQ (Texas Commission on Environmental Quality, formerly TNRCC), TDA, and TPW, as provided in §57.934. Where a local plan governs, treatment proposals are not subject to TPW approval. Local plans may or may not address specific nuisance aquatic vegetation problems and treatment alternatives. The law requires that the local plan be at least as stringent as the state plan.

Treatment proposals, by contrast, describe specific actions planned to address one or more nuisance aquatic vegetation problems. Where no local plan is in place, treatment proposals are subject to review and approval by TPW as provided in §57.932(a)(3). A treatment proposal may propose a one-time treatment event, or a series of treatment events over several months. Where a local plan is in place, treatment proposals are to be submitted to the governing entity for approval, and to TPWD for informational purposes.

3. Standards for governing entities preparing local plan

i. Local plans shall be developed in cooperation with, and approved by, TPWD, TDA, and TCEQ. The plan should be submitted to TPWD, which will coordinate approval by the other agencies. Other requirements for the content of local plans are in § 57.934 of the rules.

ii. Before final approval, there shall be a period of public review and comment for local vegetation management plans. The review period will include at least one public meeting sponsored by TPWD, TCEQ, or TDA.

iii. The period of public review will be no less than one month in duration.

4. Format for local plans

i. The rules do not prescribe in detail what local plans must look like. In developing the regulations, TPWD chose to allow governing entities maximum flexibility in designing local plans. One simple way of adopting a local plan is for a local governing entity to submit a document to TPWD stating that the local plan is the same as the state plan, with a list of exceptions where the local plan is more stringent. The governing entity should also describe how the local plan will be implemented, for example, through local ordinances or pesticide labeling. The local plan need not describe specific management actions, such as details of where target plants are. Maps may be included with the local plan if they would be helpful.

Appendix F. Evaluation of Triploid Grass Carp Permit Applications for Public Water

The use of biological controls, such as grass carp, is often viewed as a very popular option to control nuisance aquatic vegetation since they are usually cheaper than herbicides or mechanical harvesting. Unfortunately, the introduction of exotic species, even to help control existing problems, has often led to other problems. Therefore, the Texas Parks and Wildlife Department issues permits for triploid (sterile) grass carp use only, so that unchecked reproduction and over population should not occur. Each application for a permit to stock triploid grass carp in public water will be reviewed and evaluated following the procedure developed by Inland Fisheries Division to ensure compliance with Section §57.126 of the Parks and Wildlife Proclamations.

Procedure:

Step 1. Persons or entities that wish to use triploid grass carp in Texas' public waters must submit a completed "Application to Stock Triploid Grass Carp" to the Inland Fisheries Division. The application can be obtained by calling (512) 389-4444 or by visiting the TPWD website at:

http://www.tpwd.state.tx.us/publications/pwdforms/media/pwd_241d_application_stock_triploid_grass_carp.pdf

Step 2. The District Biologist responsible for managing the public water body in question reviews a copy of the permit application. The biologist is responsible for making a recommendation of whether or not to grant the permit based on the following criteria:

a. Is there is a valid vegetation problem? In general, triploid grass carp stockings in public water will be considered only if nuisance vegetation is beginning to detrimentally affect resident fish communities, and/or is a significant impediment to recreational access (including boating, fishing, swimming, hunting, etc.). Floating exotic vegetation species are usually not controlled very well by grass carp. Typically, vegetation is considered a problem only when it covers more than 20-40% of a water body. However, lesser amounts may be deemed a "problem" if infestations have spread to a large proportion of key access or use areas, and the potential for further spread is high. With exotic plant species it is often prudent to be proactive in order to avoid more serious problems in the future, which may require more drastic action. If there is no vegetation problem, the biologist may recommend against permit issuance.

b. Will the fish escape if stocked? Grass carp will not be effective if they are allowed to move away from targeted use areas. If the probability of escape is high, the biologist will recommend against permit issuance. If escape potential is high, but the construction of a containment structure is deemed feasible, the biologist may recommend issuance conditionally (i.e., only after the containment structure is in place).

c. Will the stocking detrimentally affect threatened or endangered species populations in the area? Unless the probability of negatively impacting T+E species is very low, the biologist will recommend against permit issuance.

d. Will the stocking detrimentally affect coastal wetland or estuarine areas? Public waters south and east of the freshwater/coastal water boundary line are defined as coastal waters. If stocked in this area the risk of grass carp moving into wetlands or estuaries is considered high. Biologists usually recommend against permit issuance and permits are rarely issued in the area.

e. Will the stocking, and its consequences, conflict with TPWD management objectives, or environmental policy? If so, the biologist may recommend against permit issuance.

Additionally, Biologists may contact and obtain input from nearby field personnel in other resource Divisions where appropriate. Much time can be saved if comments from the Resource Protection, Wildlife, and Coastal Divisions (where applicable) are received early in the process, and come from field personnel who are familiar with local circumstances.

District Biologists will include an evaluation of economic and recreational considerations, as well as a Checklist for Triploid Grass Carp Stocking in Public Water (completed in cooperation with headquarters staff), on the attached forms (pages 65-67) in the recommendation report.

Step 3. In order to provide a forum for public input, when the Department receives a request to use grass carp for the first time in a public water body greater than 75 acres in size, a public meeting or hearing will be arranged by the parties requesting stocking and held by the Department near the water body involved. For public water bodies less than 75 acres in size a public meeting or hearing may be arranged by the requesting party and held by the Department if the District Biologist thinks it is necessary. Supplemental stockings do not require a public hearing, but may still be held by the Department if it is deemed necessary.

Step 4. The biologist's report, a copy of the permit application, a copy of permitting criteria, a report from public hearings or meetings held, and any other pertinent information are then routed through designated staff in Inland Fisheries.

Step 5. Inland Fisheries staff will collate comments, and if appropriate meet with representatives of other affected resource Divisions and draft a recommendation for approval or disapproval of the permit. If appropriate, special conditions (including mitigation for loss of desirable aquatic plant species) may be negotiated with applicants and set as terms of permit issuance in order to ensure minimal escape potential, and compliance with Section §57.126 of the Parks and Wildlife Proclamations.

Step 6. Upon review and approval of the final recommendation and supporting materials by the Director of Inland Fisheries (or a designated staff member) applicants will be notified of the status of their applications. The Director of Inland Fisheries (or a designated staff member) may approve or deny permits, or forward them to the Executive Director for review before a final decision is made.

Step 7. Permitted triploid grass carp may only be stocked if a Treatment Proposal for the stocking has been approved by TPWD. Regardless of the number permitted, only the number indicated in the approved Treatment Proposal may be stocked.

Biologists Report

Triploid Grass Carp Public Water Stocking

Lake Name: ______________________ County: ____________________

Location: ______________________ Size (Acres): ________________

Problem Plant(s): ____________________ Area Covered: _______________

Percent of Shoreline Developed:

Recommendation: Stock __________ (Number) Deny Permit _____ (Check)

Biological Considerations:

Economic/Recreational Considerations:

Checklist for Triploid Grass Carp Stocking in Public Water

Water Body Name: ______________________

1. Applicant has **completed** and **submitted** to the Department a **triploid grass carp permit application.**
   - Date Accomplished ______________________________________
   - Comments ____
   ____
   ____

2. Applicant has **remitted** to the Department all **pertinent fees**.
   - Date Accomplished ____________ Fee______________________
   - Number of Fish in initial stocking __________
   - Comments ____
   ____
   ____

3. **All information provided** in the triploid grass carp permit application **is true and correct.**
   - Date of inspection or inquiries ______________________________
   - Person conducting inspection or inquiries _____________________
   - Comments ____
   ____
   ____

4. Applicant has **not been finally convicted**, within the last year, for violation of the Parks and Wildlife Code, 66.007, 66.015, or these rules.
   - Date of criminal background check _________________________
   - Person requesting background check ________________________
   - Comments ____
   ____
   ____

5. Issuance of a triploid grass carp permit is **consistent with department fisheries or wildlife management activities.**
   - Date of discussions and considerations _____________________
   - Persons involved ____
   - Comments ____
   ____
   ____

6. Issuance of a triploid grass carp permit is **consistent with the Parks & Wildlife Commission's environmental policy.**
   - Date of discussions and considerations _____________________
   - Persons involved ____
   - Comments ____
   ____

7. Issuance of a triploid grass carp permit and subsequent stocking **does not conflict with specific management objectives of the department**.
   - Date of discussions and considerations _____________________
   - Persons involved ____
   - Comments ____
   ____
   ____

8. Issuance of a triploid grass carp permit and subsequent **stocking will not detrimentally affect threatened or endangered species** populations or their habitat.
   - Date of discussions and considerations _____________________
   - Persons involved ____

- Comments ____
____
____

9. Issuance of a triploid grass carp permit and subsequent stocking **will not detrimentally affect coastal wetland** and estuarine ecosystems.
   - Date of discussions and considerations ____________________________
   - Persons involved ____
   - Comments ____
   ____
   ____

10. Determination of the number of triploid grass carp authorized for possession under a triploid grass carp permit will include the **consideration of the surface area of the pond or lake** named in the permit application and, as appropriate, the **percentage of the surface area infested** by aquatic vegetation.
    - Date of discussions and considerations ____________________________
    - Persons involved ____
    - Comments ____
    ____
    ____

11. A hearing or meeting was conducted to provide the TPWD with public input relative to the proposed triploid grass carp stocking.
    - Date of meeting or hearing _____________________________________
    - Persons involved ____
    - Comments ____
    ____
    ____

12. Biologists Report submitted to Austin headquarters staff.
    - Date of report ____
    - Comments ____
    ____
    ____

Appendix G. Aquatic herbicides.

		Herbicides								
Aquatic Plant		2,4-D	Diq*	End	Flu	Gly	Ima	Tri	Cop	Che
Emergent Species	Alligatorweed	-	-	-	G	G	E	E	-	-
	American Lotus	-	-	-	G	G	-	G	-	-
	Parrot feather						G	E	-	-
	Pickerelweed	G	-	-	-	-	G	G	-	-
	Smartweed	-	-	-	G	E	G	G	-	-
	Waterlily	E	-	-	G	E	G	E	-	-
	Water pennywort	-	E	-	-	-	E	E	-	-
	Water primrose	-	-	-	G	E	F	E	-	-
	Waterwillow	E	-	-	-	-	F	G	-	-
	Yellow cow-lily	G	-	-	G	E	F	E		
Submerged Species	Bladderwort	E	E	-	E	-	-	-	-	-
	Brazillian elodea	-	-	E	E	-	-	-	-	-
	Bushy	-	E	E	E	-	-	-	-	-
	Pondweed	G	E	E	E	-	-	-	-	-
	Coontail	-	E	-	E	-	-	-	-	-
	Elodea	-	-	-	E	-	-	-	-	-
	Fanwort	-	G	E	E	-	-	-	G	G
	Hydrilla	-	E	E	G	-	-	E	-	-
	Parrot feather	-	E	E	E	-	-	-	-	-
	Pondweed	E	E	E	E	-	-	E	-	-
	Watermilfoil	E	-	E	-	-	-	-	-	-
	Water stargrass									
Floating Species	Duckweed	-	E	-	E	-	F	-	-	-
	Salvinia	-	E	-	E	E	-	-	-	-
	Water hyacinth	E	E	-	-	E	E	E	-	-
	Waterlettuce	-	E	-	-	E	E	-	-	-
Marginal Species	Black willow	-	-	-	-	G	G	E	-	-
	Bulrush	-	-	-	-	E	G	G	-	-
	Cattail	-	G	-	G	E	E	-	-	-
	Giant reed	-	-	-	-	G	G	-	-	-
	Torpedograss	-	-	-	G	G	G	-	-	-
Algae	Chara	-	-	E	-	-	-	-	E	E
	Nitella	-	-	E	-	-	-	-	E	E
	Filamentous	-	-	E	-	-	-	-	E	E

*The following abbreviations appear in the table above: Diq = diquat, End = endothall, flu = fluridone, Gly = glyphosate, Ima = imazapyr, Tri = triclopyr, Cop = copper sulfate, and Che = chelated copper.

Great Trinity Forest Management Plan

Wetlands

Forestry, Wetlands and Water Quality

Forestry, Wetlands and Water Quality

12/14/2002

Why Wetlands?
"Wetland" is a general term used to describe a variety of wet environments, such as marshes, wet meadows, bogs, bottomland hardwood forests and wooded swamps, which are transitional zones between open water and dry land. Many types of wetlands are obvious. However, other wetlands are dry during certain seasons and are not always recognized as wetland sites.
Wetlands are valuable resources with many benefits including:

- Water quality protection and improvement
- Food and habitat for fish and wildlife
- Shoreline and streambank erosion control
- Flood control
- Control of saltwater intrusion
- Fish and shellfish production
- Timber production
- Recreational opportunities
- Recognition of the vital importance of American's remaining wetlands has led to federal laws to preserve and protect them.

What Are Wetlands?
Federal regulation define wetlands as "those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas." The U.S. Army Corps of Engineers (USACE) 1987 publication, Corps of Engineers Wetland Delineation Manual, (Technical Report Y-87-1), is currently used by the USACE and U.S. Environmental Protection Agency (EPA) to identify wetlands and delineate wetland boundaries. Under this methodology, wetlands possess three essential characteristics; (1) hydrophytic vegetation, (2) hydric soils, and (3) wetland hydrology.

What is forestry's role in protecting wetlands and water quality?
While working in wetland areas, the forestry community has the dual responsibility of both protecting against the loss of wetlands and protecting the water quality. Wetland protection is addressed primarily through Section 404 of the Clean Water Act of 1977. Protection of water quality from nonpoint source pollution is addressed under Section 319 of the Act. The purpose of this brochure is to outline the major responsibilities of the forestry community under these two programs.

Section 404
Under Section 404, most activities that will result in the discharge of dredged or fill materials into the waters of the United States require a permit from the USACE. Failure

to obtain a permit or comply with the terms of the permit can result in civil and/or criminal penalties.

Timber production is recognized as a land use that is compatible with wetland protection as long as provisions are made for protection of water quality and wetland characteristics. Because of this, forestry operations are exempt from having to obtain an individual Section 404 permit as long as the activity meets the following conditions:

1. The activity qualifies as normal silviculture.
2. The activity is part of an established (i.e. on-going) silvicultural operation; and
3. It is not part of an activity whose purpose is to convert an area of the waters of the United States into a use to which it was not previously subject, where the flow or circulation of the waters of the United States may be impaired or the reach of the waters reduces; and
4. Forest roads are constructed in accordance with Best Management Practices to assure that flow and circulation patterns and chemical and biological characteristics of waters of the United Sates are not impaired, that the reach of the waters of the United States is not reduces, and that any adverse effect on the aquatic environment will be otherwise minimized; and
5. Any discharge of dredged or fill materials into waters of the United Sates incidental to the activity does not contain any toxic pollutant listed under Section 307 of the Clean Water Act.

What is normal silviculture?

Normal silvicultural activities include those activities associated with plowing, seeding, cultivation, minor drainage and harvesting that are generally accepted as state-of-the-art procedures for tending and reproducing timber crops. Thus, activities such as road construction, timber harvesting, mechanical or chemical site preparation, bedding, tree planting, timber stand improvement, and fire protection are exempt from Section 404 permit requirements, as long as the other criteria for exemption are also met.

What is an established silvicultural operation?

In order for a silvicultural operation to be an exempt activity, it must be part of an established or on-going silvicultural operation. On-going activities are operations and maintenance activities that are part of a conventional silvicultural rotation system and are introduced as part of an established operation on the property. In determining whether an operation is established, the USACE will review the historical use of the property. The existence of a written management plan, evidence of past harvesting with either natural or artificial regeneration, or evidence of fire, insect or disease control to protect timber would be among the factors considered by the agency to be indicative of an established operation.

An operation ceases to be established when the area on which it was conducted has been converted to another use or has lain idle so long that modifications to the hydrological regime are necessary to resume operations.

When is forestry NOT exempt from 404 permitting?

A forestry activity will require a 404 permit from the USACE when any of the above

conditions are not met.
If harvesting will not be followed by continued regeneration of forest crops on the wetland, the operation will cease to be considered an on-going silvicultural operation. In this case, discharges of dredged and fill material associated with the activity will require a 404 permit.
When an activity will result in the conversion of wetlands to uplands, it is not exempt from permitting. If filling activities, including normal silviculture, on any wetland site would result in a change in hydrology, soil characteristics, and/or plant community structure such that the area would no longer be classified as a wetland, or if the area is reduced in size or the flow is modified, the filling activities are not exempt.
Forest management activities relating to wildlife management, recreation or other forest products other than timber are not exempt from Section 404 permit requirements. Only activities for the purpose of timber production are covered under the silvicultural exemption.
One example of an activity that would require a permit would be a farmer who wishes to harvest the timber from a wetland site where timber production has been the established use and convert it to use as pasture, cropland, or real estate development. IN this case, the timber harvesting activity is not exempt because it is an activity whose purpose is to convert a wetland to another use.

Section 319
Section 319 of the Clean Water Act relates to the protection of water from nonpoint source pollution (NPS). NPS pollution is water pollution that is created from an activity that has many diffuse sources. Typically, NPS pollution arises from man's activities and is carried over and through the soil by rainfall runoff. Silvicultural activities such as road construction, timber harvesting and site preparation have the potential to create NPS pollution by introducing sediment, nutrients, organic material, and chemicals into the water.
To deal with the potential for NPS pollution, a set of non-regulatory Best Management Practices (BMP's) have been developed for forestry activities. These guidelines provide practical methods of minimizing erosion and keeping sediment and other pollutants out of water bodies.
Texas does not have a separate set of voluntary BMP's for wetland operations; the BMP's are intended for use on both upland and bottomland sites.

The Texas Forestry BMP's are organized into eight activity areas:

- Planning
- Road Construction and Maintenance
- Road Material Sites
- Harvesting
- Mechanical Site Preparation/Planting
- Prescribed Fire
- Silvicultural Chemicals Streamside Management Zones

Special consideration for protecting water quality in wetlands
Forested wetlands are environmentally sensitive areas. Unless precautions are taken, a harvesting operation can be many times more damaging to wetland sites and water quality than on upland sites. For this reason, special attention to the proper use of BMP's is essential if water quality is to be protected while working in wetland areas.
Careful planning is an essential first step. Planning will assist in identifying sensitive ares to avoid, help minimize stream crossings, and identify the best locations for roads, skid trails and log sets. Also, planning will allow operations to be scheduled during dry periods to minimize adverse impact on soils and water. If wet conditions develop, the operator should consider temporarily closing down the activity until the area dries out sufficiently. Be prepared to move off the site before conditions reach a point where moving equipment will cause excessive damage.
Research has shown that logging roads and skid trails are the primary cause of NPS pollution in forestry operations. Remember that the federal mandatory BMP's for road construction must be followed in jurisdictional wetlands in order to maintain the Section 404 permit exemption for the operation. These mandatory BMP's are designed to protect wetland values. Additionally, Texas' non-regulatory BMP guidelines for road construction and maintenance should also be followed to insure protection of water quality.
Rutting along skid trails and roads will be minimized if operations are conducted during the dry season of the year. During the dry season, soil compaction is minimized if skidding is dispersed across the tract. During wet conditions, concentrated skidding with subsequent repair of rutted ares may be less damaging. However, operators should also consider using wood mats, board roads, or other means to reduce rutting and soil compaction in wet spots.
Streamside Management Zones (SMZ's), buffers of specially managed forest along the banks of water bodies, are particularly important in wetland areas. Timber may be logged carefully and selectively from within these areas. The forest floor is maintained in a relatively undisturbed condition to act as a filter for any sediment that may flow overland toward the protected water body. When necessary to preserve the filtering effect of the SMZ, disturbed areas should be re-vegetates as quickly as possible.

MANDATORY Road BMP's
Forest roads must be constructed and maintained in accordance with the following baseline Best Management Practices in order to retain Section 404 permit exemption status for the road operations:

1. Permanent roads, temporary access roads and skid trails in waters of the U.S. shall be held to the minimum feasible number, width, and total length consistent with the purpose of specific silvicultural operations and local topographic and climatic conditions.
2. All roads, temporary or permanent, shall be located sufficiently far from streams or other water bodies (except for portions of such roads which must cross water bodies) to minimize discharges of dredged or fill materials into waters of the U.S.
3. The road fill shall be bridged, culverted or otherwise designed to prevent the restriction of expected flood flows.

4. The fill shall be properly stabilized and maintained during and following construction to prevent erosion.
5. Discharges of dredged or fill material into waters of the United States to construct a road fill shall be made in a manner that minimized the encroachment of trucks, tractors, bulldozers, or other heavy equipment within waters of the United States (including adjacent wetlands) that lie outside the lateral boundaries of the fill itself.
6. In designing, construction and maintaining roads, vegetative disturbances in the waters of the U.S. shall be kept to a minimum.
7. The design, construction and maintenance of the road crossing shall not disrupt the migration or other movement of those species of aquatic life inhabiting the water body.
8. Borrow materials shall be taken from upland sources whenever feasible.
9. The discharge shall not take, or jeopardize the continued existence of, a threatened or endangered species as defined under the Endangered Species Act, or adversely modify or destroy the critical habitat of such species.
10. Discharge into breeding and nesting areas for migratory waterfowl, spawning areas, and wetlands shall be avoided if practical alternatives exist.
11. The discharge shall not be located in the proximity of a public water supply intake.
12. The discharge shall not occur in areas of concentrated shellfish production.
13. The discharge shall not occur in a component of the Natural Wild and Scenic River System.
14. The discharge of material shall consist of suitable material free from toxic pollutants in toxic amounts.
15. All temporary fills shall be removed in their entirely and the area restored to its original elevation.

More information is available...
Landowners or operators who have questions about their operations as they relate to wetland regulations should contact the local USACE office, their county Soil Conservation Office, or the Texas Forest Service.
Copies of the complete set of voluntary BMP's for water quality protection are available in the handbook entitled Texas Best Management Practices for Silviculture. In addition, the Texas Forest Service offers Forestry Best Management Practices for Water Quality, a brochure that provides a summary of the NPS problem and outlines the BMP's in non-technical terms. Both publications are available through any office of the Texas Forest Service.

BROOKHAVEN NATIONAL LABORATORY

TECHNOLOGY FACT SHEET

PECONIC RIVER REMEDIAL ALTERNATIVES

Wetlands Restoration/Constructed Wetlands

Introduction

For nearly two decades, wetlands have been restored or constructed to meet a number of regulatory requirements, including compensatory mitigation for wetland losses, treatment of wastewater, and reduction of non-point-source pollution. Wetland restoration attempts to reestablish ecological processes in damaged or destroyed natural wetlands, while wetland construction attempts to initiate wetland processes, typically on a non-wetland site, often for such purposes as improving water quality.

Technology Description

Wetlands restoration and construction have been used frequently as mitigation to compensate for wetlands lost, typically due to construction projects. Wetlands can be designed to provide specific functions lost from the landscape. These functions may include development of wetland plant communities that can provide valuable habitats for invertebrates, fish, and wildlife. They also include surface water storage, which provides for the absorption of stormwater flows, and retention, transformation, and removal of nutrients, sediments, and contaminants.

Figure 2 Wetland construction.

Restoration (Fig. 1) is used to replace wetlands or adjacent habitats eliminated during the remediation of contaminated sites. The restoration process is designed to replace the necessary soil structure and chemistry, soil microorganisms, and plant and animal communities. Both plants and soils can be salvaged from the remediation site, or ecologically similar sites, and used in restoration to decrease the recovery time. Following the final grading of clean soils, vegetation is planted as seed or live plants. Species are selected based on the wetland type desired and are matched to the characteristics of the planting site, such as soil moisture and light availability. Preparation of the soil increases the successful growth of plants and often includes loosening of compacted soils and addition of organic material, such as decaying leaves. Streambank stabilization is often required for wetland restorations along stream channels to prevent erosion and quickly establish bank-lining vegetation. Stabilization methods generally include use of plants (either as live plants or seeds) in combination with natural or artificial fiber rolls or mats.

Figure 1 Wetland restoration.

Constructed wetlands (see Fig. 2) are also now used frequently for the treatment of contaminated or nutrient-enriched wastewater. These wetlands typically receive discharges from stormwater collection systems, sewage treatment systems, and other outfalls. Wetlands constructed for water treatment make use of natural wetland processes involving plants, soil, and associated microorganisms. These wetlands are designed to reduce flow velocity, capture suspended sediments, and adsorb contaminants. As retention time of water within the wetlands is increased, the effect of biological and nonbiological processes (both chemical and physical) that remove or transform organic and inorganic compounds, and incorporate materials such as metals into plant material or substrate, is also increased. Flow velocity may be reduced by such design features as decreasing the slope of the wetland soil, increasing the density of wetland vegetation, or reducing water depth by dispersal over a broader floodplain area in free water surface systems (see Fig. 3).

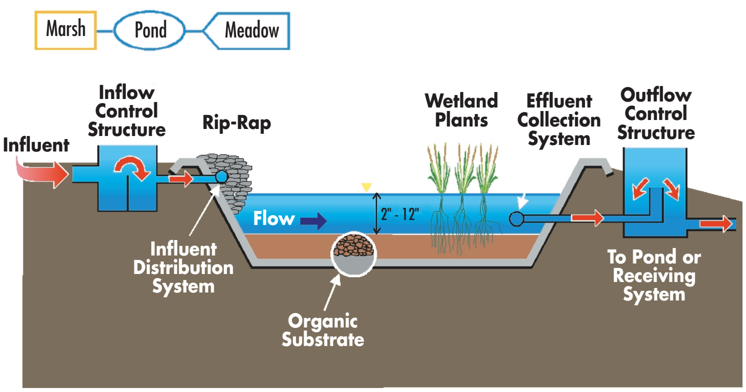


Figure 3   Free water surface wetland: marsh component.

Other applications of constructed wetlands include mitigation of surface runoff from agricultural fields, livestock operations, and golf courses. These wetlands reduce surface flow velocities, retain sediments, and remove or transform nutrients or contaminants, improving water quality in downstream waters.

Advantages

A diversity of wildlife habitats can be successfully developed on restored or constructed wetland sites. Ecosystem function can be restored to degraded or impacted wetland areas. Restoration can rapidly establish a stable biological community, including invertebrates and soil microorganisms. A good cover of fast-growing annual, as well as perennial, vegetation can be established within the first year. Within three years, a wetland restoration effort can produce a diverse community of desired plants and animals. In addition, constructed wetlands can be very effective in improving water quality in downstream waters. Constructed wetlands are effective in removing or stabilizing sediments, metals, and organic contaminants.

Disadvantages

Although constructed wetlands may function as sediment retention systems, excessive amounts of sediment can reduce function over time. In addition, contaminants immobilized in upstream sediments are not eliminated by downstream constructed wetlands. These contaminants remain in place unless they are removed using a separate remediation technology, such as phytoremediation or physical removal.

Relative Cost

The degree of impact or alteration of the natural wetland system influences the cost of successful restoration. Soil replacement and grading can increase the cost of restoration over that of simply preparing the existing soil and planting. Site-specific factors, such as slopes, water currents, or plant species required, can also influence the cost of wetland restoration. In general, restoring wetlands costs $3,500 to $80,000 per acre. This cost would increase with planting of trees and shrubs. Initial construction costs of treatment wetlands are relatively low compared with traditional water treatment systems. Because the wetlands require little maintenance, long-term costs are also quite low. The cost of the constructed wetland is proportional to the number and sizes of treatment cells required. In general, however, it costs $35,000 to $150,000 per acre for constructed treatment wetlands, or about 50% to 90% less than conventional treatment techniques.

Maturity of the Technology

The unique and complex characteristics of wetlands that are associated with specific wetland functions are well understood, and these characteristics can be incorporated into restored and created wetlands in a variety of landscape settings. Many wetland restoration and creation projects have been undertaken in the past two decades. Wetlands are often constructed or restored to provide specific functions, and the success of both wetland construction and restoration projects has greatly increased in the past 10 years.

The successful rehabilitation of degraded or impacted wetland systems includes revegetation, streambank stabilization, habitat creation for fish and wildlife, and creation of new wetland areas. A variety of wetland types can be restored, including stream-side wetlands composed of trees, shrubs, sedges, and cattails, as are found along the Peconic River.

Constructed wetlands have been used successfully for the treatment of degraded water quality at many sites for various problems, including suspended sediments. Constructed wetlands have been shown to remove and trap 86-100% of the sediments from water entering the wetland in summer.

Potential Technology Applicability – Peconic River

The potential impacts of the removal of contaminated sediment from areas of the Peconic River include the disturbance of wetlands within or adjacent to the stream channel. Wetlands are an integral component of the Peconic River system and provide numerous functions, such as waterfowl and fish habitat, and they are an important component of a remediation program. Disturbed wetlands can be restored and exposed banks and substrates stabilized in a cost-effective manner. For wetland restoration, clean soil will be added to areas along the Peconic River from which contaminated sediments have been removed. The soil surface will be contoured to match the pre-remediation elevation, and organic materials will be added. Plants and seeds of desired species, such as those present prior to sediment removal, will be planted. The desired biological communities will develop at these locations within several years and continue to increase in habitat value as the plants mature.

Constructed wetlands can be utilized to capture sediments moving downstream from contamination sites. Application of this technology would aid in the retention of contaminated sediments mobilized from unremediated areas of the Peconic River, thereby preventing migration of contaminants to downstream areas. An open area of several acres would be cleared, adjacent to the Peconic River, for the construction of one or more treatment cells. A gravity flow system may be used to convey Peconic River water to the constructed wetlands, or a pumping system may be installed. Contaminated sediments immobilized in the Peconic River would not be removed by this technology.

Following the completion of remedial activities, the constructed wetlands may remain in place to continue providing water quality improvements to the Peconic River.

Infrastructure Requirements

Wetland restoration would not require additional access roads or staging areas, other than those remaining from the remedial activities. Clean soil, plants, and other materials would be easily transported directly to remediation sites. Construction of treatment wetlands requires access roads for construction equipment. However, decontamination areas are not required.

Long-Term Remedy

Wetlands located within contamination zones will be left undisturbed, unless contaminants are removed using other technologies. Wetlands removed or disturbed by application of other technologies will be restored to pre-remediation conditions. A floodplain location several acres in size, downstream of the contamination zones, can be utilized for the construction of treatment wetlands. One or more cells will be constructed adjacent to the river channel.

Process Residuals Management

Wetland restoration would be undertaken in areas remediated by other technologies, and therefore process residuals are not expected. Contaminated sediments trapped within the constructed treatment wetland will remain in place. Organic and inorganic contaminants will be primarily incorporated within the wetland substrate.

Site Closure Requirements

Unless other remedial technologies are used to extract or remove these metals from sediments within the contaminant zones, the concentrations of copper, silver, and mercury will remain at present levels within the Peconic River sediments. The constructed wetlands will retain mobilized Peconic River sediments and adsorbed contaminants. The metals will be stabilized primarily within the wetland organic and inorganic substrates.

Need for Site-Specific Testing

Restoration of Peconic River wetlands would not require a pilot study prior to implementation. A pilot study, however, would provide valuable information regarding the parameters for effective contaminant treatment within constructed treatment wetlands. It will take about one year to conduct the pilot study. The unique aspects of the site, including hydrology, water chemistry, contaminants of concern, and suitable plant species, make a pilot study desirable to test and refine design criteria prior to construction.

Need for Long-Term Monitoring

Following wetland restoration or construction, a monitoring program will be maintained. Restored wetlands in sediment removal areas will be monitored to identify changes in wetland quality or functions, such as erosion, insufficient growth of wetland species, or introduction of invasive species. If other technologies are not utilized to remove contaminants from Peconic River sediments, a monitoring program will identify continued contaminant effects. Wetlands constructed for treatment of mobilized contaminants will be monitored periodically for effectiveness of contaminant retention.

Synergy with Other Technologies

Short of no action, wetland restoration will be implemented in coordination with other remediation technologies, such as phytoremediation or sediment and contaminant removal. Wetland restoration will restore Peconic River wetlands disturbed during sediment removal operations, or planting and harvesting, to pre-disturbance conditions. Restored wetland communities, including habitat structure, plant and animal species, and hydrology, are expected to reflect undisturbed regional wetland types. Wetlands constructed for water quality improvement will be designed to retain sediments transported from upstream areas or for longer-term protection against inadvertent releases.

Resources

USEPA, 1993, *Constructed Wetlands for Wastewater Treatment and Wildlife Habitat*
http://www.epa.gov/owow/wetlands/construc/

USEPA *Guiding Principles for Constructed Treatment Wetlands: Providing Water Quality and Wildlife Habitat*
http://www.epa.gov/owow/wetlands/constructed/guide.html

USEPA River Corridor and Wetland Restoration Webpage
http://www.epa.gov/owow/wetlands/construc/
http://www.epa.gov/owow/wetlands/restore/

U.S. Army Corps of Engineers, Environmental Laboratory, Wetlands Publications
http://www.wes.army.mil/el/wetlands/wlpubs.html

Natural Resource Conservation Center, Wetland Science Institute, Wetlands Restoration Webpage
http://www.pwrc.usgs.gov/wli/wetres.htm

Contact

For information regarding this fact sheet, please contact **Ken White (631/344-4423, kwwhite@bnl.gov)**.

This fact sheet was prepared by Argonne National Laboratory. Argonne National Laboratory is operated by The University of Chicago for the U.S. Department of Energy under contract No. W-31-109-Eng-38.

Great Trinity Forest Management Plan

Wetlands

Wetlands

I. Introduction

"Wetlands" is the collective term for marshes, swamps, bogs, and similar areas. Wetlands are found in flat vegetated areas, in depressions on the landscape, and between water and dry land along the edges of streams, rivers, lakes, and coastlines. Wetland areas can be found in nearly every county and climatic zone in the United States. Inland wetlands receive water from precipitation, ground water and/or surface water. Coastal and estuarine wetlands receive water from precipitation, surface water, tides, and/or ground water. Surface water sources include runoff and stormwater.

Since the 1600s, more than half of the original wetlands in the lower 48 states have been destroyed. Twenty two states have lost at least 50 percent of their original wetlands. Indiana, Illinois, Missouri, Kentucky, Louisiana, and Ohio have lost more than 80 percent of their original wetlands and California and Iowa have lost nearly ninety-nine (99 percent) percent. Since the 1970s, the most extensive losses of wetlands have occurred in Louisiana, Mississippi, Arkansas, Florida, South Carolina, and North Carolina. Wetlands have been drained and converted to farmland, filled for housing developments and industrial facilities, and used as receptacles for waste. Human activities continue to adversely affect wetland ecosystems.

More recently, society has begun to understand the functions of wetlands and the values humans obtain from them. Wetlands help regulate water levels within watersheds; improve water quality; reduce flood and storm damages; provide important fish and wildlife habitat; and support hunting, fishing, and other recreational activities. Wetlands are important features in watershed management.

The use of regulation to protect wetlands as integral and essential parts of the nation's waters began formally in 1972 through the Clean Water Act (also known as the 1972 Federal Water Pollution Control Act, as amended). Section 404 of the Clean Water Act establishes the federal authority to regulate activities in wetlands. Under Section 404, jointly administered by U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA), the discharge of material into waters of the United States, including wetlands, requires a permit from the Corps based on regulations developed in conjunction with EPA (Section 404(b)(1) guidelines). Failure to obtain a permit or comply with the terms of a permit can result in civil and/or criminal penalties. Other federal regulations and guidelines have been issued which further the goal of wetlands protection and improved wetlands management. Many state and local governments have also enacted regulations and ordinances protecting wetlands.

II. What are Wetlands?

Although federal agencies, states, and text book authors vary in the way in which they define wetlands, in general terms, wetlands are lands on which water covers the soil or is present either at or near the surface of the soil or within the root zone, all year or for varying periods of time during the year, including during the growing season. The recurrent or prolonged presence of water (hydrology) at or near the soil surface is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface.

Wetlands can be identified by the presence of those plants (hydrophytes) that are adapted to life in the soils that form under flooded or saturated conditions (hydric soils) characteristic of wetlands (NAS 1995; Mitsch and Gosselink 1993). There also are wetlands that lack hydric soils and hyrdrophytic vegetation, but support other organisms indicative of recurrent saturation (NAS 1995).

The federal regulations implementing Section 404 of the Clean Water Act define wetlands as:

Those areas that are inundated or saturated by surface or ground water (hydrology) at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation (hydrophytes) typically adapted for life in saturated soil conditions (hydric soils). Wetlands generally include swamps, marshes, bogs, and similar areas (40 CFR 232.2(r)).

Jurisdictional wetlands -- those that are regulated by the U.S. Army Corps of Engineers (Corps) under Section 404 -- must exhibit all three characteristics: hydrology, hydrophytes, and hydric soils (US ACOE 1987). It is important to understand that some areas that function as wetlands ecologically, but exhibit only one or two of the three characteristics, do not currently qualify as Corps jurisdictional wetlands and thus activities in these wetlands are not regulated under the Section 404 program. Such wetlands, however, may perform valuable functions.

Another federal agency, the U.S. Fish and Wildlife Service defines wetlands as: lands that are transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water, and that have one or more of the following attributes:

1. At least periodically, the land supports predominantly hydrophytes;
2. the substrate is predominantly undrained hydric soil; and,
3. the substrate is non-soil and is saturated with water or covered by shallow water at some time during the growing season of each year (Cowardin et al. 1979).

This definition differs from the EPA and U.S. Army Corps of Engineers definition used for jurisdictional wetlands which requires that all three attributes (hydrophytes, hydric soils, and hydrology) be evident. The 1987 Corps of Engineers Manual on wetland delineation does not consider unvegetated aquatic sites such as mudflats and coral reefs or vegetated shallow water to be wetland areas, whereas the Cowardin classification does (US ACOE 1987).

Wetland Classification

Cowardin
U.S. Fish and Wildlife Service
Wetland Classification System

In 1979, a comprehensive classification system of wetlands and deepwater habitats was developed for the U.S. Fish and Wildlife Service (Cowardin et al. 1979).

Under this system, wetlands are of two basic types: coastal (also known as tidal or estuarine wetlands) and inland (also known as non-tidal, freshwater, or palustrine wetlands).

Coastal wetlands are found along the Atlantic, Pacific, Alaskan, and Gulf coasts and include estuaries. The salt water and tides combine to create an environment in which most plants, except salt-tolerant species (halophytes), cannot survive. Mangrove swamps, dominated by halophytic shrubs or trees, are common in warm climates, for example, in southern Florida, Puerto Rico, and Louisiana. Tidal freshwater wetlands form in upstream coastal wetlands where the influence of salt water ends.

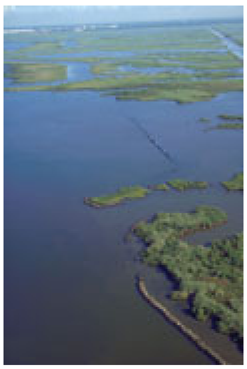


Photo courtesy of USDA NRCS

Inland wetlands include floodplains along rivers and streams (e.g., bottomlands and other riparian wetlands); isolated depressions surrounded by dry land (e.g., prairie potholes); areas where the groundwater intercepts the soil surface (e.g., fens) or where precipitation saturates the soil for a season or longer (e.g., vernal pools and bogs). Marshes and wet meadows are dominated by grasses and other herbaceous plants or shrubs; and swamps are dominated by trees. Certain types of inland wetlands are common to particular regions of the country: the Carolina bays and pocosins in the Southeast; bogs and fens in the northeastern and north-central states and Alaska; inland saline and alkaline marshes, playas, and riparian wetlands in the arid and semiarid West; prairie potholes, including the Nebraska Sandhills, in the northern Midwest; and bottomland hardwood swamps of the South.

Photo courtesy of USDA NRCS

The USFWS's Cowardin classification system defines deepwater habitats as: permanently flooded lands lying below the deepwater boundary of wetlands (2 meters), including environments where surface water is permanent, with water, rather than air, the principal medium within which the dominant organisms live.

The Cowardin system is hierarchical and includes several layers of detail for wetland classification including: a subsystem of water flow; classes of substrate types; subclasses of vegetation types and dominant species; as well as flooding regimes and salinity levels for each system. This system is appropriate for an ecologically based understanding of wetland definition. The entire Classification of Wetlands and Deepwater Habitats of the United States, including tables and figures of the hierarchical structure, is available online.

Cowardin Wetland and Deepwater Systems

The following is a brief description of the major classes of wetlands under the Cowardin system.

Marine - Open ocean overlying the continental shelf and coastline exposed to waves and currents of the open ocean shoreward to (1) extreme high water of spring tides; (2) seaward limit of wetland emergents, trees, or shrubs; or (3) the seaward limit of the Estuarine System, other than vegetation. Salinities exceed 30 parts per thousand (ppt).

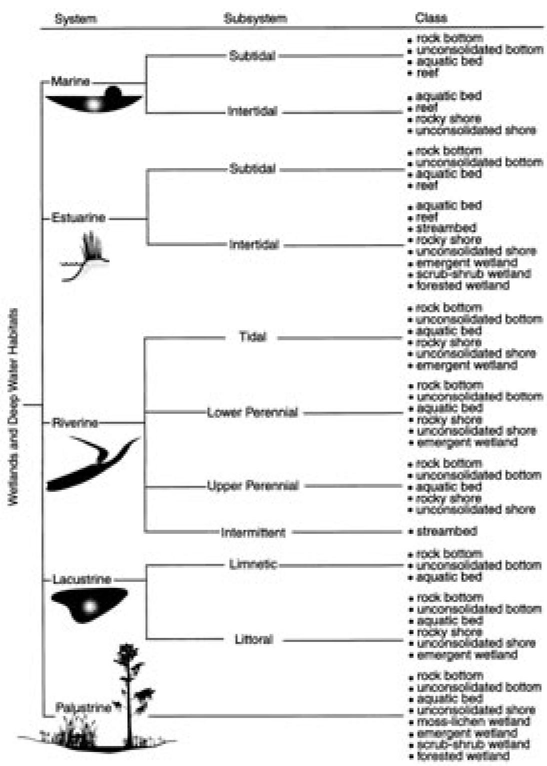
Estuarine - Deepwater tidal habitats and adjacent tidal wetlands that are usually semi-enclosed by land but have open, partly obstructed, or sporadic access to the ocean, with ocean-derived water at least occasionally diluted by freshwater runoff from the land. The upstream and landward limit is where ocean-de rived salts measure less than .5 ppt during the period of average annual low flow. The seaward limit is (1) an imaginary line closing the mouth of a river, bay, or sound; and (2) the seaward limit of wetland emergents, shrubs, or trees when not included in (1).

Riverine - All wetlands and deepwater habitats contained within a channel except those wetlands (1) dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and (2)which have habitats with ocean-derived salinities in excess of .5 ppt.

Lacustrine - Wetlands and deepwater habitats (1) situated in a topographic depression or dammed river channel; (2) lacking trees, shrubs, persistent emergents, emergent mosses, or lichens with greater than 30% areal coverage; and (3)whose total area exceeds 8 hectares (20 acres); or area less than 8 hectares if the boundary is active wave-formed or bedrock or if water depth in the deepest part of the basin exceeds 2 m (6.6 ft) at low water. Ocean-derived salinities are always less than .5 ppt.

Palustrine - All nontidal wetlands dominated by trees, shrubs, persistent emergents, emergent mosses, or lichens, and all such tidal wetlands where ocean-derived salinities are below .5 ppt. This category also includes wetlands lacking such h vegetation but with all of the following characteristics: (1) area less than 8 ha; (2) lacking an active wave-formed or bedrock boundary; (3) water depth in the deepest part of the basin less than 2 m (6.6 ft) at low water; and (4) ocean-derived salinities less than .5 ppt.

A Palustrine system can exist directly adjacent to or within the Lacustrine, Riverine, or Estuarine systems.



Wetland and deepwater habitat classification hierarchy showing systems, subsystems, and classes (after Cowardin et al., 1979).

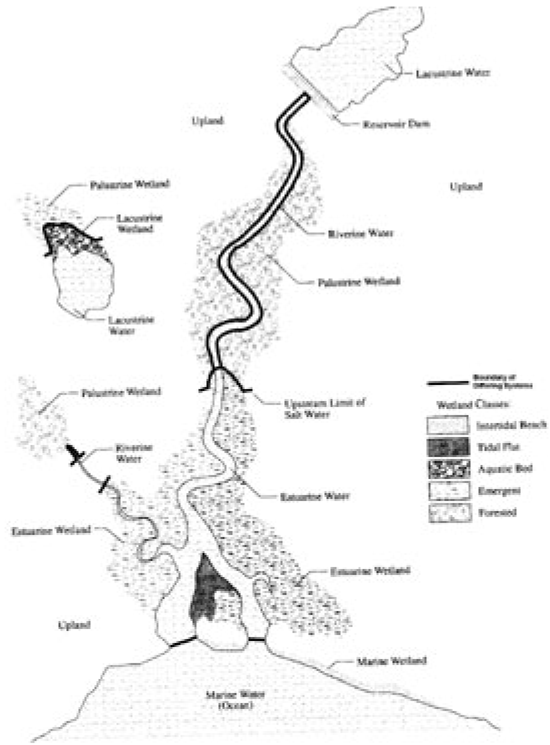


Diagram showing relationships between major wetlands and deepwater habitat systems on the landscape (Tiner and Burke, 1995).

Wetland Definition/Delineation Controversy

Federal wetland regulation began as permitting of dredge and fill disposal within "navigable waters" of the United States by the Army Corps of Engineers (Corps) under the 1972 CWA Section 404. In 1975, supported by federal court decisions expanding the definition of waters of the United States to include wetlands, the Corps issued revised regulations for the 404 program that clearly encompassed wetland protection. While wetlands are not directly included anywhere in Section 404 itself, even to the pre sent, the Corps regulations established under Section 404 have been upheld by the U.S. Supreme Court, and other subsequent federal regulations and actions have firmly ensconced wetland protection within the national policy framework.

However, given the ever-controversial nature of wetland regulation as a form of land use restriction, the federal regulatory effort required a clear, legally defensible wetland definition. Unfortunately, wetlands are difficult to reduce to a single definition, largely because their essential elements are so diverse and variable in character. Wetlands inhabit a transitional zone between terrestrial and aquatic habitats, and are influenced to varying degrees by both. They differ widely in character around the country because of regional and local differences in climate, soils, topography, landscape position, hydrology, water chemistry, vegetation, and other factors. Depth and duration of inundation, a key defining force, can differ greatly between wetland types and can vary from year to year within a single wetland type. Wetlands definition by vegetation is difficult, as some wetland species can live in either wetlands or uplands, while others are adapted to only a wet environment. Because wetland habitats are so diverse as to form a continuum connecting terrestrial to aquatic ecotypes, and because they can vary so significantly within a given type, no universally recognized wetland definition exists.

Nevertheless, in 1977, the Corps issued regulations for implementation of Section 404 of that year's expanded CWA Amendments. The regulations included a wetland definition (which stands essentially unchanged to the present), modified from the original 1975 version. Over time, as the 1977 regulations were implemented, the need for a clear method of determining wetland limits on-site, or the extent of federal wetland jurisdiction, became evident. During the 1980s, different governmental agencies and even different branches of the same agency issued their own field guidelines for wetland delineation. In 1987, the Corps released its Manual for Delineation of Wetlands (1987 Manual http://www.saj.usace.army.mil/permit/documents/87manual.pdf). Application of the Manual varied among the regional Corps offices. The focus of the wetland regulatory debate thus became the guidelines used for field delineation of wetland boundaries.

In 1989, the Interagency Wetlands Delineation Manual ("1989 interagency manual") was jointly released by the EPA, U.S. Fish and Wildlife Service, U.S. Army, and the U.S. Department of Agriculture to address the problem of inconsistency in wetland delineation among these four agencies. Although the 1989 interagency manual was supported by the scientific community, the development and agricultural communities criticized the manual, claiming that the agencies had expanded regulatory jurisdiction without allowing public participation in the decision making process.

The Bush Administration attempted to move the debate with a 1991 manual ("1991 proposed revisions") that was immediately challenged by the scientific community for it's delineation method, which lacked a technical basis. The regulated community criticized the manual for making the permit process more complex than it had been under the 1989 manual. By 1992, EPA had received more than 80,000 comments on the 1991 proposed revisions. President Bush then signed the Energy and Water Development Appropriations Act of 1992, which included a provision prohibiting the Corps from expending funds for the performance of wetland delineation using the 1989 interagency manual. In response, the Corps returned to the 1987 manual as the standard for wetland delineation. The 1987 manual has since become the most commonly used guide to delineation.

During this time, Congress requested a National Academy of Sciences (NAS) study of wetlands delineation. The National Academy of Science study ("WETLANDS: Characteristics and Boundaries"), published in August 1995, concluded that a new federal delineation manual should be issued, and that it should modify the 1987 manual by broadening the determination of wetland limits based on both current scientific understanding and almost ten years of regulatory practice. Current delineation methodology does not encompass all areas that the NAS would define as wetlands (NAS 1995). The NAS report provides a definition for "wetlands" as well as criteria for identification and indicators of wetland conditions.

Sources: OTA 1993; OEP 1992; Want 1993; NAS 1995

Identification Methods

Onsite Identification: Corps of Engineers Methodology

Many federal, state, and local agencies, private organizations, and landowners need to identify or delineate the boundaries of wetlands for a variety of purposes. Each agency may be required to use one or more federal, state, or local laws or guidelines defining wetlands in specific ways. For example, the U.S. Army Corps of Engineers (Corps) administers the Section 404 program governing the discharge of dredge and fill material into waters in the U.S. as defined and guided by Section 404 of the Clean Water Act. The wetlands which fall within the Section 404 regulation are referred to as jurisdictional wetlands. The indicators of wetlands suggested by the Corps in their 1987 Manual for Delineation of Wetlands, (US ACOE 1987), are used as the basis for determining the presence of a wetland by most scientists and engineers. Other, broader, definitions of wetlands are generally used in addition to, or in place of, the Corps guidelines when the ecological aspects of wetlands are the focus. The U.S. Fish and Wildlife Service scientists and many other scientists, land use planners, and watershed or water quality managers, utilize the Cowardin system for more in-depth identification or classification of wetlands.

The U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (formerly the Soil Conservation Service) will perform identification of wetlands on agricultural lands, as well as on non-agricultural lands within agricultural lands, or on non-agricultural lands, for landowners/operators who are USDA program participants (USEPA 1995). Natural Resources Conservation Service agents can determine the extent of wetlands for both the Swampbuster program and Section 404 at the same time using the definitions under Section 404 and the 1987 Manual. Formerly, Corps agents were required to make the Section 404 delineation. "Agricultural lands" are intensively used and managed cropland, hay land, pasture land, orchards, vineyards, and areas which support wetland crops (e.g. cranberries, rice, taro, and watercress) (USDA 1995).

The indicators of the presence of a wetland listed below are used in the Corps process of delineation provided in the 1987 Manual for Delineation of Wetlands (US ACOE 1987). A jurisdictional wetland requires three conditions (hydrophytes, hydrology, and hydric soils). The information given below is just basic information for onsite identification and should **not** be used for permitting or wetland delineation in a legal context. It is provided as a tool for watershed and water quality managers who want to assess whether an area is a wetland and thus may contribute to the watershed functionally. Onsite identification of the presence of a wetland will require familiarity with soil science and plant identification.

Wetland Indicators for Delineation (based on the 1987 Manual (US ACOE 1987))

The indicators of the presence of a wetland are hydrophytic vegetation (plant life growing in water, soil, or on a substrate that is periodically deficient in oxygen due to excess water), presence of water, and hydric soils (soils saturated, flooded, or ponded, long enough during the growing season to develop anaerobic conditions in the upper profile). Observations of field indicators are used to determine whether the criteria are satisfied since the criteria alone may not be enough to document presence of a wetland. In particular, flooding or saturated soil conditions may occur for only a short time during the year, and generally not when delineators are present. For an ecological determination of the presence of a wetland, all that may be required is the presence of hydrophytic vegetation that require flooded or saturated conditions for survival. Such vegetation is outcompeted by upland species when wetlands are drained.

Hydrophytic vegetation

Photo courtesy of
USDA NRCS

Photo courtesy of
US Army Corps of Engineers

Photo courtesy of
USDA NRCS

Criteria for a wetland: more than 50% of the composition of the dominant species (largest relative basal area (trees), greatest height (woody understory), number of stems (vines) or greatest areal cover (herbaceous understory)) from all strata (overstory, understory, woody vines, ground cover/herbaceous understory), must be obligate wetland (OBL) species, facultative wetland species (FACW), and/or facultative (FAC) species.

- Obligate wetland species (OBL) occur more than 99% of the time only in wetlands.
- Facultative Wetland species (FACW) occur in wetlands 67-99% of the time.
- Facultative species (FAC) are tolerant of wet and dry conditions. They are as likely to occur in uplands as in wetlands and are found in wetlands 34-66% of the time.
- Facultative Upland species (FACU) are flood-intolerant and usually occur in uplands (66-99%) but occasionally (1-33% of the time) are found in wetlands.

Field Indicators for hydrophytic vegetation

If obligate species comprise all dominant species in the community and there has been no recent significant hydroperiod alteration, soils and hydrology need not be determined for ecological determination of wetland presence.

Obligate and facultative wetland species are the most reliable indicators of the presence of a wetland. Since OBL species only occur in wetlands, their presence signifies that the area is a wetland. FACW species are less reliable, however, they do occur most often in wetlands (67-99%) than in uplands. A community dominated by OBL or by OBL and FACW should always be a wetland unless the area's hydrology has been significantly altered by human activity or other impacts.

If an area has FAC species but still greater than 10% areal cover of OBL species, the presence of a wetlands is indicated (Tiner 1993).

The U.S. Fish and Wildlife Service has listings of wetland plant species by region available on the WWW at URL HTTP://www.nwi.fws.gov/Ecology.html

Hydrology

Wetlands require permanent or periodic inundation or soil saturation at the surface for a week or more during the growing season to be a wetland ecologically as well as for jurisdictional purposes. These conditions create an anaerobic environment which affects the plants and soil. Hydrology is not as useful for wetland identification as the use of vegetation and soil characteristics since many wetlands are dry for much of the year. Hydrology is a feature of the regulatory determination of "jurisdictional wetlands" but is considered "technically flawed" by experts in the field of delineation who recommend that only vegetation and soil characteristics be used (Tiner 1993; Day et al. 1993).

However, if obligate species comprise all dominants in the community and there has been no recent significant hydroperiod alteration, the hydrology characteristic is fulfilled for jurisdictional wetland delineation even if no water is present.

Field indicators of wetland hydrology:

1. visual observation of inundation
2. visual observation of soil saturation in 18" hole to 12" depth
3. watermarks (stains on bark or other fixed objects)
4. water-borne debris deposition, particularly in aboveground vegetation
5. water-borne sediment deposits on plants and other vertical objects
6. drainage patterns within wetlands, including scouring
7. water stained (blackened or grey) leaves

Other indicators of wetland hydrology are morphological adaptations to flooded or saturated conditions (see below), and hydric soil characteristics.

Recorded data of soil inundation and saturation for a significant time (more than a week) during the growing season and aerial photographs displaying inundation are other useful information sources to determine hydrology.

Morphological adaptations to permanent or periodic inundation or soil saturation and examples of species displaying adaptations

Adaptation	**Species**
<hr>	
Buttressed tree trunk (swollen bases)	Taxodium distichum (Bald cypress), Nyssa (Gum)
Multiple trunks	(Acer rubrum) Red maple
Pneumatophores (knees) Stubby projections extending from the roots to heights above the average water level.	Taxodium distichum, Nyssa aquatica
Adventitious Roots Roots occurring on plant stems and above soil surface.	Plantanus occidentalis (Sycamore), Salix (Willow), Ludwigia (Water primrose)
Shallow roots (exposed)	Acer rubrum (Red maple)
Hypertrophied lenticels Large lenticels, allowing greater gas exchange	Salix (Willows), Acer rubrum (Red maple)
Aerenchyma in roots and stems spongy, air filled tissue	Juncus spp. (Rush), Typha spp. (Cattails), Cyperus spp. (Sedges)
Polymorphic leaves Leaves that have different shapes depending on site conditions	Sagittaria (Arrowheads),
Floating leaves	White water lily,

Hydric soils

Hydric soils take time to form, and are formed from regular or constant water saturation or inundation. Hydric soils include:

1. All Histosols except Folists,

Histosols are organic soils (more than 50% of upper 32 inches by volume is organic) or any depth of organic material on bedrock; Folists are non hydric organic soils originating from excessive moisture in tropical and boreal mountains.

or,

2. Soils in Aquic suborders and Aquic subgroups that are:

a. Somewhat poorly drained and water table <0.5 ft from the surface (>1 week during the growing season.
b. Poorly drained or very poorly drained and have either:

1. Water table <1 ft from the surface for (>1 week during the growing season if permeability (6 in/hr in all layers within 20 inches of the surface
2. Water table < 1.5 ft from the surface for (>1 week during the growing season if permeability <6 in/hr in all layers within 20 inches of the surface.
3. Soils that are ponded for long duration (or inundation by a single event for (7 days) during the growing season.
4. Soils that are frequently flooded (> 50% probability of flooding in a given year) for long duration during the growing season.

Field indicators of hydric soils:

These are listed in the order in which they can be used to definitively indicate whether soils are hydric and the area is a wetland.

1. Histosols (except Folists)*
2. Histic epipedon *
3. Sulfidic materials (H_2S) in mineral soils emitting the smell of rotten eggs
4. Aquic moisture regime (usually hydric soil) or peraquic moisture regime*
5. Reducing soil conditions as indicated by:
   a. Gleyed soils (blueish or greenish gray) immediately below A horizon, matrix chroma (predominant color) less than or equal to 1 (using Munsell Soil Color Book)
   b. Bright mottles immediately below A horizon or 10 inches and/or matrix chroma of less than or equal to 2 (if soil has mottles; color determined with wet or moist soils)
   c. Iron (reddish brown) and/or manganese (black) concretions

*always hydric soils

NOTE: Color is not a reliable indicator in sandy or coarse textured soils.

Coarse-textured or sandy hydric soils:

1. High organic matter content in the surface horizon. The mineral surface layer will appear darker than the mineral layer below it.
2. Dark vertical streaking of subsurface horizons by organic matter movement as water table fluctuates.
3. Wet Spodosols. Accumulation of organic matter 12 to 30 inches below the mineral surface.

Useful references for determining hydric soils are the USDA Soil Surveys and the USDA Hydric Soils List.

The Primary Indicators Method (PRIMET), developed by Ralph Tiner, U.S. Fish and Wildlife Service, is a technically sound, precise, practical, efficient, method of wetlands delineation requiring a single site inspection. It is based on the same information as is presented above but puts it into a series of questions. It is usable throughout most of the year and encompasses regional variation. PRIMET is a useful tool for watershed and water quality managers who want to get a sound but efficient assessment of whether an area is technically a wetland and thus may contribute to the watershed functionally. Wetlands Vol. 13, No. 1, 1993 p. 56.

Offsite Identification of Wetlands

Offsite identification of wetlands can be a useful screening tool to determine the possible existence of wetlands. However, on-site verification is necessary to establish the existence, size, shape, and type of wetlands. Some resources for offsite identification of wetlands include:

U.S. Geological Survey (USGS) Topographic Maps

These maps portray vegetation cover types, surface features, rivers, lakes, canals, submerged areas, and bogs. Specific terms are used. A marsh or swamp is characterized by saturated, not inundated, soil conditions in the root zone, with emergent herbaceous or floating vascular (aquatic bed) vegetation. A wet meadow is an example. A submerged marsh or swamp has inundated soil conditions with emergent herbaceous or floating vascular (aquatic bed) vegetation. An example is a cattail (Typha) marsh. A wooded swamp or marsh has saturated soil conditions with shrub (including sapling) or forest vegetation. A red maple (Acer rubrum) swamp is an example. A submerged wooded marsh or swamp, has inundated (ponded) soil conditions with shrub (including sapling) or forest vegetation. A bottomland hardwood forest with cypress (Taxodium) is an example. The term land subject to inundation indicates floodplain areas. Rice fields and cranberry bogs are often wetlands that have been manipulated by man. The USGS Topographic Maps allow historical evaluation of a site which can be useful for restoration purposes. Small wetlands, however, are often not included because of their size and the scale of the maps -- generally 1:24000 -- (1 inch = 610 meters).

National Wetlands Inventory

The National Wetlands Inventory (NWI) was initiated by the U.S. Fish and Wildlife Service in 1975 to characterize the extent of wetlands and open water in the United States. Under the Emergency Wetlands Resources Act of 1986, the Fish and Wildlife Service is required to map wetlands of the lower 48 states and to assess the nation's wetland resources every 10 years.

The maps are produced from high altitude aerial photographs at a scale of 1:600,000 and use U.S. Geological Survey Topographic Maps (USGS Topo Maps) as basemaps with the wetlands and deepwater systems as overlays. The Cowardin system specifically corresponds to the NWI maps. There is error inherent in the NWI maps beyond the normal human error involved in photointerpretation and mapmaking, since small wetlands are generally not distinguishable from the surrounding uplands at a scale of 1:600,000 and small wetlands may not have been mapped on the USGS Topo Maps. The National Wetlands Inventory maps are available in paper as well as digital format and magnetic tape in MOSS export, DLG3, Arc for workstations, and Arc/Info for PC.

USDA Soil Conservation Service Soil Surveys and Hydric Soils List

Soil surveys may be used to identify and delineate hydric soils, however accuracy of the maps is variable. The Soil Conservation Service is now called the Natural Resources Conservation Service.

The three types of maps described above may be used together to develop an estimate of the location and type of wetlands in a particular area.

Aerial photographs and satellite images may be used as well and are available in many formats and scales.

Some states have developed wetlands maps and mapping is ongoing in other states.

Source: (Kent 1994a)

Hydrogeomorphic Model (HGM)

The Hydrogeomorphic Model is a relatively new classification system for determining wetland functions. The federal agencies responsible for wetland regulations and permitting are working together to develop the system. Wetland permitting requires evaluating the effect of potential projects on wetland functions. This system develops methods for evaluating the physical, chemical, and biological functions of wetlands, and can be fitted to various types of wetlands in different geographic regions.

For more information visit the following websites:

- A Hydrogeomorphic Classification for Wetlands, technical report by Brinson
- NRCS Wetland Science Institute
- EPA

III. Importance of Wetlands: Functions and Values

Many people use the terms functions and values interchangeably when discussing wetlands, even though functions and values are different. Functions are the physical, chemical, and biological processes occurring in and making up an ecosystem. Processes include the movement of water through the wetland into streams or the ocean; the decay of organic matter; the release of nitrogen, sulfur, and carbon into the atmosphere; the removal of nutrients, sediment and organic matter from water moving into the wetland; and the growth and development of all the organisms that require wetlands for life.

Values are "an estimate, usually subjective, of worth, merit, quality, or importance" (Richardson 1994). Wetland "values" may derive from outputs that can be consumed directly, such as food, recreation, or timber; indirect uses which arise from the functions occurring within the ecosystem, such as water quality, and flood control; possible future direct outputs or indirect uses such as biodiversity or conserved habitats; and from the knowledge that such habitats or species exist (known as existence value) (Serageldin 1993).

The difficulty with determining the value of a wetland is that valuation can be a subjective assessment, particularly the valuation of indirect use, future use, or existence values. Some wetlands may have multiple uses or worth. Wetlands that are remote may not directly benefit any humans but may be critical, for instance, to the existence of a type of salamander. People may value the intangible fact that wetlands exist, but would not be able to place a price on them, perhaps feeling offended by the concept. In contrast, the value of estuaries in producing shrimp can be calculated based on the price of shrimp.

Conflicts may also arise between public and private valuation. For example, although an individual landowner may not receive the financial benefits of the wetland on his or her property, it may have worth to the town or county in improving public water quality or quantity. In such a case, the town or county could pay the landowner to preserve a wetland. In more complex cases involving endangered wetland species found on private property, the government attributes a value to the preservation of the species and regulates the development of the private property, although the property owner may not value the organism at all or values it less than he does other possible land uses.

Within watersheds and ecosystems, human activities can cause depletion or pollution. The watershed and its ecosystems sustain our way of life, regardless of our understanding of the biology, chemistry, and geology involved. However, when decision makers do not understand the basics of ecosystem functions and values, they may make choices that prevent ecosystems from fully functioning. The result may be long term and possibly irreversible changes. Such changes reduce the value of the ecosystem. They can even affect the economy. A familiarity with the functions and values of an ecosystem such as a wetland can improve decision making today and protect values that may be held by future generations as well.

Functions

Hydrologic Flux and Storage

Water balance

Wetlands play a critical role in regulating the movement of water within watersheds as well as in the global water cycle (Richardson 1994; Mitsch and Gosselink 1993). Wetlands, by definition, are characterized by water saturation in the root zone, at, or above the soil surface, for a certain amount of time during the year. This fluctuation of the water table (hydroperiod) above the soil surface is unique to each wetland type.

Wetlands store precipitation and surface water and then slowly release the water into associated surface water resources, ground water, and the atmosphere. Wetland types differ in this capacity based on a number of physical and biological characteristics, including: landscape position, soil saturation, the fiber content/degree of decomposition of the organic soils, vegetation density and type of vegetation (Taylor et al. 1990):

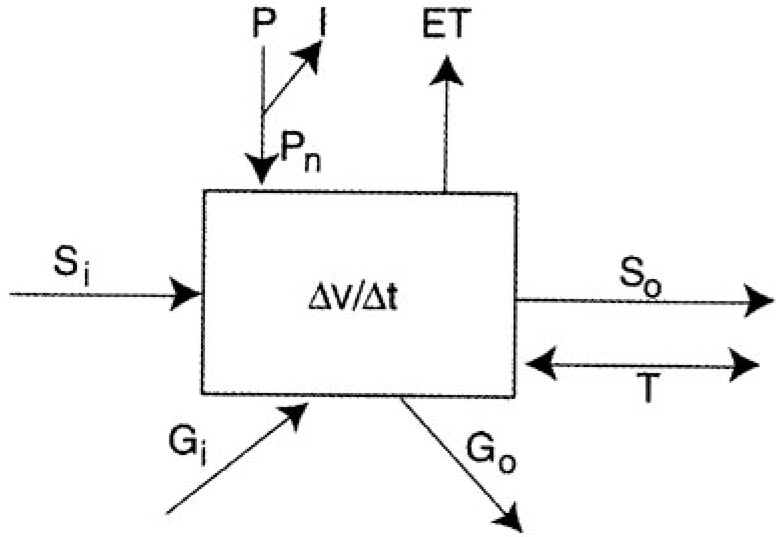
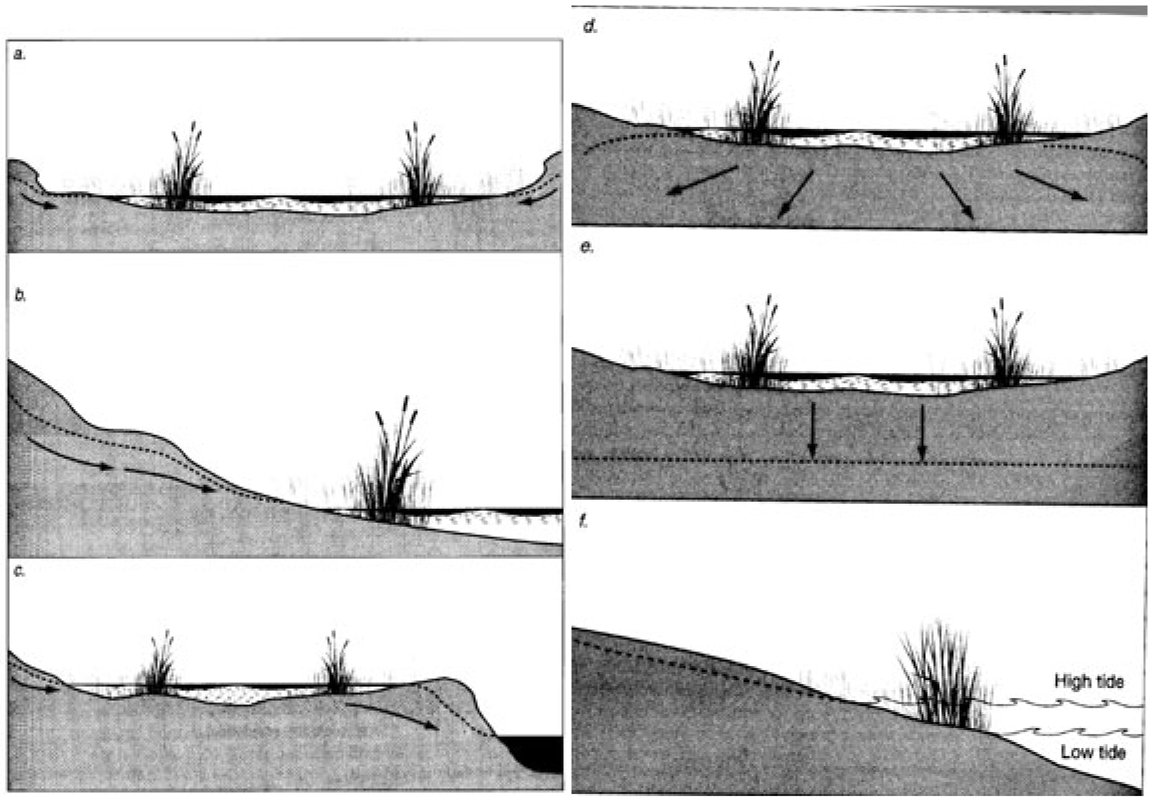


Diagram of a waterbalance, where P=precipitation, Pn= net precipitation, ET=evapotranspiration, I=Interception, Si=surface water inflow, So=surface water outflow, Gi= groundwater inflow, Go=groundwater outflow, T= Tide, V=change in storage, and t=time (Mitsch and Gosselink, 2000).

Landscape position

Landscape position affects the amount and source of water in a wetland. For example, wetlands that are near a topographical height, such as a mountain bog, will not receive as much runoff as a marsh in a low area amidst fields. Wetlands can be precipitation dominated, ground water dominated, or surface flow dominated. Wetlands on local topographic heights are often precipitation dominated. Precipitation dominated wetlands may also be in flat or slightly elevated areas in the landscape, where they receive little or no surface runoff. Generally such wetlands have a clay and peat layer that retains the precipitation and also prevents discharge from ground water. Wetlands also form in landscape positions at which the water table actively discharges, particularly at the base of hills and in valleys. Such groundwater dominated wetlands may also receive overland flow but they have a steady supply of water from and to groundwater. Most wetlands in low points on the landscape or within other water resources are dominated by overland flow. Such riverine, fringe (marsh), and tidal wetlands actively play a role in the landscape since they come in contact with, store, or release large quantities of water and act upon sediments and nutrients. These wetlands may be recharged by ground water as well, but surface water provides the major source of water.



Discharge-recharge interchanges between wetlands and groundwater systems including: a. marsh as a depression receiving groundwater flow, a ‘discharge’ wetland. b. groundwater spring or seep wetland or groundwater slope wetland at the base of a steep slope. c. floodplain wetland fed by groundwater. d. marsh as a ‘recharge wetland’ adding water to groundwater. e. perched wetland or surface water depressin wetland. f. groundwater flow through a tidal wetland (Mitsch and Gosselink, 2000).

Soil saturation and fiber content

Soil saturation and fiber content are important factors in determining the capacity of a wetland in retaining water. Like a sponge, as the pore spaces in wetland soil and peat become saturated by water, they are able to hold less additional water and are also able to release the water more easily. Clay soils retain more water than loam or sand, and hold the water particles more tightly through capillary action since pore spaces are small and the water particles are attracted to the negatively charged clay. Pore spaces between sand particles are large and water drains more freely since less of the water in the pore is close enough to be attracted to the soil particle.

Water drains more freely from the least decomposed (fibric) peat because pore spaces are large and the surface area for capillary action is small. Sapric peat (most decomposed, fibers unrecognizable) and hemic peat (intermediate) have very small pores. Water moves very slowly in such peats. Water in wetlands, as a result, flows over the surface or close to the surface in the fibric layer and root zone (acrotelm) (Boelter and Verry 1977). Thus wetlands with sapric peat and clay substrate will store water but will have no ground water discharge (inflow) or outflow (recharge).

Vegetation density and type

Stems cause friction for the flow of the water, thus reducing water velocity. As density of vegetation increases, velocity decreases. Plants that are sturdy, such as shrubs and trees are more important in this function than grasses.

During the growing season, plants actively take up water and release it to the atmosphere through evapotranspiration. This process reduces the amount of water in wetland soil and increases the capacity for absorption of additional precipitation or surface water flow. As a result, water levels and outflow from the wetland are less than when plants are dormant. Larger plants and plants with more surface area will transpire more.

Ground water recharge

Wetlands help maintain the level of the water table and exert control on the hydraulic head (O'Brien 1988; Winter 1988). This provides force for ground water recharge and discharge to other waters as well. The extent of ground water recharge by a wetland is dependent upon soil, vegetation, site, perimeter to volume ratio, and water table gradient (Carter and Novitzki 1988; Weller 1981). Ground water recharge occurs through mineral soils found primarily around the edges of wetlands (Verry and Timmons 1982) The soil under most wetlands is relatively impermeable. A high perimeter to volume ratio, such as in small wetlands, means that the surface area through which water can infiltrate into the ground water is high (Weller 1981). Ground water recharge is typical in small wetlands such as prairie potholes, which can contribute significantly to recharge of regional ground water resources (Weller 1981). Researchers have discovered ground water recharge of up to 20% of wetland volume per season (Weller 1981).

Climate control

Climate control is another hydrologic function of wetlands. Many wetlands return over two-thirds of their annual water inputs to the atmosphere through evapotranspiration (Richardson and McCarthy 1994). Wetlands may also act to moderate temperature extremes in adjacent uplands (Brinson 1993).

Oxidation-Reduction

The fluctuating water levels (also known as hydrologic flux) that are characteristic of wetlands control the oxidation-reduction (redox) conditions that occur. These redox conditions governed by hydroperiod play a key role in: nutrient cycling, availability, and export; pH; vegetation composition; sediment and organic matter accumulation; decomposition and export; and metal availability and export.

When wetland soil is dry, microbial and chemical processes occur using oxygen as the electron acceptor. When wetland soil is saturated with water, microbial respiration and biological and chemical reactions consume available oxygen. This shifts the soil from an aerobic to an anaerobic, or reduced, condition. As conditions become increasingly reduced, other electron acceptors than oxygen must be used for reactions. These acceptors are, in order of microbial preference, nitrate, ferric iron, manganese, sulfate, and organic compounds.

Wetland plants are adapted to changing redox conditions. Wetland plants often contain arenchymous tissue (spongy tissue with large pores) in their stems and roots that allows air to move quickly between the leaf surface and the roots. Oxygen released from wetland plant roots oxidizes the rhizosphere (root zone) and allows processes requiring oxygen, such as organic compound breakdown, decomposition, and denitrification, to occur (Steinberg and Coonrod 1994).

Hydrologic flux and life support

Changes in frequency, duration, and timing of hydroperiod may impact spawning, migration, species composition, and food chain support of the wetland and associated downstream systems (Crance 1988). Normal hydrologic flux allows exchange of nutrients, detritus, and passage of aquatic life between systems.

Values of wetlands as a result of the functions of hydrologic flux and storage include: water quality, water supply, flood control, erosion control, wildlife support , recreation, culture, and commercial benefits.

Biogeochemical Cycling and Storage

Wetlands may be a sink for, or transform, nutrients, organic compounds, metals, and components of organic matter. Wetlands may also act as filters of sediments and organic matter. A wetland may be a permanent sink for these substances if the compounds become buried in the substrate or are released into the atmosphere; or a wetland may retain them only during the growing season or under flooded conditions. Wetland processes play a role in the global cycles of carbon, nitrogen, and sulfur by transforming them and releasing them into the atmosphere.

The values of wetland functions related to biogeochemical cycling and storage include: water quality and erosion control.

Nitrogen (N)

The biological and chemical process of nitrification/denitrification in the nitrogen cycle transforms the majority of nitrogen entering wetlands, causing between 70% and 90% to be removed (Reilly 1991; Gilliam 1994).

In aerobic substrates, organic nitrogen may mineralize to ammonium, which plants and microbes can utilize, adsorb to negatively charged particles (e.g., clay), or diffuse to the surface. As ammonia diffuses to the surface, the bacteria Nitrosomonas can oxidize it to nitrite. The bacteria Nitrobacter oxidizes nitrite to nitrate. This process is called nitrification. Plants or microorganisms can assimilate nitrate, or anaerobic bacteria may reduce nitrate (denitrification) to gaseous nitrogen (N_2) when nitrate diffuses into anoxic (oxygen depleted) water. The gaseous nitrogen volatilizes and the nitrogen is eliminated as a water pollutant. Thus, the alternating reduced and oxidized conditions of wetlands complete the needs of the nitrogen cycle and maximize denitrification rates (Johnston 1991).

See the section on Nitrogen in the Water Quality and Land Treatment Information section for an in-depth discussion of this compound and the nitrogen cycle.

Phosphorus (P)

Phosphorus can enter wetlands with suspended solids or as dissolved phosphorus. Significant quantities of phosphorus associated with sediments are deposited in wetlands (Walbridge and Struthers 1993). Phosphorus removal from water in wetlands occurs through use of phosphorus by plants and soil microbes; adsorption by aluminum and iron oxides and hydroxides; precipitation of aluminum, iron, and calcium phosphates; and burial of phosphorus adsorbed to sediments or organic matter (Richardson 1985; Johnston 1991; Walbridge and Struthers 1993). Wetland soils can, however, reach a state of phosphorus saturation, after which phosphorus may be released from the system (Richardson 1985). Phosphorus export from wetlands is seasonal, occurring in late summer, early fall, and winter as organic matter decomposes and phosphorus is released into surface water.

Dissolved phosphorus is processed by wetland soil microorganisms, plants, and geochemical mechanisms. (Walbridge and Struthers 1993) Microbial removal of phosphorus from wetland soil or water is rapid and highly efficient, however, following cell death, the phosphorus is released again. Similarly, for plants, litter decomposition causes a release of phosphorus. Burial of litter in peat can, however, provide long term removal of phosphorus. Harvesting of plant biomass is needed to maximize biotic phosphorus removal from the wetland system.

The potential for long-term storage of phosphorus through adsorption to wetland soil is greater than the maximum rates of phosphorus accumulation possible in plant biomass (Walbridge and Struthers 1988; Johnston 1991). In alkaline wetlands, such as found in the West, phosphorus precipitates with calcium as calcium phosphate (Novotony and Olem 1994; Walbridge and Struthers 1988). However, the presence of aluminum is the significant predictor of dissolved phosphorus sorption and removal from water in most wetland systems (Richardson 1985; Gale et al. 1994; Walbridge and Struthers 1993). The capacity for phosphorus adsorption by a wetland, however, can be saturated in a few years if it has low amounts of aluminum and iron or calcium (Richardson 1985).

Wetlands along rivers have a high capacity for phosphorus adsorption because as clay is deposited in the floodplain, aluminum (Al) and iron (Fe) in the clay accumulate as well (Gambrell 1994). Thus floodplains tend to be important sites for phosphorus removal from the water column, beyond that removed as sediments are deposited (Walbridge and Struthers 1993).

See the section on Phosphorus in the Water Quality and Land Treatment Information section for an in-depth discussion of this compound.

Carbon

Wetlands store carbon within peat and soil. Storing carbon is an important function within the carbon cycle, particularly given observations of increasing levels of carbon dioxide in the atmosphere and concerns about global warming. When wetlands are drained, the oxidizing conditions increase organic matter decomposition, thus increasing the release of carbon dioxide. When wetlands are preserved or restored, the wetlands act as a sink for carbon since organic matter decomposition is stable or slowed.

Sulfur (S)

Wetlands are capable of reducing sulfate to sulfide. Sulfide is released to the atmosphere as hydrogen, methyl, and dimethyl sulfides or is bound in insoluble complexes with phosphate and metal ions in wetland sediments (Mitsch and Gosselink 1993). Dim ethyl sulfide released from wetlands may act as a seed for cloud formation (Hader et al. 1991). Sulfate may exist in soils or may enter wetlands through tidal flow or atmospheric deposition.

Suspended solids

Wetlands filter suspended solids from water that comes into contact with wetland vegetation. Stems and leaves provide friction for the flow of the water, thus allowing settling of suspended solids and removal of related pollutants from the water column (Johnston 1991). Wetlands may retain sediment in the peat or as substrate permanently (Johnston 1991). Sediment deposition is variable across individual wetlands and wetland types, as deposition depends upon the rate and type of water flow (channelized or sheet flow), particulate size, and vegetated area of the wetland (Aust et al. 1991;Johnston 1991; Crance 1988; USEPA 1993c; Hemond and Benoit 1988).

Metals

All soils contain at least a low concentration of metals but in some locations human activities have resulted in metal levels high enough to cause health or ecological risks in water resources. Metals may exist in wetland soils or enter wetlands through surface or ground water flow.

Wetlands can remove metals from surface and ground water as a result of the presence of clays, humic materials (peats), aluminum, iron, and/or calcium (Gambrell 1994). Metals entering wetlands bind to the negatively ionized surface of clay particles, precipitate as inorganic compounds (includes metal oxides, hydroxides, and carbonates controlled by system pH), complex with humic materials, and adsorb or occlude to precipitated hydrous oxides. Iron hydroxides are particularly important in retaining metals in salt marshes. Wetlands remove more metals from slow flowing water since there is more time for chemical processes to occur before the water moves out of the wetland. Burial in the wetland substrate will keep bound metals immobilized. Neutral pH favors metal immobilization in wetlands (Gambrell 1994). With the exception of very low pH peat bogs, as oxidized wetland soils are flooded and reduced, pH converges toward neutrality (6.5 to 7.5) whether the wetland soils were originally acidic or alkaline (Ponnamperuna 1972).

See the Heavy Metal section for more general information on metals.

Biological Productivity

Wetlands are among the most productive ecosystems in the world (Mitsch and Gosselink 1993). Immense varieties of species of microbes, plants, insects, amphibians, reptiles, birds, fish, and other wildlife depend in some way on wetlands. Wetlands with seasonal hydrologic pulsing are the most productive.

Wetland plants play an integral role in the ecology of the watershed. Wetland plants provide breeding and nursery sites, resting areas for migratory species, and refuge from predators (Crance 1988). Decomposed plant matter (detritus) released into the water is important food for many invertebrates and fish both in the wetland and in associated aquatic systems (Crance 1988). Physical and chemical characteristics such as climate, topography, geology, hydrology, and inputs of nutrients and sediments determine the rate of plant growth and reproduction (primary productivity) of wetlands (Brinson 1993; Mitsch and Gosselink 1993; Weller 1981; Crance 1988).

A wetland with more vegetation will intercept more runoff and be more capable of reducing runoff velocity and removing pollutants from the water than a wetland with less vegetation (Demissie and Khan 1993; Richardson and McCarthy 1994; NC DEM 1993). Wetland plants also reduce erosion as their roots hold the streambank, shoreline, or coastline.

Values associated with biological productivity of wetlands include: water quality, flood control, erosion control, community structure and wildlife support, recreation, aesthetics, and commercial benefits.

Decomposition

Decomposition rates vary across wetland types, particularly as a function of climate, vegetation types, available carbon and nitrogen, and pH (Johnston 1991).

A pH above 5.0 is necessary for bacterial growth and survival (Richardson 1995). Liming, to increase pH, accelerates decomposition, causing the release of carbon dioxide from wetlands and land subsidence (Richardson 1995).

The nutrients and compounds released from decomposing organic matter may be exported from the wetland in soluble or particulate form, incorporated into the soil, or eventually transformed and released to the atmosphere. Decomposed matter (detritus) forms the base of the aquatic and terrestrial food web.

Decomposition requires oxygen and thus reduces the dissolved oxygen content of the water. High rates of decomposition -- such as occur after algae has bloomed -- can reduce water quality and impair aquatic life support. For more information on low dissolved oxygen see DO.

Community structure and wildlife support

The inundated or saturated conditions occurring in wetlands limit plant species composition to those that can tolerate such conditions. Beaver, muskrat and alligators create or manipulate their own wetland habitat that other organisms, such as fish, amphibians, waterfowl, insects, and mammals can then use or inhabit (Weller 1981; Mitsch and Gosselink 1993).

Wetland shape and size affect the wildlife community and the wetland's function as suitable habitat (Kent 1994b; Brinson 1993; Harris 1988). The shape of the wetland varies the perimeter to area ratio. The amount of perimeter versus area has importance for the success of interior and edge species (Kent 1994b). Shape is also important for the possibility of movement of animals within the habitat and between habitats. Wetland size is particularly important for larger and wide ranging animals that utilize wetlands for food and refuge, such as black bear or moose, since in many locations wetlands may be the only undeveloped and undisturbed areas remaining.

Values associated with community structure and wildlife support in wetlands include: fish and wildlife support, recreation, aesthetics, and commercial benefits.

<u>Values</u>

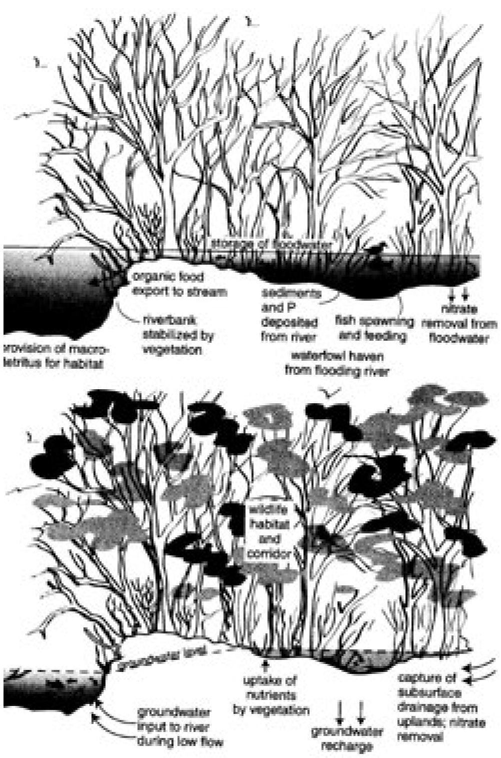


Illustration of several of the potential wetland values for

riparian wetlands during a. flood season b. dry season
(Mitsch and Gosselink, 2000).

Water Quality

Wetlands help maintain and improve the water quality of our nation's streams, rivers, lakes, and estuaries. Since wetlands are located between uplands and water resources, many can intercept runoff from the land before it reaches open water. As runoff and surface water pass through, wetlands remove or transform pollutants through physical, chemical, and biological processes. For example, the Congaree Bottomland Hardwood Swamp in South Carolina removes a quantity of pollutants from watershed water resources equivalent to that which would be removed by a $5 million water treatment plant (USEPA 1995). In another case, scientists estimate that a 2,500 acre wetland in Georgia saves $1 million in water pollution control costs annually (OTA 1993).

Nutrient Removal

Scientists have estimated that wetlands may remove between 70% and 90% of entering nitrogen (Reilly 1991; Gilliam 1994). Riparian forests can reduce nitrogen concentrations in runoff and floodwater by up to 90% and phosphate concentrations by 50% (Gilliam 1994). The estimated mean retention of phosphorus by wetlands is 45% (Johnston 1991). Wetlands with high soil concentrations of aluminum may remove up to 80% of total phosphorus (Peterjohn and Correll 1984; Richardson 1985; Gale et al. 1994; Walbridge and Struthers 1993).

Ranchers and watershed managers in the West are utilizing beaver-created wetlands to improve water quality (USEPA 1993b; SCS 1989). Beaver impoundments can be extremely useful in agricultural watersheds because they may retain up to 1000 times more nitrogen than streams that are not impounded (Whigham et al. 1988).

Removal of Biological Oxygen Demand from Surface Water

Biological oxygen demand (BOD) is a measure of the oxygen required for the decomposition of organic matter and oxidation of inorganics such as sulfide. BOD is introduced into surface water through inputs of organic matter such as sewage effluent, surface runoff, and natural biotic processes. If BOD is high, low dissolved oxygen levels result. Low dissolved oxygen

levels can lead to mortality of aquatic life. Wetlands remove BOD from surface water through decomposition of organic matter or oxidation of inorganics (Hemond and Benoit 1988). BOD removal by wetlands may approach 100% (Hemond and Benoit 1988).

Removal of Suspended Solids and Associated Pollutants from Surface Water

Suspended solids (such as sediment and organic matter) may enter wetlands in runoff, as particulate litterfall, or with inflow from associated water bodies. Sediment deposition in wetlands depends upon water velocity, flooding regimes, vegetated area of the wetland, and water retention time (Gilliam 1994; Johnston 1991). Sediment deposition in wetlands prevents a source of turbidity from entering downstream ecosystems. Typically wetland vegetation traps 80-90% of sediment from runoff (Gilliam 1994; Johnston 1991). Less than 65% of the sediment eroded from uplands exits watersheds that contain wetlands (Johnston 1991).

Other pollutants that impact water quality such as nutrients, organics, metals and radionuclides are often adsorbed onto suspended solids. Deposition of suspended solids, to which such substances are adsorbed, removes these pollutants from the water. Thus sediment deposition provides multiple benefits to downstream water quality (Johnston 1991; Hemond and Benoit 1988; Hupp et al. 1993; Puckett et al. 1993).

Removal of Metals

Certain wetlands play an important role in removing metals from other water resources, runoff, and ground water (Owen 1992; Gambrell 1994; Puckett et al. 1993). Wetlands remove 20% - 100% of metals in the water, depending on the specific metal and the individual wetland (Taylor et al. 1990). Forested wetlands play a critical role in removing metals downstream of urbanized areas (Hupp et al. 1993).

Delfino and Odum (1993) found that lead leaking from a Florida hazardous waste site was retained at high levels by a wetland; less than 20 - 25% of the total lead in the soil and sediments was readily bioavailable. The majority of the lead was bound to soil and sediments through adsorption, chelation, and precipitation. Bioavailable lead was absorbed primarily by eel grass, which had bioaccumulated the majority of the lead. In another case, researchers found that wetland vegetation and organic (muck) substrate retained 98% of lead entering the wetland (Gambrell 1994).

Removal of Pathogens

Fecal coliform bacteria and protozoans, which are indicators of threats to human health, enter wetlands through municipal sewage, urban stormwater, leaking septic tanks, and agricultural runoff. Bacteria attach to suspended solids that are then trapped by wetland vegetation (Hemond and Benoit 1988). These organisms die: after remaining outside their host organisms, through degradation by sunlight, from the low pH of wetlands, by protozoan consumption, and from toxins excreted from the roots of some wetland plants (Hemond and Benoit 1988; Kennish 1992). In this way wetlands have an important role in removing pathogens from surface water.

Water Supply

Wetlands act as reservoirs for the watershed. Wetlands release the water they retain (from precipitation, surface water, and ground water) into associated surface water and ground water. In Wisconsin watersheds composed of 40% lakes and wetlands, spring stream outflows from the watersheds were 140% of those in watersheds without any wetlands or lakes (Mitsch and Gosselink 1993). Forested wetlands, kettle lakes and prairie potholes have significant water storage and ground water recharge (Brown and Sullivan 1988; Weller 1981). Forested wetlands overlying permeable soil may release up to 100,000 gallons/acre/day into the ground water (Anderson and Rockel 1991). Verry and Timmons (1982) studied a Minnesota bog which released 55% of the entering water to stream and ground water.

Ground water can be adversely affected by activities that alter wetland hydrology (Winter 1988). Drainage of wetlands lowers the water table and reduces the hydraulic head providing the force for ground water discharge (O'Brien 1988; Winter 1988). If a recharge wetland is drained, the water resources into which ground water discharges will receive less inflow, potentially changing the hydrology of a watershed (Brinson 1993; Winter 1988). Ewel (1990) calculated that if 80 percent of a 5-acre Florida cypress swamp were drained, available ground water would be reduced by an estimated 45 percent.

Flood Protection

Photo courtesy of USDA NRCS

Wetlands help protect adjacent and downstream properties from potential flood damage. The value of flood control by wetlands increases with: (1) wetland area, (2) proximity of the wetland to flood waters, (3) location of the wetland (along a river, lake, or stream), (4) amount of flooding that would occur without the presence of the wetlands, and, (5) lack of other upstream storage areas such as ponds, lakes, and reservoirs (Mitsch and Gosselink 1993). The cost of replacing the flood control function of the 5,000 acres of wetlands drained each year in Minnesota was determined to be $1.5 million (USEPA 1995).

Wetlands within and upstream of urban areas are particularly valuable for flood protection. The impervious surface in urban areas greatly increases the rate and volume of runoff, thereby increasing the risk of flood damage. The drainage of wetlands, the diversion of the Mississippi and Missouri Rivers from their original floodplains, and the development allowed in the floodplains over the past 100 years were partly responsible for the billions of dollars in damage to businesses, homes, crops, and property that occurred as a result of the Midwest flood of 1993 (OEP 1993).

Erosion Control

Photo courtesy of USDA NRCS

By virtue of their place in the landscape, riparian wetlands, salt marshes, and marshes located at the margin of lakes protect shorelines and streambanks against erosion. Wetland plants hold the soil in place with their roots, absorb wave energy, and reduce the velocity of stream or river currents. Coastal wetlands buffer shorelines against the wave action produced by hurricanes and tropical storms (Mitsch and Gosselink 1993). The ability of wetlands to control erosion is so valuable that states and landowners are restoring wetlands to control shoreline erosion in coastal areas (Lewis 1990).

Fish and Wildlife Habitat

Photo courtesy of
US Army Corps of Engineers

Photo courtesy of
US Army Corps of Engineers

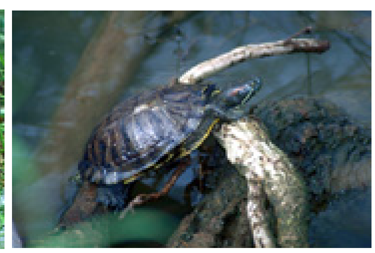


Photo courtesy of
US Army Corps of Engineers

Diverse species of plants, insects, amphibians, reptiles, birds, fish, and mammals depend on wetlands for food, habitat, or temporary shelter. Although wetlands make up only about 3.5 percent of U.S. land area, more than one-third of the United States' threatened and endangered species live only in wetlands (Mitsch and Gosselink 1993). An additional 20% of the United States' threatened and endangered species use or inhabit wetlands at some time in their life.

Coastal and estuarine wetlands provide food and habitat for estuarine and marine fish and shellfish, bird species, and some mammals (NOAA 1990a; NOAA 1990b). Most commercial and game fish breed, and their young develop, in coastal marshes and estuaries. Menhaden, flounder, salmon, sea trout, and striped bass are among the more familiar fish that depend on estuaries during their life cycles. Shrimp, oyster, clams, and blue and Dungeness crabs likewise rely on coastal wetlands and estuaries for food and habitat.

Many of America's bird species utilize wetlands as sources of food, water, nesting material, or shelter. Migratory waterbirds rely on wetlands for staging areas, resting, feeding, breeding, or nesting grounds.

Recreation, Aesthetics, Culture, and Science

Photo courtesy of
US Army Corps of Engineers

Wetlands have archeological, historical, cultural, recreational, and scientific values. Societies have traditionally formed along bodies of water and artifacts found in wetlands provide information about these societies. The culture of the Louisiana bayou and the Chesapeake Bay formed as a result of their wetland ecosystems.

Historically, painters and writers have used wetlands as their subject matter. Today, such artists are often joined by others with cameras and camcorders. The monetary value derived from the observation and photography of wetland-dependent birds by more than 50 million Americans is at least $10 billion per year (USEPA 1994b).

More than half of all U.S. adults hunt, fish, birdwatch or photograph wildlife, spending a total of $59.5 billion annually (USEPA 1995). Waterfowl hunters spend over $630 million annually to harvest wetland-dependent birds (OTA 1993). Coastal areas alone attract at least 100 million Americans annually (NOAA 1995a). The coastal wetlands-dependent recreational fishing of 17 million Americans generates at least $18 billion in economic activity annually (NOAA 1995a).

Scientists value the processes of wetlands individually, particularly the role of wetlands in the global cycles of carbon, nitrogen, and water. Many scientists consider the removal of carbon dioxide from the atmosphere into plant matter and its burial as peat (sequestration) the most valuable function of wetlands (OTA 1993). Carbon sequestration is thought to be an important process in reducing the greenhouse effect and the threat of global warming.

Commercial Benefits

Commercially important products harvested from wetlands include fish, shellfish, cranberries, timber, and wild rice, as well as some medicines derived from wetland soils and plants. Fish and shellfish species dependent on wetlands for food or habitat comprise more than 75% of the commercial and 90% of the recreational harvest (USEPA 1994b; Feierabend and Zelazny 1987). Seafood is a $50 billion industry (NOAA 1995a). In the Southeast, fish and shellfish that depend on coastal and estuarine wetlands comprise nearly all of the commercial catch (USEPA 1994b). Louisiana's coastal marshes alone produce an annual commercial fish and shellfish harvest amounting to 1.2 billion pounds, worth $244 million in 1991 (USEPA 1995). The U.S. commercial fisheries harvest is valued at more than $2 billion annually and is the basis for a $26.8 billion fishery processing and sales industry (USEPA 1995).

Many mammals and reptiles harvested for their skins, including muskrat, beaver, mink, otter, and alligator, require wetland habitats. The nation's harvest of muskrat pelts alone is worth over $70 million annually, while the alligator industry is valued at $16 million (Mitsch and Gosselink 1993; OTA 1993).

Wetlands containing timber comprise approximately 55 million acres (22 million hectares), with two-thirds of the acreage east of the Rocky Mountains (Mitsch and Gosselink 1993). Although historically the practice has been to clear-cut and drain the forests of the bottomland hardwood swamps, with proper management, the timber industry can harvest wetland timber with minimal adverse effect (Conner 1994; Shepard 1994). In addition, replicating wetland conditions may improve production of desired flood-tolerant pine and hardwood species by preventing competition by non-wetland species (Conner 1994).

Examples of Functions and Values of Wetlands

Functions Specific examples Examples of Values

Hydrology

Aquifer recharge/discharge Water quality/quantity,
Water storage and regulation Flood control
Climate control

Biogeochemical cycling and storage

Nutrient source/transformer/sink Water quality,
Sediment and organic matter sink Erosion control

Bioproductivity and decomposition

Net primary productivity Food chain support,
Carbon storage/release Water quality,
Detritus output for aquatic organisms Recreation,
Mineralization and release of N,S,C,P Commercial products

Ecosystem Processes

Habitat for species Recreation/Aesthetics,
Food chain support Commercial products,
Maintenance of biotic diversity Water quality/quantity

IV. Importance of Wetland Type: Watershed Roles

Introduction

This section focuses on wetlands as water resources within a watershed and, specifically, how they are both a product of and an influence on watershed hydrology and water quality. One useful way to categorize wetlands, for those interested in water quality management and watershed management, is by dominant water source. Wetlands may be precipitation dominated, surface flow dominated, or ground water dominated (Brinson 1993).

Wetlands may have different functions as a result of their position in the landscape and their dominant water source. Although all wetlands receive precipitation, precipitation events serve as the sole source of water for some wetlands. Precipitation-dominated wetlands may supply water to headwater streams and ground water by infiltration.

Riparian wetlands, marshes, and tidal wetlands, which are dominated by surface flow, may remove, store, or release water, nutrients, and sediments.

Mangrove wetlands are not included in this discussion because they are marine or estuarine systems that have little significant function in watershed freshwater dynamics. They do, however, provide aquatic life support similar to that of a tidal salt marsh (described below).

The terms used below for types of wetlands are commonly recognized terms in the United states and are typically used in the wetlands literature.

Precipitation Dominated Wetlands

Bogs

Bogs are waterlogged peatlands in old lake basins or depressions in the landscape, forming where peat accumulation exceeds decomposition as a result of climatic conditions. Bogs in the lower 48 states are found largely in the glaciated northeast, Wisconsin, Minnesota, and Michigan; in the southeast (pocosins and Carolina bays); and on mountains (Mitsch and Gosselink 1993). Bogs are precipitation dominated because the accumulated peat formations elevate the system surfaces sufficiently relative to the surrounding landscape that there are few or no surface inflows. Since bogs do not receive nutrients or organic matter transported by surface water, they have low rates of primary productivity and decomposition.

Bogs are typically acidic because the dominant living plant matter, Sphagnum moss, releases H+ ions (acidity), and the peat releases organic acids (Mitsch and Gosselink 1993). The pH in bogs can be as low as 3.0 - 4.0 (Camp, Dresser, and McKee 1981). Bogs have specialized and unique flora that has evolved in their nutrient-poor and acidic conditions. An example of this unique flora is the carnivorous pitcher plant, which obtains nutrients from the flies it traps.

Values related to watershed management

Bogs generally have no significant inflows or outflows (Mitsch and Gosselink 1993). Some bogs, however, may act as headwaters, supplying water to downstream reaches; recharge ground water; and maintain the hydraulic pressure of the water table (Brinson 1993).

The role wetlands play in ground water recharge depends in large part on substrate permeability. A characteristic of bogs is a fairly impermeable layer of peat; thus, most bogs do not recharge ground water. If the edges of a bog do consist of permeable soil, recharge into the ground water can occur. One Minnesota bog converts 55% of water input to water yield (stream and ground water), while the adjacent upland hardwood forest converts only 34% (Verry and Timmons 1982).

Life support

Bogs do not support large populations of animals because productivity is low and the water can be quite acidic. However, bogs provide important habitat for such species as moose, deer, black bear, beaver, lynx, fishers, snowshoe hare, otter, and mink, either because bogs occur in remote areas due to the climate or altitude, or because they are not suitable for agriculture, forestry, or development (Mitsch and Gosselink 1993). As the land use in surrounding areas changes, wildlife species are driven to these relatively undisturbed habitats.

Migratory birds use bogs on their flight paths. From warblers to wood ducks, many bird species breed, nest, and feed in bog habitats. The greater sandhill crane, great gray owl, short eared owl, sora rail, and sharp-tailed sparrow depend completely on bogs and fens for survival (Mitsch and Gosselink 1993). Bogs with a pH greater than 4.5 may provide habitat for game fish species such as pike, walleye, bluegill, and smallmouth bass (Camp, Dresser, and McKee 1981; Novotony and Olem 1995).

Pocosins

Pocosins are evergreen shrub bogs found on the Coastal Plain of the southeastern United States, with an estimated 70% occurring in North Carolina. Typically, pocosins are found on high areas of a flat, "water-logged, acidic, nutrient-poor landscape" (the name means swamp on a hill) (Richardson 1991). Pocosins retain rainfall for long periods of time, releasing water slowly through sheet flow. Thus, they may remove nutrients and other compounds from atmospheric deposition. Because of their slightly raised position on the landscape, their contribution to surface water quality improvement is generally limited to situations where the landscape has been modified to permit surface water inflow (for example, pine plantation ditches) (Richardson 1991). Pocosins producing sustained discharges that provide an important contribution to surface water supplies moderate water flow from storm events in the southeastern Coastal Plain. They also provide an important contribution to the global water cycle through evapotranspiration (Richardson and Gibbons 1993; Richardson and McCarthy 1994).

Vernal Pools, Playas, Prairie Potholes, Wet Meadows, and Wet Prairies

These five types of wetlands are often categorized as marshes, but their dependence on precipitation rather than surface water inputs is important enough to distinguish them from typical surface water dominated marshes.

Vernal (spring) pools are small, shallow, intermittently flooded depressions in grasslands or forests, and are usually wet only in the winter and early spring. Vernal pools are found wherever precipitation in the winter and early spring exceeds evapotranspiration and soil infiltration rates.

Photo courtesy of USDA NRCS

Playas are marshlike ponds found in the arid Southern Great Plains of Texas, New Mexico, Kansas, Oklahoma, and Colorado. Prairie potholes are marshlike ponds that have formed in shallow basins caused by glaciation in the Dakotas, Iowa, and the Canadian prairies. Both playas and prairie potholes receive runoff from surrounding land uses because of their depressional nature. However, water levels fluctuate seasonally as a result of dependence on precipitation, and these two wetland types may be periodically dry for up to several years.

Photo courtesy of USDA NRCS

Two other wetland types, wet meadows and wet prairies, derive a significant amount of their water supply from precipitation. Wet meadows are grasslands with soil that is waterlogged after precipitation events. Wet prairies are hydrologically intermediate between marshes and wet meadows: standing water occurs for a shorter duration and frequency than in marshes. Wet prairies may receive water from intermittent streams as well as from ground water and precipitation.

Wet meadows and prairies are often categorized as marshes because their vegetative communities are similar to those of marshes. However, they are drier than most marshes and are typically found in lower areas on flat landscapes, surrounded by upland meadows or prairie grasses. These systems may also exist as broad transition zones surrounding or leading downgradient to deeper marshes. Because wet meadows and wet prairies depend largely on precipitation for water inputs, they are generally dry during the summer.

Values related to watershed management

Because these four wetland types are largely isolated from other surface water resources, they typically contribute little to watershed surface water quality. When they do receive surface water inflow, they function like marshes, removing nutrients and other pollutants (Mitsch and Gosselink 1993; Rickerl et al. 1993).

Prairie potholes, wet meadows, and wet prairies generally contribute to ground water recharge (Weller 1981; Mitsch and Gosselink 1993). Potholes also appear to provide water quality improvement values for agricultural runoff (Jacobsen 1994).

Life support

Vernal pools are critical habitats for the life cycles of some animals, including certain amphibians, which rely on them exclusively. The playas of the Southern Great Plains provide refuge to several million migrating ducks, geese, shorebirds, and wading birds each year, as well as habitat for mammals, amphibians, and reptiles. Playas are particularly critical wetland habitat in the intensively farmed, dry plains of New Mexico and Texas (Ducks Unlimited 1991). The Southern Great Plains area is within the migratory corridor known as the Central Flyway; the birds rely on playas for staging, resting, and breeding areas. The prairie potholes form the northern staging, resting, and breeding part of the Central Flyway. An estimated 50 to 75 percent of all the waterfowl in North America are hatched in the prairie potholes (Mitsch and Gosselink 1993).

Ground Water Dominated Wetlands

Fens

Fens are peat-accumulating wetlands that form at low points in the landscape or near slopes where ground water intercepts the soil surface (Mitsch and Gosselink 1993). Water levels are fairly constant all year because the water supply is provided by ground water inputs. Fens, like bogs, tend to be glacial in origin and are found in the northern United States or on mountains and mountainsides. Fens are dominated by herbaceous plants, such as grasses and sedges, typically lack the Sphagnum moss that predominates in bogs, and look like meadows.

Fens may represent an earlier successional stage of peat accumulation than bogs, and over geologic time, fens may become bogs. Unlike bogs, fens receive minerals and nutrients from ground water, because they have built up less peat and ground water is still sufficiently close to the surface. Fens are less acidic than bogs because they have little or no Sphagnum, and because ground water inputs tend to be neutral or alkaline. The pH of fens ranges from 4.0 - 8.0, depending on vegetation and peat type (Camp, Dresser, and McKee 1981). Fens provide less stressful growing conditions for plants and microbes and thus have higher primary productivity and a greater variety of flora and fauna than bogs.

Fens may depend on aquifers that are recharged in uplands. These upland recharge areas may be distant from the wetlands (Brinson 1993). Thus, excessive withdrawal or interception of ground water for municipal and agricultural uses, and reduced urban ground water recharge as a result of increased impervious surfaces can decrease water supply to fens, potentially leading to degradation of these wetland communities (USEPA 1993b).

Values related to watershed management

In addition to their ground water inputs and precipitation, fens may receive runoff and other surface water. They tend to contribute more to downgradient surface water supplies than do bogs because of additional ground and surface water inputs to fens. Fens may help maintain surrounding water tables, exerting influence on the recharge and discharge of local aquifers and thus on the hydrology of other water resources (O'Brien 1988).

Life support

Fens, like bogs, support a great diversity of wildlife species in relatively limited quantities. Like bogs, they are increasingly important habitat for moose, deer, black bear, beaver, lynx, fishers, snowshoe hare, otter, and mink because of development elsewhere (Mitsch and Gosselink 1993). Because fens are more productive than bogs, they support a greater variety of small mammals and are host to greater numbers of their predators. Many bird species (including migratory birds) breed, nest, feed, and find refuge in fens. The greater sandhill crane, great gray owl, short eared owl, sora rail, and sharp-tailed sparrow depend on fens and bogs for survival. Fens provide habitat for more fish species than bogs because fens may have inflow and outflow streams. Species such as pike, walleye, bluegill, smallmouth bass, brook trout, brown trout, and killifish may inhabit fens or streams fed by fens (Camp, Dresser, and McKee 1981). One third of fish taxa in the deserts of the southwestern United States are completely dependent on ground water-fed wetlands and downstream riparian marshes (cienegas) (Meffe, 1989).

Surface Water Dominated Wetlands

Marshes (freshwater)

Photo courtesy of USDA NRCS

Marshes are one of the broadest categories of wetlands and in general harbor the greatest biological diversity. They are characterized by shallow water, little or no peat deposition, and mineral soils. Marshes are dominated by floating-leafed plants (such as water lilies and duckweed) or emergent soft-stemmed aquatic plants (such as cattails, arrowheads, reeds, and sedges). Marshes form in depressions in the landscape, as fringes around lakes, and along slow-flowing streams and rivers (such riparian marshes are also referred to as sloughs). Marshes are frequently or continually inundated with water (Mitsch and Gosselink 1993). Marshes derive most of their water from surface water, including streams, runoff, and overbank flooding; however, they receive inputs from ground water as well (Mitsch and Gosselink 1993; Brinson 1993). Environmental conditions in marshes lead to high productivity since the pH of most marshes is generally circumneutral and nutrients derived from runoff are plentiful (Mitsch and Gosselink 1993).

Values related to watershed management

Water supply: Marshes may recharge ground water, depending on soil permeability and wetland size. As noted in the Functions section, ground water recharge is related to the perimeter: volume ratio and soil permeability. The frequent lack of a perched water table resulting from peat accumulation and compression allows marshes to recharge more ground water than a peat-accumulating wetland such as a fen or a pocosin. Recharge is relatively plentiful in marshes, and may contribute significantly (up to 20% of volume) to regional ground water supplies (Weller 1981; O'Brien 1988).

Marshes may help reduce local peak and flood flows and moderate stream flow (Demissie and Khan 1993; Mitsch and Gosselink 1993; Gosselink et al. 1990).

Water Quality: As a gross estimation, removal of nitrogen from surface water by marshes is approximately 50% and phosphorus removal is approximately 10 - 15% of inputs (Mitsch and Gosselink 1993). Marshes slow the flow of water moving through the system and facilitate the settling of suspended solids and pollutants adhering to sediment. As noted in the Functions section, vegetation quantity and type are important factors in determining the ability of a wetland to reduce water velocity. Marsh vegetation utilizes nutrients, and, more importantly, provides attachment surfaces and a carbon source for organisms that assimilate and transform nutrients. Plant roots oxygenate the soil and provide additional microbial habitat, facilitating such processes. The greater the amount of open water present, such as when marshes border lakes, the less water quality improvement functions will dominate, and the more sediment-attached pollutants will remain suspended in the water column (Whigham et al., 1988).

Life support

Mammals, reptiles, amphibians, and birds depend on marshes for food, water, and habitat. Although waterfowl such as ducks and herons are commonly associated with marshes, other birds, such as songbirds and hawks, also feed on the life generated within wetlands.

Marshes with deeper water or riparian marshes that are open to rivers (riverine marshes) and lakes (lacustrine marshes) support more diverse and abundant fish life (Mitsch and Gosselink 1993). The cienegas, or riparian marshes of the Southwest, provide essential habitat for one-third of all fish species in this arid region, and many more depend on these small marshes for habitat (Meffe 1989). Species such as pike, muskellunge, largemouth bass and other sunfish species, gar, and bullhead are a few of the game fish that can be found in marshes (Levine and Willard 1990; Camp, Dresser, and McKee 1981). Shallower marshes without predatory fish such as bass may support diverse fish species and amphibians which would not survive if carnivorous fish were stocked.

Riparian Forested Wetlands

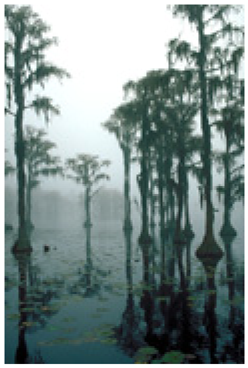


Photo courtesy of
US Army Corps of Engineers

Riparian forested wetlands are dominated by surface water; they are linear systems found along lakes, streams, and rivers from headwaters down to the sea. Riparian forested wetlands are saturated or inundated with water during the winter, when evapotranspiration is low, because plants are dormant and precipitation is high; and during the early part of the growing season, when precipitation and runoff are still abundant. These wetlands are generally not wet in the summer or fall except during flood conditions.

Riparian wetlands do not have particular characteristics of pH or nutrient load, but differ based on inputs, substrate, and vegetation type (Mitsch and Gosselink 1993). However, riparian wetlands are particularly productive ecosystems, receiving large inputs of water and nutrients from upstream sources during flooding. This feature has led to their conversion for agricultural use, a practice that has contributed to water quality degradation.

Southern deepwater swamps are riparian systems notable for the standing water present during much of the year. While they may be traversed by rivers or streams, which provide seasonal water inputs, these systems may also be headwaters. A cypress dome is an anomalous southern deepwater swamp type that is typically precipitation versus surface water, dominated. Cypress domes typically exist as isolated depressions in very gently sloping landscapes.

Other examples of riparian forested wetlands include maple swamps, bottomland hardwood forests, and cottonwood riparian areas.

Values related to watershed management

Riparian systems provide a continuum of water quality benefits. Headwater wetlands are the source of water; the forested wetlands and marshes along low order streams protect water quality and aquatic life; and wetlands along higher order streams provide flood control, water quality maintenance, and life support.

Water supply: Riparian forested wetlands and swamps have a significant water storage and ground water recharge role, and thus are valuable in water supply and flood control (Reilly et al. 1991; Hook et al. 1988; Ewel 1990; Brinson 1993; Demissie and Khan 1993; Brown and Sullivan 1988; Gosselink et al. 1990). The wider the floodplain, the greater the storage action and reduction of flood peaks that can occur. Large floodplains with long retention times can be important ground water recharge areas, depending on substrate permeability (Taylor et al. 1990; O'Brien 1988). A forested wetland overlaying permeable soil may produce 100,000 gallons of water per acre per day (Anderson and Rockel 1991).

Water quality: Riparian wetlands are important sinks for pollutants carried in upland runoff and from upstream areas (Brinson 1993). Riparian wetlands that are adjacent to small streams are particularly valuable in trapping pollutants and preventing nonpoint source pollution from ever reaching larger water resources (Gilliam 1994; Walbridge 1993). Riparian wetlands also serve as valuable transformers of pollutants. They are noted for processing large fluxes of energy and materials from upstream sources, and they typically show high primary productivity, functions that make them important ecological links and valuable habitat.

Examples of the importance of forested wetlands in nutrient removal from water resources:

- A 50-meter wide riparian forest in an agricultural watershed of the Chesapeake Bay removed about 89% of the nitrogen that entered the forest from runoff, ground water, and precipitation (Peterjohn and Correll 1984).
- Riparian forests can reduce phosphate concentrations in runoff and flood water by 50% (Gilliam 1994). Systems with high concentrations of aluminum may remove up to 80% of total phosphorus (Peterjohn and Correll 1984; Richardson 1985; et al. 1994; Walbridge and Struthers 1993).
- Forested wetlands can protect ground water from agricultural runoff. The concentration of nitrate in ground water in an agricultural area was lower beneath forested wetlands than it was beneath upland covers (Phillips et al. 1993).

Life support

Forested riparian wetlands provide cover, spawning, and nursery habitat for numerous fish and shellfish species (Crance 1988). For instance, 90 fish species use the wooded floodplains of the Atchafalaya River in Louisiana. Deepwater swamps can be important refuges for fish during dry periods. In the western United States, healthy fisheries are related to perennial streams with undisturbed riparian wetland zones (Mitsch and Gosselink 1993). Transpiration by coniferous trees maintains a low soil and water temperature that is critical to the survival of cold water fish in streams fed by or within such forested wetlands (Sharitz and Gibbons 1989).

Many animal and bird species depend on riparian forested wetlands for habitat (Mitsch and Gosselink 1993). For example, at least 88 species of birds are completely dependent on western riparian systems. Other bird species use forested wetlands throughout the United States for food and rest during migration, or for breeding and nesting habitat (Mitsch and Gosselink 1993).

Tidal Freshwater Marshes

Photo courtesy of
US Army Corps of Engineers

Tidal freshwater marshes are found upstream of estuaries where the tides still influence water levels, but where the water is predominantly fresh. Tidal freshwater marshes receive substantial water and nutrients from upstream water resources, as well as inputs from runoff and precipitation. High nutrient inputs contribute to the extremely high primary productivity and biodiversity of these systems.

Values related to watershed management

The physical, biological, and chemical processes occurring in tidal freshwater marshes provide valuable water quality improvement for flows entering estuaries (Mitsch and Gosselink 1993). Tidal freshwater marshes remove approximately 50% of the nitrogen entering the estuarine systems (Novotny and Olem 1995). Nitrogen removal by tidal freshwater marshes is extremely valuable, since most estuaries are nitrogen limited systems. When high levels of nitrogen enter estuaries, algal blooms and fish kills may result. Since the nutrients are used to fuel high productivity in the marshes, they tend to act as sinks for nitrate and phosphorus during the growing season. Nutrients may be exported as detritus in the fall and winter. Like inland marshes, tidal marshes slow the flow of water moving through the system and facilitate the settling of sediment and pollutants adhering to sediment.

Tidal freshwater marshes may help maintain the water table level and protect ground water against saltwater intrusion (OTA 1993).

Life support

Tidal freshwater marshes provide habitat, food, shelter, and nurseries for many fish and shellfish. In addition, approximately half of the organic matter produced in these marshes is transported downstream to the estuary or the sea as detritus, forming the base of the food web.

Some fish species, such as minnows, carp, sunfish, bass, and catfish, spend their entire life cycle in tidal freshwater marshes. (Mitsch and Gosselink 1993). Other fish and shellfish rely on the freshwater marshes for parts of their life cycle and spend the remainder of their lives in the marine environment. Killifish, anchovy, herring, salmon, shad, striped bass, menhaden, spot, tarpon, juvenile brown shrimp, and juvenile white shrimp are examples (Mitsch and Gosselink 1993). Coastal freshwater marshes may support the largest and most diverse bird populations of all wetland habitats.

Tidal Salt Marshes

Photo courtesy of
US Army Corps of Engineergs

Salt marshes are tidally influenced systems that may receive inflow of fresh water from rivers, runoff, or ground water. Freshwater inflow is important in diluting the salinity of the system. Salinity is the major stressor in this wetland system and limits species to those that have evolved adaptive mechanisms. Readily available nutrients and organic matter from upstream sources and runoff, and the alternating aerobic and anaerobic conditions caused by the tides result in the very significant productivity of salt marsh ecosystems. Salt marshes have the highest primary productivity of all wetland systems and have higher primary productivity than most upland systems.

Values related to watershed management

Tidal salt marshes are efficient nitrogen transformers because of the daily hydrologic cycle, which removes a significant portion of total inputs from the aquatic system in the form of gaseous nitrogen (Mitsch and Gosselink 1993). Marshes act as sinks for total phosphorus, although there may be discharge of inorganic phosphorus into the marine system (Mitsch and Gosselink 1993).

The high rates of sulfur retention in salt marshes (sulfur enters from sea water) may play an important role in immobilization and detoxification of toxic metals (Novotny and Olem 1995).

Life support

The unparalleled primary productivity of salt marshes yields abundant habitat and food for both resident species and marine species that utilize the marshes for only portions of their life cycles. Mussels, oysters, and the majority of the other commercially and recreationally important fish and shellfish of the southeast Atlantic and Gulf coasts utilize salt marshes and meadows of submerged aquatic plants for habitat, refuge, and food (NOAA 1990b, NOAA 1995b). Salt marshes provide critical food and refuge for migrating waterfowl and shore birds as well (Mitsch and Gosselink 1993).

V. Human Impacts: Wetland Loss and Degradation

Major Causes of Wetland Loss and Degradation

In the 1600's, over 220 million acres of wetlands existed in the lower 48 states (Dahl and Johnson 1991). Since then, extensive losses have occurred, with many of the original wetlands drained and converted to farmland. Today, less than half of the nation's original wetlands remain. Activities resulting in wetlands loss and degradation include: agriculture; commercial and residential development; road construction; impoundment; resource extraction; industrial siting, processes, and waste; dredge disposal; silviculture; and mosquito control (USEPA 1994b; USEPA 1993a). The primary pollutants causing degradation are sediment, nutrients, pesticides, salinity, heavy metals, weeds, low dissolved oxygen, pH, and selenium (USEPA 1994).

Twenty-two states have lost at least 50 percent of their original wetlands. Indiana, Illinois, Missouri, Kentucky, and Ohio have lost more than 80 percent of their original wetlands and California and Iowa have lost nearly 99 percent (USEPA 1995). Since the 1970's, the most extensive losses of wetland acreages have occurred in Louisiana, Mississippi, Arkansas, Florida, South Carolina, and North Carolina (Dahl and Johnson 1991). Between the mid-1970's and the mid-1980's, approximately 4.4 million acres of inland freshwater wetlands (-4%) and 71,000 acres (-1.5%) of coastal wetlands were destroyed (Dahl and Johnson 1991). Inland forested wetlands were impacted the most during the mid-1970's to the mid-1980's, with a loss of 3.4 million acres (-6.2%), primarily in the Southeast (Dahl and Johnson 1991). Approximately 900,000 acres were converted from forested wetlands to other wetland types. Conversion to agricultural usage of land was responsible for 54 percent of the losses of both freshwater and coastal wetlands; drainage for urban development for 5 percent and "unspecified usage" (planned development) was responsible for 41 percent of the losses. This is in contrast to the mid-1950's to mid-1970's, when agricultural drainage of wetlands was responsible for 87 percent of the losses and urban development for 8 percent.

To see a map, Wetland Loss Measured by National Wetlands Inventory

Although wetlands can improve watershed water quality, their capacity to process pollutants without becoming degraded can be exceeded. Many wetlands have suffered functional degradation, although it is difficult to calculate the magnitude of the degradation. Wetlands are threatened by air and water pollutants and by hydrologic alteration (USEPA 1994b). Some researchers believe that a significant percentage of the nation's remaining wetlands has been substantially compromised hydrologically (Whigham 1988; Dahl and Johnson 1991). Measurements of the frequency or magnitude of such degradation have not been attempted to any significant degree in the United States.

The Main Activities That Cause Wetland Impairment:

- Hydrologic Alteration;
- Urbanization (including development);
- Marinas/Boats;
- Industry (including industrial development);
- Agriculture;
- Silviculture/Timber Harvest;

- Mining;
- Atmospheric Deposition

1. Hydrologic Alterations of Wetlands

Photo courtesy of US Army Corps of Engineers

Wetlands form as a result of certain hydrologic conditions which cause the water table to saturate or inundate the soil for a certain amount of time each year.

The frequent or prolonged presence of water at or near the soil (hydrology) is the dominant factor determining the nature of soil development and the types of plant and animal communities living in the soil and on its surface. Wetlands can be identified by the presence of those plants (hydrophytes) that are adapted to life in the soils that form under flooded or saturated conditions (hydric soils) characteristic of all wetlands (Mitsch and Gosselink 1993). Thus alteration of wetland hydrology can change the soil chemistry and the plant and animal community. Alteration which reduces or increases the natural amount of water entering a wetland or the period of saturation and inundation can, in time, cause the ecosystem to change to an upland system or, conversely, to a riverine or lacustrine system. This alteration can be natural, such as through the successional process of stream impoundment by beavers or climate change.

Wetland loss and degradation through hydrologic alteration by man has occurred historically through such actions as: drainage, dredging, stream channelization, ditching, levees, deposition of fill material, stream diversion, ground water withdrawal, and impoundment.

Implications of hydrologic alterations of wetlands

Habitat loss and fragmentation
In Louisiana, coastal areas are subsiding as a result of the redirection of sediment by the Mississippi River levees, subsurface withdrawals of water, oil, gas, sulfur, and salt, from under wetlands, channelization of wetlands, and drainage of wetlands for development (Carney and Watson 1991; Boesch 1983; Duffy and Clark 1989). As the coast subsides, sea levels rise, essentially, to cover the land. The loss of $300 million worth of coastal real estate in the next 50 years is possible if subsidence continues (Carney and Watson 1991). The cost of the loss of wetland habitat as the sea levels rise to cover the land has not been determined. Land subsidence

also allows saltwater intrusion into freshwater wetlands and causes shifts in the plant and animal community (Pezenski et al. 1990). Saltwater intrusion and the subsequent modification of wetlands habitat threaten the billion dollar fishery industry as well as the multi-million dollar trapping business (Boesch 1983; Duffy and Clark 1989).

Habitat fragmentation, as wetlands are drained or hydrologically altered, may result in changes in species composition as wetlands species are replaced by upland species; loss of large, wide-ranging species; loss of genetic integrity when isolated habitats are too small to support viable populations; reduced populations of interior species that can only reproduce in large tracts; and increased numbers of competitor, predator, and parasite species tolerant of disturbed environments (Harris 1988; Fleming e t al. 1994).

Water diversion structures
Water diversion structures, such as canals (channels), ditches, and levees have been used to modify wetlands to achieve flood control, drainage, mosquito control, irrigation, timber harvest, navigation, transportation, and industrial activity (Mitsch and Gosselink 1993). Canals and channelization change the hydrology of wetlands and increase the speed with which water moves into and through wetlands. As a result, patterns of sedimentation are altered and wetland functions and values that depend on the normal slow flow of water through a wetland can be affected. High sediment loads entering wetlands through channels, irrigation ditches and drainage ditches can smother aquatic vegetation, shellfish beds and tidal flats, fill in riffles and pools, and contribute to increased turbidity (USEPA 1993a). However, normal sedimentation rates in coastal wetlands are necessary to reduce land subsidence. Channelization and channel modification alter instream water temperature and diminish habitat suitable for fish and wildlife (USEPA 1993a). Normal sheet flow through wetlands is inhibited by the spoil banks that line a canal and by road embankments. Spoil banks and embankments also increase water stagnation. Channels often connect low-salinity areas to high-salinity areas, resulting in saltwater intrusion upstream, and causing species change and mortality of salt-intolerant vegetation.

Impoundments
Impoundment of natural wetlands for stormwater management or wildlife and habitat management may exploit one function of wetlands at the expense of others (USEPA 1993a; Mitsch and Gosselink 1993). Impoundment alters the natural wetlands' hydrology and decreases water circulation. Decreased water circulation causes increased water temperature, lower dissolved oxygen levels, and changes in salinity and pH; prevents nutrient outflow; and increases sedimentation (USEPA 1993a). Sedimentation reduces the water storage capacity, smothers vegetation, reduces light penetration, reduces oxygen content and affects the entire ecosystem richness, diversity, and productivity. Toxic substances, adhering to sediments, may accumulate in impoundments as a result of decreased water circulation and bioaccumulation of contaminants by wetland biota may occur.

Impoundment of coastal wetlands reduces the exchange of tidal water in salt marshes and can impede the movement of fish that use the marsh for a part of their life cycle. Impoundments are often invaded by non-native plant species such as common reed (Phragmites) and purple loosestrife (Lytherium) which outcompete the native species and change the wetland community structure.

2. Urbanization

Urbanization is a major cause of impairment of wetlands (USEPA 1994b). Urbanization has resulted in direct loss of wetland acreage as well as degradation of wetlands. Degradation is due to changes in water quality, quantity, and flow rates; increases in pollutant inputs; and changes in species composition as a result of introduction of non-native species and disturbance. The major pollutants associated with urbanization are sediment, nutrients, oxygen-demanding substances, road salts, heavy metals, hydrocarbons, bacteria, and viruses (USEPA 1994b). These pollutants may enter wetlands from point sources or from nonpoint sources. Construction activities are a major source of suspended sediments that enter wetlands through urban runoff.

Impervious surfaces

As roads, buildings, and parking lots are constructed, the amount of impervious surface increases. Impervious surfaces prevent rainfall from percolating into the soil. Rainfall and snowmelt carry sediments; organic matter; pet wastes; pesticides and fertilizers from lawns, gardens, and golf courses; heavy metals; hydrocarbons; road salts; and debris into urban streams and wetlands (USEPA 1993a; USEPA 1993c). Increased salinity, turbidity, and toxicity; and decreased dissolved oxygen, all affect aquatic life and, therefore, the food web (Crance 1988). Excessive inputs of nutrients can lead to eutrophication or result in the release of pollutants from a wetland into adjacent water resources (USEPA 1993a).

As runoff moves over warmed impervious surfaces, the water temperature rises and dissolved oxygen content of the runoff water decreases (USEPA 1993c). Increased water temperature, as well as the lower dissolved oxygen levels, can cause stress or mortality of aquatic organisms. Rising water temperatures can trigger a release of nutrients from wetland sediment (Taylor et al. 1990). For example, as temperature rises, sediments release phosphorus at an exponential rate. Thus water temperature increases can lead to eutrophication.

Impervious surfaces decrease ground water recharge within a watershed and can reduce water flow into wetlands (USEPA 1993c). Significant increases in stormwater peakflow rates, and longer-term changes in wetland hydrology, as a result of stormwater discharge, can cause erosion and channelization in wetlands, as well as alteration of species composition and decreased pollutant removal efficiency (USEPA 1993a; USEPA 1993c). Changes in frequency, duration, and timing of the wetland hydroperiod may adversely affect spawning, migration, species composition, and thus the food web in a wetland as well as in associated ecosystems (Crance 1988; USEPA 1993c).

Wastewater and stormwater

Wastewater treatment plant effluent and urban stormwater are a source of pollutants that continue to degrade wetlands (USEPA 1994b). The "aging" of wetlands can occur when wetlands filter organic matter. "Aging" is the saturation of the ecosystem by nutrients and heavy metals over time that results in the reduced effectiveness and degradation of the wetland (Mitsch and Gosselink 1986). Wastewater and stormwater can alter the ecology of a wetland ecosystem if high nutrient levels cause extended eutrophication and metals cause plant and aquatic organism toxicity (Ewel 1990). Iron and magnesium, in particular, may reach toxic concentrations, immobilize available phosphorous, and coat roots with iron oxide, preventing nutrient uptake.

Over one-third of shellfish waters can not be harvested because of habitat degradation, pollutants, algal blooms, and pathogens. To a large extent, this degradation is caused by urban pollution (NOAA 1995b; NOAA 1990b; USEPA 1994b).

Heavy metals may bioaccumulate in estuarine wetlands, causing deformities, cancers, and death in aquatic animals and their terrestrial predators. Heavy metal ingestion by benthic organisms (including many shellfish) in estuarine wetlands occurs because the metals bind to the sediments or the suspended solids that such organisms feed on or settle on the substrate where such organisms live.

Urban and industrial stormwater, sludge, and wastewater treatment plant effluent, rich in nitrogen and phosphorus, can lead to algal blooms in estuaries. Algal blooms deplete dissolved oxygen, leading to mortality of benthic organisms. Some algae are toxic to aquatic life (Kennish 1992). Excess algae can shade underwater sea grasses (part of the coastal wetland ecosystem), preventing photosynthesis and resulting in sea grass death (Batiuk et al. 1992; USEPA 1994b). Because sea grass meadows reduce turbidity by stabilizing sediments and provide critical food, refuge, and habitat for a variety of organisms, including many commercially harvested fish, the death of these plants profoundly impairs the estuarine ecosystem. (Dennison et al. 1993; USEPA 1994 b; Batiuk et al. 1992).

Roads and bridges

Roads and bridges are frequently constructed across wetlands since wetlands have low land value. It is often considered to be more cost effective to build roads or bridges across wetlands than around them (Winter 1988). Roads can impound a wetland, even if culverts are used. Such inadvertent impoundment and hydrologic alteration can change the functions of the wetland (Winter 1988). Road and bridge construction activities can increase sediment loading to wetlands (Mitsch and Gosselink 1993). Roads can also disrupt habitat continuity, driving out more sensitive, interior species, and providing habitat for hardier opportunistic edge and non-native species. Roads can impede movement of certain species or result in increased mortality for animals crossing them. Borrow pits (used to provide fill for road construction) that are adjacent to wetlands can degrade water quality through sedimentation and increase turbidity in the wetland (Irwin 1994).

The maintenance and use of roads contribute many chemicals into the surrounding wetlands. Rock salt used for deicing roads can damage or kill vegetation and aquatic life (Zentner 1994). Herbicides, soil stabilizers, and dust palliatives used along roadways can damage wetland plants and the chemicals may concentrate in aquatic life or cause mortality (USEPA 1993a). Runoff from bridges can increase loadings of hydrocarbons, heavy metals, toxic substances, and deicing chemicals directly into wetlands (U SEPA 1993a). Bridge maintenance may contribute lead, rust (iron), and the chemicals from paint, solvents, abrasives, and cleaners directly into wetlands below.

Innovative methods of constructing roads and bridges, and end-state (master) planning that reduces the need for new roads, can reduce the impacts of urbanization on wetlands.

Sanitary landfills

Landfills can pose an ecological risk to wetlands. Landfill construction may alter the hydrology of nearby wetlands. Leachate from solid waste landfills often has high biological oxygen demand (BOD), and ammonium, iron, and manganese in concentrations that are toxic to plant and animal life (Lambou et al. 1988). Sanitary landfills may receive household hazardous waste and some hazardous waste from small quantity operators, as well as sewage sludge and industrial waste. Although regulated (under RCRA Subtitle D), these facilities may not always be properly located, designed, or managed, in which case some surface water contamination may occur. Researchers who conducted a study of the proximity of 1,153 sanitary landfills to wetlands in 11 states, found that 98 percent of the sanitary landfills were 1 mile or less from a wetland, and 72 percent were 1/4 mile or less from a wetland (Lambou et al. 1988).

Non-native plants and animals

As a result of disturbance and habitat degradation, wetlands can be invaded by aggressive, highly-tolerant, non-native vegetation, such as purple loosestrife *(Lythrum salicaria)*, water hyacinth *(Eichornia crassipes)*, and salvinia *(Salvinia molesta*), or can be dominated by a monoculture of cattails *(Typha spp.)* or common reed *(Phragmites spp.)* (McColligan and Kraus 1988; Weller 1981; Mitsch and Gosselink 1993). Particularly in constructed wetlands, including restored wetlands, non-native and tolerant native species may outcompete other species leading to a reduction in species diversity.

Non-native species may be introduced on purpose. For example, water hyacinth has been noted for its ability to sequester nutrients and is used for wastewater purification (Mitsch and Gosselink 1993). Water hyacinth and similar species can rapidly fill a wetland and are a threat to water quality in some areas.

Carp and nutria are two introduced exotic animal species that degrade wetlands (Mitsch and Gosselink 1993). Carp, introduced for recreational fishing, severely increase the turbidity of water resources. Nutria, introduced for their pelts, are rodents that voraciously eat, as well as destroy, freshwater and coastal wetland vegetation. Domestic and feral cats can be extremely damaging as they prey on wetland birds.

Mosquito control programs

Mosquito control efforts in urbanized and resort communities has resulted in wetlands loss and degradation through drainage, channelization, and use of toxic pesticides.

? Information about methods of mosquito control that do not degrade wetland ecosystems

3. Marinas/Boats

Marina construction and dredging activities can contribute suspended sediments into waters adjacent to wetlands. Intense boating activity can also increase turbidity and degradation of wetlands.

Wetlands can be adversely affected by pollutants released from boats and marinas. Pollutants include: hydrocarbons, heavy metals, toxic chemicals from paints, cleaners, and solvents (USEPA 1993a). Dumping of wastes from fish cleaning and discharge of human waste from marinas and boats can increase the amount of nutrients and organic matter in a wetland. The increased organic matter and nutrients can lead to eutrophication.

4. Industry

Adverse effects of industry on wetlands can include: reduction of wetland acreage, alteration of wetland hydrology due to industrial water intake and discharge, water temperature increases, point and nonpoint source pollutant inputs, pH changes as a result of discharges, and atmospheric deposition.

Saline water discharges, hydrocarbon contamination, and radionuclide accumulation from oil and gas production can significantly degrade coastal wetlands (Rayle and Mulino 1992). Most petroleum hydrocarbon inputs into coastal wetlands are either from coastal oil industry activities, from oil spills at sea, from runoff, or from upstream releases (Kennish 1992). Oil can alter reproduction, growth, and behavior of wetland organisms, and can result in mortality. Plants suffocate when oil blocks their stomata (Dibner 1978).

Polynuclear aromatic hydrocarbons (PAHs) are extremely toxic compounds that can enter estuarine wetlands through industrial effluent and atmospheric deposition. PAHs concentrate in sediments and thus contaminate benthic organisms (Kennish 1992). Fish contaminated with PAHs exhibit external abnormalities, such as fin loss and dermal lesions.

Superfund (CERCLA) or RCRA sites

Toxic, radioactive, or acidic compounds and high concentrations of metals in abandoned industrial wastes at Superfund sites, or in operative (RCRA) waste sites, may be an ecological risk to wetlands fauna and flora. Many sites are close enough to directly or indirectly (through water flow) impact wetlands (Magistro and Lee 1988). Clean-up activities at Superfund and RCRA sites can degrade adjacent wetlands as well through disturbance of hydrology, introduction of contaminants, and degradation of habitat by equipment.

Metals and radionuclides tend to naturally concentrate in wetlands sediments and peat (Owen 1992). Such concentrations can be released in a flush from the wetland into surface water or ground water as a result of pollutant inflow or hydrologic alteration of the wetland (Owen 1992). Such a release of toxic compounds could generate serious environmental consequences. Intake of very low concentrations of radionuclides, such as uranium, from a water supply, for instance, will cause kidney failure and death . If radioactive peat or peat with a high metal concentration is used for gardening or agricultural activities, it can pose a human health risk as well (Owen 1992).

5. Agriculture

Photo courtesy of USDA NRCS

Historically, agriculture has been the major factor in freshwater and estuarine wetland loss and degradation. Although the passage of the Food Security Act of 1985 "Swampbuster" provision prevented the conversion of wetlands to agricultural production, certain exempted activities performed in wetlands can degrade wetlands:

- harvesting food, fiber, or forest products;
- minor drainage;
- maintenance of drainage ditches;
- construction and maintenance of irrigation ditches;
- construction and maintenance of farm or forest roads;
- maintenance of dams, dikes, and levees;
- direct and aerial application of damaging pesticides (herbicides, fungicides, insecticides, fumigants); and
- ground water withdrawals.

These activities can alter a wetland's hydrology, water quality, and species composition. Excessive amounts of fertilizers and animal waste reaching wetlands in runoff from agricultural operations, including confined animal facilities, can cause eutrophication.

Wetlands provide critical habitat for waterfowl populations. The drainage of U.S. and Canadian prairie potholes for agricultural production has been linked to a concomitant 50% - 80% decline in waterfowl populations since 1955 (USEPA 1995; DU 1995). Since the Swampbuster legislation was promulgated, the waterfowl population has begin to increase. Swampbuster rendered drainage of prairie potholes costly, and encouraged farmers to allow prior converted wetlands to revert to their previous natural wetland state and to construct farm ponds or restore marshes. Duck populations in 1994 increased by 24% over 1993 populations, and were the highest since 1980, when duck populations had plunged to a low (USEPA 1995).

Toxic compounds

Irrigation ditching can increase contamination of wetlands receiving irrigation drainage water, particularly where soil is alkaline or contains selenium or other heavy metals (Deason 1989). Untreated runoff containing extremely high concentrations of selenium led to mortality and deformities in bird, amphibian, and fish embryos and the disappearance of species from wetlands in California (USEPA 1995).

Agricultural pesticides entering wetlands in runoff, as well as through atmospheric deposition, may bioaccumulate in fish and other aquatic organisms (Kennish 1992).

Grazing

Grazing livestock can degrade wetlands that they use as a food and water source. Urea and manure can result in high nutrient inputs. Cattle traffic may cause dens and tunnels to collapse. Overgrazing of riparian areas by livestock reduces streamside vegetation, preventing runoff filtration, increasing stream temperatures, and eliminating food and cover for fish and wildlife. As vegetation is reduced, streambanks can be destroyed by sloughing and erosion. Streambank destabilization and erosion then cause downstream sedimentation (Kent 1994b). Sedimentation reduces stream and lake capacity, resulting in decreased water supply, irrigation water, flood control, hydropower production, water quality, and impairment of aquatic life and wetland habitat (USEPA 1993b).

The economic losses attributed to the reduced quality and quantity of water and habitat from overgrazing of riparian wetland vegetation is more than $200 million (USEPA 1993b). The depletion of vegetation from riparian areas causes increased water temperatures and erosion and gully formation, prevents runoff filtration, and eliminates food and cover for fish and wildlife (USEPA 1993b). If stocking of livestock is well managed, grazing can coexist with wetlands, benefiting farmers and increasing habitat diversity.

6. Silviculture/Timber Harvest

If best management practices are used and careful monitoring occurs, silviculture and timber removal may only minimally affect some wetland functions. Habitat and community structure, however, still may be seriously degraded.

Drainage, clearing, haul road construction, rutting, and ditching of forested wetlands, all may affect wetlands in some way, although the impact may only be temporary. Since timber removal generally occurs in 20-50 year rotations, careful harvest may not be a permanent threat to wetlands. Adverse effects of timber harvest can include a rise in water table due to a decrease in transpiration, soil disturbance and compaction by heavy equipment, sedimentation and erosion from logging decks, skid trails, roads, and ditches, and drainage and altered hydrology from ditching, draining, and road construction (Shepard 1994). By utilizing best management practices, hydrology and biogeochemical processes of wetlands may be altered for only one to three years following timber harvest (Shepard 1994).

Pesticides and fertilizers used during silvicultural operations can enter wetlands through runoff as well as through deposition from aerial application. Fertilizers may contribute to eutrophication of wetlands.

7. Mining

Peat mining

Peat is mined for agricultural and horticultural uses on a relatively small scale in the United States (Mitsch and Gosselink 1993). Wetlands that are mined for peat are significantly modified, often being transformed into open water habitat (Camp Dresser and McKee 1981). Peat mining not only removes peat but requires clearing of vegetation, drainage of the wetland, and creation of roads for equipment access to harvest the peat. These activities destroy the portion of the wetland selected for harvest and degrade adjacent areas.

An alternative to mining peat in pristine wetlands is to mine in former wetlands or wetlands that have been severely degraded through conversion to other uses.

Other mining operations

Phosphate mining has resulted in the loss of thousands of acres of wetlands in central Florida (Mitsch and Gosselink 1993). Other types of mining operations can also degrade wetlands through hydrologic alterations, high metal concentrations, and/or decreased pH.

Acid drainage from active and abandoned mines causes extensive ecological damage. Acid mine drainage introduces high levels of acidity and heavy metals into the wetland environment through runoff and through direct drainage from mines into wetlands. The acidity and the high metal concentrations alter the biotic community composition and can result in mortality (Lacki et al. 1992; Mitsch and Gosselink 1993). Although natural wetlands may have the capacity to buffer some of the acidity and absorb a certain amount of the pollutants, over time, the assimilative capacity will be saturated (Kent 1994; Weider 1993).

8. Atmospheric Deposition

Nitrous oxides, sulfurous oxides, heavy metals, volatilized pesticides, hydrocarbons, radionuclides, and other organics and inorganics are released into the atmosphere by industrial and agricultural activities, and from vehicles. These compounds can enter wetlands through wet and dry atmospheric deposition and can adversely affect aquatic organisms and the terrestrial organisms that feed on them.

VI. Wetland Protection: Government Programs

FEDERAL WETLAND POLICY INITIATIVES
Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990
(CZARA)
No Net Loss
Ramsar Convention
Chronology of Key Federal Legislation and Regulations Affecting Wetlands
WETLAND PROTECTION AT THE STATE AND LOCAL LEVELS
State Wetland Protection
Local Wetland Protection
Public-Private Sector Partnerships
Advance Identification of Disposal Areas (ADID)
North American Waterfowl Management Plan

INTRODUCTION

Perhaps the most notable feature of federal wetland protection policy today is that there is no specific, comprehensive national wetland law. Rather, federal statutes regulating or otherwise protecting wetlands have evolved piecemeal over the years, and often utilize laws originally intended for other purposes (Mitsch and Gosselink, 1993; GAO, 1991). As a result, jurisdiction for wetland protection is spread over several agencies and federal wetland protection is not as effective or cohesive as it could be.

Federal, state, and local government regulatory, or permitting, programs are essential tools in the nationwide effort to protect wetlands. While essential, current programs do not, in most cases, provide sufficient protection. Regulatory programs typically include thresholds of applicability, allowing destruction of small wetlands or small portions of larger wetlands. They often contain loopholes, such as allowing direct drainage or excavation of wetlands provided none of the spoil material is placed in the wetland. Programs almost universally fail to address activities in surrounding areas which can lead to wetland degradation, such as diversion of surface or ground water inputs (see Wetland Loss and Degradation section). Almost all regulatory programs contain exemption categories for many agricultural, silvicultural, and sometimes mining activities. Regulatory programs are typically vulnerable to economic arguments for allowing development of wetlands, and often rely on the safety net of mitigation to offset wetland losses or degradation. Yet the technology and reliability of wetland mitigation lags well behind the expectations placed on it (see Wetland Mitigation section). In a larger perspective, regulatory programs are the reactive, compulsory arm of wetland protection, and can only provide partial protection in the long run.

Despite the efforts of regulatory programs and private conservation organizations, degradation and destruction of wetlands will continue unless offset by additional protection approaches. Approaches needed to achieve comprehensive wetland protection must be proactive, far-sighted, planned strategies that utilize positive motivation to succeed long-term. These can be grouped by type of approach: incentive/disincentive; acquisition/legal restriction; restoration; and others, including policy statements, educational efforts, and inventories. Each has its advantages and disadvantages, and all are needed to effectively protect wetlands. For example, regulatory programs are essential for basic wetland protection and for recourse when detrimental impacts occur. Incentive/disincentive programs provide wetland property owners with a reason to protect wetlands without requiring an enforcement presence. But incentive programs tend to apply only to certain land use activities, and incentive mechanisms can become less compelling over time as economic forces change. Acquisition greatly increases the likelihood of minimizing detrimental impacts to wetlands, as do legal restrictions short of acquisition, depending on their design. But acquisition and some legal restrictions provide limited coverage because of funding constraints, and some legal restrictions require active enforcement. Restoration is important for correcting historical damages, but should be coupled with legal protections and, again, is invariably limited by funding. Policy support and educational efforts are essential in the long run, but are inadequate without favorable economics or enforceable authority. Thus, a combination of these approaches is essential for the effective short- and long-term protection of wetlands.

Many opportunities exist for private citizens and corporations to assist federal, state and local government agencies in slowing the rate of wetland loss and improving the quality of the nation's remaining wetlands. Individual landowners and corporations own the majority (75%) of the nation's wetlands: they are in a key position to determine the fate of wetlands on their properties (USEPA 1995).

The following is a synopsis of federal, state, and local wetland regulatory efforts, along with discussion of existing and potential non-regulatory programs that can also support wetland protection in the United States.

FEDERAL WETLAND REGULATION

Section 404 of the Clean Water Act

Significant protection of wetlands as integral and essential parts of the nation's waters began with the 1972 Federal Water Pollution Control Act, now commonly referred to as the Clean Water Act (CWA), and continued through amendments to the Act passed in 1977. Section 404 of the 1972 Act establishes the major federal program regulating activities in wetlands, and the 1977 Amendments significantly expand on the design of the Section 404 program, including exemption categories, the option of delegation of the 404 program to states, and enforcement powers.

Section 404, jointly administered by the U.S. Army Corps of Engineers (Corps) and the U.S. Environmental Protection Agency (EPA), regulates the discharge of dredged or fill material into "waters of the United States," which include wetlands. Discharge of dredged or fill material requires a permit from the Corps based on regulatory guidelines developed in conjunction with EPA (pursuant to Section 404(b)(1)). Failure to obtain a permit or comply with the terms of a permit can result in civil and/or criminal penalties. Under Section 404(c), the Administrator of the EPA may prohibit or restrict the use of any defined area as a disposal site if it is determined that the discharge may cause unacceptable adverse effects on municipal water supplies, wildlife, shellfish beds and fishery areas, or recreational areas. This section is referred to as EPA's "veto authority." Parties intending to discharge material into waters of the U.S. must obtain an individual permit or be covered under a general permit issued by the Corps. Effective 9/93, not only the discharge is regulated under 404 (see examples below).

General Permits

Under Section 404(e), the Corps may issue general permits on a nationwide, regional, or statewide basis for particular categories of activities that, when conducted in waters of the U.S., are presumed to cause only minimal adverse environmental impacts. Landowners undertaking these activities are not required to obtain an individual permit. The Corps has identified and periodically updates a list of categories (40 to date that apply nationwide) of activity that merit such blanket approval. General permits that apply nationwide, or "nationwide permits," are issued by Corps headquarters and apply throughout the country. Some of these categories require simply notifying the Corps prior to commencement of the activity in a wetland, and some do not. Information about regional or state-level general permits may be obtained from Corps division or district offices.

Of the forty nationwide permits issued by the Corps as of March 1993, seven always require notification of the Corps prior to project activity: outfall structures, hydropower projects, surface mining, temporary construction, cranberry production, emergency watershed protection, and cleanup of hazardous wastes. Eight nationwide permits require notification of the Corps in certain circumstances: scientific measurement devices, temporary recreation structures, bank stabilization, road crossing, minor discharges, removal of vessels, isolated wetlands, and hazardous waste cleanup. The remaining 25 permits do not require that the landowner notify the Corps prior to project initiation if the landowner complies with the conditions of the permit. All activities allowed by nationwide permits must include the use of appropriate erosion and siltation controls. Activities may not disrupt the movement of indigenous aquatic species, and heavy equipment must be placed on mats.

Individual Permits

An individual 404 permit is required for activities with more significant wetland impact potential. Individual permit applications are evaluated on a case-by-case basis using the Section 404(b)(1) Guidelines. The Guidelines spell out a sequential review process whereby the applicant must first show that all available alternatives to the impact (the "discharge of dredged or fill material") have been considered, and that no practicable alternative exists which would have less adverse impact on the aquatic ecosystem. Non-water-dependent activities face a more rigorous evaluation from the Corps. Next, no discharge can be permitted if it would violate other applicable laws, including state water quality standards, toxic effluent standards, the Endangered Species Act, and marine sanctuary protections. Further, the discharge "cannot cause or contribute to significant degradation of wetlands by adversely impacting wildlife, ecosystem integrity, recreation, aesthetics, and economic values." If these conditions are met, then the applicant must show that all appropriate and practicable steps will be taken to minimize adverse impacts of the discharge on wetlands. Only after avoidance and minimization criteria are satisfied can the Corps consider compensation, which is commonly known as "mitigation" (USEPA 1991a). In establishing mitigation requirements, the Corps must strive to achieve a goal of no overall net loss of wetland values and functions, meaning a minimum of one-for-one functional replacement with an adequate margin of safety to reflect scientific uncertainty. An environmental assessment or Environmental Impact Statement (EIS) must be prepared for each individual permit application.

Mitigation

Under the Section 404(b)(1) guidelines (codified at 40 CFR 230) and Corps regulations (codified at 33 CFR 320.4(r)), the Corps (or EPA) has the right to require the developer to mitigate any unavoidable impacts on a wetland as a condition of an individual 404 permit. The developer can be required to enhance, restore, or create wetlands on or near the development site. Mitigation projects are meant to replace the loss of natural wetland functions due to the permitted activity. Mitigation is discussed in a separate section of this document (Sucessful Mitigation or Mitigation Banking>).

Section 404 Exemptions

Section 404(f) exempts discharges of dredged or fill material associated with normal ongoing farming, ranching, and forestry activities, such as plowing, seeding, cultivating, or harvesting food, fiber, or forest products; minor drainage; maintenance (not construction) of drainage ditches; construction and maintenance of irrigation ditches; construction and maintenance of farm or stock ponds; construction and maintenance of farm or forest roads, in accordance with best management practices; and maintenance of dams, dikes, and levees. These discharges are exempt from the 404 permitting requirements if they do not convert a wetland to an upland area through the discharge of dredged or fill material.

Minor drainage activities covered by this exemption are those involving the discharge of dredged or fill material incidental to:

- connecting upland drainage facilities to waters under Section 404 jurisdiction to remove excess soil moisture from upland croplands;
- installing ditching or other water control facilities associated with the planting, cultivating, protecting, or harvesting of wetland crops (e.g., cranberries, loblolly pine);
- manipulating the water level, flow, or distribution of impoundments that are in established use for production of cranberries or other wetland crops; and
- removing sandbars, gravel bars, or other similar blockages formed by flood flows on an emergency basis, which, if not promptly removed, would result in damage to or loss of existing crops.

Minor drainage activities do not include enlarging or extending the affected drainage area beyond the dimensions that existed prior to development of the blockage that necessitated maintenance (USEPA 1991a).

Recapture of Exempt Discharges

Exempted discharges may be regulated or "recaptured" by Section 404 if they 1) involve an impairment of the reach or flow and circulation of the water or wetland, e.g., converting a wetland to upland and 2) represent a new use of the water or wetl and (USEPA 1991a). The term "new use" includes:

- switching from an upland crop to a wetland crop, or from one upland crop to another that would require modifying the wetland by draining, ditching, diking, tiling, or other activities necessary to retain or manage water on the fields;
- redistributing soil such that low wetland areas or streams are filled; or
- changing use from normal crop production to a non-agricultural use.

Want (1994); USEPA (1991a); USEPA (1995)

Section 404 is the backbone of wetland protection in the United States today. Yet, the vague language of the regulation, multiple exemptions, loopholes, and activities not covered allow many wetlands to be legally degraded or destroyed. For example, Section 404 has no control over ground water pumping that can completely de-water a wetland (USEPA 1989). As a result of the above caveats, by most estimates, only about 20 percent of the activities that destroy wetlands are regulated under the Section 404 program (GAO, 1991). It should be noted that a large part of the remaining activities involve agriculture, which has been a major cause of past wetland losses. As discussed below, the 1985 and 1990 Farm Bills have attempted to fill this gap in coverage.

A recent change in wetland regulation closed a major loophole that had enabled unregulated wetland conversion by nondischarge activities. The scope of the 404 program was clarified in August 1993 as a result of the lawsuit *North Carolina Wildlife Federation, et al. v. Tulloch* (58 Federal Register 45008, August 25, 1993), and is now reflected in federal regulations at 33 CFR 332223.2(d). The COE revised the definition of "discharge of dredged material" in its guidance to include "any addition, including redeposit, of dredged material, including excavated material, into waters of the United States which is incidental to any activity, including mechanized landclearing, ditching, channelization, or other excavation" when such activities destroy or degrade waters of the United States, including wetlands. This revision is "of great national significance to the Section 404 program" (58 *Federal Register* 45008, August 25, 1993), taking a clear position in favor of regulating excavation in wetlands, an area with a mixed history of enforcement (Want, 1994). This change will also help to narrow the exemption for drainage of wetlands, since most draining involves some degree of dredging (Want, 1994). As a caveat, this provision does not affect, in any manner, the existing statutory exemptions for normal farming, ranching, and silviculture activities in Section 404(f)(1)(58 *Federal Register* 45008, August 25, 1993).

Want, (1994)

Section 401 of the Clean Water Act

Section 401, the state water quality certification process, gives states authority to grant, deny, or condition issuance of federal permits or licenses that may result in a discharge to waters of the United States, including the discharge of dredged or fill material. Through the 401 certification process, states can prevent noncompliance with water quality standards through permit denials (such as Section 404 individual permits discussed above) or conditions of permit issuance (for example, mitigation requirements). States are encouraged by EPA to use 401 certification as a means of protecting wetlands and of offsetting unavoidable impacts by obtaining mitigation proposals before granting 401 certification. EPA offers guidance to the states on this process (USEPA 1989), and some states have implemented it, resulting in essentially de facto Section 404 dredge and fill regulation at the state level. Of course, this approach to wetland protection is only as effective as the associated 404 protections.

FEDERAL NON-REGULATORY WETLAND PROTECTION

As mentioned above, wetland protection efforts in federal legislation have occurred piecemeal over the years. No other federal programs have the direct, interventionary control of the 404/401 regulatory process. However, other sections of the CWA and other federal laws do lend varying degrees of support to federal wetland protection efforts. Non-regulatory acts and orders can also be grouped by the protection approach taken: acquisition/legal restriction; restoration; incentive/disincentive; other programs, such as policy statements, educational efforts, and inventories; or combinations of these approaches. Some of the more important of these non-regulatory approaches are discussed below.

Sections 101 and 303 of the Clean Water Act

Section 101 of the CWA established national goals for the attainment of good water quality (fishable and swimmable waters). Section 101(a)(2) identifies a key goal: to protect and enhance propagation of fish, shellfish, wildlife, and recreation in and on waters of the United States. Under Section 303, states are required to develop and implement water quality standards for all waters of the United States, including wetlands. In the absence of specific wetland standards, water quality standards established for other surface waters can apply to wetlands as well. Thus, wetlands are theoretically protected from water quality degradation. However, in 1989, about half of the states did not explicitly recognize wetlands in their water quality standards and most had no standards tailored to wetlands (USEPA 1990). This prompted EPA in 1990 to set requirements for states to establish standards for wetlands by the end of FY1993. EPA also provided national Agency Operating Guidance to facilitate state action (USEPA 1990). However, by the deadline, state compliance with the Guidance was low. In any case, while water quality standards can help to protect preserved wetlands, such standards provide no direct means to avert or discourage the elimination of wetlands. Water quality standards tailored to wetlands can, however, facilitate the implementation of Section 401 Water Quality Certifications to protect wetlands (see section on Section 401 above).

Section 319 of the Clean Water Act

Section 319 establishes a national program for the control of nonpoint source pollution. The section requires states to assess nonpoint source impacts to state waters, including wetlands, and to prepare management programs to control impacts. Under Sect ion 319, EPA funds activities to protect or restore wetlands for nonpoint source water quality improvement, and EPA encourages such dual-purpose, wetland/water quality improvement activities (USEPA 1990b). Section 319 uses financial incentives to encourage voluntary state prioritization and protection of wetlands, but provides no regulatory wetlands protection.

Section 402 of Clean Water Act

Section 402(p), which establishes the National Pollutant Discharge Elimination System (NPDES) program, requires stormwater permits for four major classes of stormwater discharges. Section 402 advocates the use of best management practices (BMPs) to minimize or eliminate the introduction of stormwater pollutants into waters of the United States. While the NPDES program does not regulate activities conducted in wetlands nor destruction of wetlands in any direct way, its goal is to reduce pollutant discharges that may otherwise degrade wetlands from a water quality standpoint.

Source: USEPA 1995

Swampbuster Provision of the 1985 and 1990 Farm Bills

As mentioned above, agriculture has historically played a significant role in the alteration and loss of wetlands in the United States, and much agricultural activity is exempted from the Section 404 program. To address this gap, the Food Security Act (Farm Bill) of 1985 included two major wetlands provisions, "Swampbuster" and the Conservation Reserve Program (CRP). The Swampbuster provision of the 1985 Farm Bill, and amendments in the Food, Agriculture, Conservation, and Trade Act (Farm Bill) of 1990, were designed to discourage the further conversion of wetlands for agricultural commodity production and can be categorized as disincentives. The Swampbuster provision requires the withholding of all USDA program benefits from any person who 1) plants an agricultural commodity on a wetland that was converted after December 23, 1985, or 2) converts a wetland for agricultural commodity production after November 28, 1990, even if the crop is not planted (USEPA 1991a). Benefits that can be lost under the Swampbuster provision include commodity supports, crop insurance, and disaster payments. These can be substantial losses for commodity crop producers. Benefits are withheld for the year in question and all subsequent years, until the wetland is either restored or replaced (mitigated). An agricultural commodity is defined as any annual crop planted by the tilling of the soil, including crops such as corn, tomatoes, potatoes, oats, peas, wheat, and broccoli.

Exemptions to the Swampbuster Provision

Perennial crops (e.g., hay, berries, apples, pulpwood, ornamental shrubs,Christmas trees, etc.) are not classified as agricultural commodities and are therefore exempt from the Swampbuster provision.

Wetlands converted to cropland prior to passage of the 1985 Farm Bill (prior converted croplands) are exempt from the Swampbuster provision. These are former wetlands that were cleared of woody vegetation before the cut-off date of December 23, 1985, and hydrologically modified for agricultural production. As defined in the Swampbuster provision, prior converted croplands no longer have the characteristic hydrology of a wetland (currently, inundation for at least 15 consecutive days during the growing season); must have had an agricultural commodity planted or produced at least once before December 23, 1985; and must not have been out of production for more than 5 consecutive years. If these conditions are not met, the land in question is subject to Swampbuster and Section 404 regulations.

Herbaceous wetlands that do not require any hydrologic alteration for crop production may be farmed without the loss of USDA program subsidies, and are thus also exempt from the Swampbuster provision.

From these criteria, it is apparent that Swampbuster provides a significant disincentive for new conversions of wetland to cropland. In fact, a recent survey of cornbelt farmers showed that about half of those surveyed with unfarmed wetlands would put them to agricultural use in the absence of Swampbuster (Lant et al, 1995). However, it is also clear that Swampbuster is by no means comprehensive. Most significantly, it does not protect wetlands converted for non-commodity crops, and there is relatively little overlap nationwide of farms relying on commodity programs and wetlands (Wiebe et al, 1995). Also, commodity programs themselves are affected by federal budget considerations; thus loss of program benefits cannot always be counted on as a reliable deterrent. In fact, on March 29, 1996, President Clinton signed the most recent quintennial Farm Bill, phasing out 60 years of commodity support programs entirely within 7 years. These factors, combined with the fact that Swampbuster does nothing to ad dress ongoing, pre-existing farming operations in wetlands, make this disincentive approach weak. Partly for these reasons, positive incentive programs, such as the Wetlands Reserve and Conservation Reserve Programs, were developed along with the Swampbuster program.

Source: USEPA (1991a).

Conservation Reserve and Wetlands Reserve Programs (1985 and 1990 Farm Bills)

Two important incentive approaches for protection and restoration of wetlands were parts of the 1985 and 1990 Farm Bills. Both the Conservation Reserve Program and the Wetlands Reserve Program pay farmers to take land out of production or set land aside for a designated time period.

The focus of the Conservation Reserve Program (CRP), which was created in the 1985 Farm Bill, was to encourage farmers to take highly erodible lands out of production for ten years. While most CRP monies went to protection of highly erodible upland areas, the CRP also provided funds to restore previously cropped wetlands, floodplains, and riparian areas adjacent to streams (WMI 1994; NGPC 1995a). The CRP originally was funded for 36.5 million acres (and the 1996 reauthorization continues this enrollment level). Of that total, 410,000 acres of wetlands were enrolled, with 60% in the Dakotas (Lant et al., 1995). Over 114,000 individual wetlands in North Dakota alone are part of the CRP, further highlighting the major role CRP plays in efforts to restore prairie potholes in the Midwest. (NGPC 1995a). The CRP has been extremely successful and has prevented the erosion of almost 700 million tons of topsoil annually since its inception (WMI 1994). As a result, the CRP improved water quality through reduced sedimentation as well as reduced pesticide and fertilizer in runoff. Over the 10 years that the CRP has been in effect, the program has provided billions of dollars in environmental benefits to the nation, saving it up to $2 billion per year that would have been expended through agricultural subsidies, disaster relief, and crop loans (WMI 1994). USDA economists estimated that the CRP would provide between $3.4 and $11.2 billion in environmental benefits over the life of the original program (NGPC 1995a). The CRP has also provided more than $13 billion through overall recreation-based economic activity (WMI 1994). CRP contracts began expiring in 1995, and 80% of contracts expire in 1996 and 1997. However, the Farm Bill passed by Congress March 28, 1996 and signed by the President on March 29, 1996 included CRP reauthorization at the same level of 36.4 million acres.

The Wetlands Reserve Program (WRP) is a voluntary incentive program, created in the 1990 Farm Bill, to encourage wetland restoration and protection in agricultural areas. The WRP authorizes purchases of easements containing wetlands from participating landowners and cost-share payments for wetland restoration. Landowners retain control of access to these areas; may utilize the land for hay, grazing, and recreation if activities do not impact the wetlands; and may sell the land. Areas that may be enrolled include lands with restorable wetlands, lands adjacent to wetlands that contribute to wetland values, wetlands restored by other federal and state programs, riparian areas that link WRP wetlands, and non-forested CRP land that is likely to be returned to production. Unlike the CRP, WRP wetland easements are permanent in nature, a high ante price that both provides for long-term protection and has deterred many farmers from signing up (Despain, 1995). The WRP authorized enrollment of 1,000,000 acres of prior converted or farmed wetlands by the year 2000. Pilot enrollments of 50,000 and 75,000 acres took place in 1992 and 1994, and the first nationwide enrollment occurred in June 1995 for another 118,000 acres.

The greatest benefits of the WRP so far have been to the lower Mississippi River states; the majority of acres accepted in the first sign-up were in Louisiana and Mississippi, and almost half of the 1994 enrollment was in those two states and Arkansas (Heimlich et al 1994).

In terms of the value of WRP, Lant et al. (1995) observed that "even if only a small percentage of eligible farmed wetlands were to be enrolled, the WRP would constitute the largest wetland restoration program in the history of the U.S. Moreover, even at the higher end of our (possible rental rate) price range, the per acre costs are low compared to mitigation projects currently conducted under the Clean Water Act Section 404 program." Besides economics, primary reasons identified by cornbelt farmers for not enrolling in the WRP included potential negative effects on farming beyond the wetland site due to a loss of drainage capability, or obligations to drainage districts (Lant et al. 1995). The authors concluded that it would be worth making the effort to overcome these problems with WRP implementation. An indication of the Program's perceived value is found in the 1996 Farm Bill reauthorization, which extended the WRP through 2002 with the same acreage cap and broadened eligibility criteria.

Water Bank Act

The Water Bank Program is another federally operated incentive approach geared largely to agricultural wetland protection, similar to the CRP, but initiated long before it, with the 1970 passage of the Water Bank Act (16 U.S.C. 1301). The Water Bank is targeted to the Prairie Pothole region, and offers 10-year easements on wetlands and adjacent areas. Landowners agree not to drain, fill, level, burn, or otherwise destroy wetlands and to maintain ground cover essential for the resting, breeding, or feeding of migratory waterfowl in exchange for annual payments. The Program had enrolled 543, 208 acres as of July, 1991 (GAO, 1991). Thus, the Program, which has been in place for 26 years, has amassed more than twice the wetland acreage of the WRP, and almost a third more than the CRP, making a significant contribution to wetland protection.

Migratory Bird Hunting and Conservation Stamp Act / Small Wetland Acquisition Program (SWAP)

The SWAP, established under the Migratory Bird Hunting and Conservation Stamp Act, is an old federal acquisition program rooted in bird hunting interests. Since 1934, waterfowl hunters have been required to purchase "duck stamps," the proceeds of which a re used to acquire habitat, in the form of wetlands and surrounding nesting cover, for water fowl. Under this program, which is similar to the Water Bank Program, landowners give up their rights to drain, fill, burn, or level wetlands Through FY1989, easements had been obtained on more than 1.2 million acres of wetlands, and another 564,000 acres in the Prairie Pothole region had been purchased under the SWAP, making this easily the oldest and largest of the federal wetland protection programs (GAO 1991).

FEDERAL WETLAND POLICY INITIATIVES

Section 6217 of the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA)

The Coastal Zone Act, as reauthorized in 1990, included a new Section 6217 that requires states to develop and implement coastal nonpoint pollution control programs. Section 6217 broke new ground for federal nonpoint source management by requiring the use of "enforceable policies and mechanisms" by the states to address nonpoint source problems. Protection and restoration of wetlands and use of vegetated treatment systems for nonpoint source control are practices encouraged in guidance adopted pursuant to this legislation (USEPA 1993a). However, wetland protection is not a main focus of the law, and no regulatory or other mechanisms are established to forward this goal, so the real value for wetlands lies only in the practical guidance given on wetland restoration and protection strategies and technical approaches.

No Net Loss

In 1987, the National Wetlands Policy Forum was sponsored by the U.S. Environmental Protection Agency to advance protection of wetlands in the United States and to address major policy concerns relative to wetlands protection and management. The end result was a series of recommendations for improving wetlands protection that were agreed upon by the lawmakers, farmers, environmentalists, business leaders, and academics who participated in the forum. The major goal articulated by this group was "to achieve no net loss of the nation's overall wetlands base" and "to increase the quantity and quality of the nation's wetlands resource base" through voluntary and regulatory efforts in the long term. The federal government and many states have since adopted this goal. Former President Bush raised the profile of this philosophy when he made it a theme of his 1988 presidential campaign. The goal has been supported by the Clinton administration, and it is now an accepted guiding principle of EPA philosophy.

Ramsar Convention

On the international level, the United States is party to a treaty adopted at the 1971 Ramsar Convention on Wetlands of International Importance Especially to Waterfowl Habitat. The treaty was established to protect wetlands as ecosystems of international importance. The Ramsar Treaty was developed specifically to protect migratory waterfowl species that are dependent on certain wetlands and that do not observe international borders (Mitsch and Gosselink 1993). The objective of the treaty is to reduce wetlands loss and to encourage the recognition of the ecological functions and social and scientific values of wetlands. The Treaty represents an early, global act of recognition of the importance of wetlands and essentially serves to forward a "wise use " philosophy.

Chronology of Key Federal Legislation and Regulations Affecting Wetlands

The above discussion of federal government regulatory and non-regulatory wetland protection and restoration programs is by no means comprehensive, although it does cover the major, and perhaps most compelling, efforts made to date. The following is a more inclusive list of federal initiatives, and the reader is also referred to other sources, such as Wiebe and Heimlich (1995), Heimlich et al. (1994), Mitsch and Gosselink (1993), and GAO (1991).

- 1899 - Rivers and Harbors Act of 1899
  Approval by war secretary required for all construction activities in and deposition of refuse into navigable water.
- 1967 - Fish and Wildlife Coordination Act
  Required U.S. Army Corps of Engineers to include ecological effects in their regulations.
- 1969 - National Environmental Policy of 1969 (NEPA)
  Requires the filing of environmental impact statements (EIS) for major federal activities. EISs must identify environmental impacts of proposed activities and alternatives to those activities. The process has been applied to proposed federal actions affecting wetlands. NEPA can serve as a significant deterrent to controversial activities largely because of time delays and adverse publicity.
- 1972 - Federal Water Pollution Control Act Amendments of 1972 (Clean Water Act)
  Section 404 vested authority for wetlands regulations in the US Army Corps of Engineers and the EPA. Specifically, this refers to the authority to issue permits to discharge dredged and fill material into waters of the United States (Corps) and to review and veto Corps actions and policies (EPA).
- 1972 - Coastal Zone Management Act
  Authorized grants for state coastal zone management program planning and implementation.
- 1973 - Endangered Species Act
  Required federal agencies to ensure that any actions authorized would not jeopardize endangered or threatened species or hurt or destroy their habitat, including wetlands. It also prohibited the "taking" of an endangered species.

- 1973 - Flood Disaster Protection Act (reauthorized in 1977)
  Instituted a National Flood Insurance program offering federally subsidized flood insurance to states and local governments that enact regulations against floodplain development.
- 1977 - Amendments to Federal Water Pollution Control Act (Clean Water Act of 1977)
  Exempted from regulation certain farming, forestry, and ranching activities located in wetlands.
- 1977 - Executive Order 11988
  Floodplain Management
  Required government agencies, wherever possible, to avoid activity in and consider impact on floodplains.
- 1977 - Executive Order 11990
  Protection of Wetlands
  Required government agencies to provide leadership and take action to minimize the destruction, loss, or degradation of wetlands and to preserve and enhance the natural and beneficial values of wetlands in carrying out agency activities and programs affecting land use. It also ended all direct federal assistance for wetland conversion, including assistance with drainage and channelization.
- 1980 - Section 404(b)(1) Guidelines
  Final guidelines issued by EPA for evaluating Section 404 permit applications required by Section 404(b)(1) of the Clean Water Act.
- 1985 - Food Security Act of 1985 (Farm Bill)
  "Swampbuster" provision provided that producers converting wetlands after December 23, 1985 would no longer be eligible for commodity price supports, loans, crop insurance, disaster payments, and storage payments.
- 1986 - Corps Wetland Regulations
  U.S. Army Corps of Engineers issued a comprehensive set of regulations on wetlands at 51 Fed. Reg. 41206 (Nov. 13, 1986).
- 1986 - Emergency Wetlands Resources Act
  Promoted conservation through intensified cooperation among private interests and government agencies, and through increased acquisition efforts. Required development of a National Wetlands Priority Conservation Plan. It authorized acquisition of wetlands consistent with the Plan, and created revenue options for doing so. Included support for National Wetlands Inventory mapping initiative.
- 1986 - Tax Reform Act of 1986
  Eliminated favorable treatment of capital gains from land conversion and restricted landowners' ability to write off drainage costs, thereby reducing incentives for the sale or conversion of wetlands (Wiebe et al., 1995).
- 1989 - North American Wetlands Conservation Act of 1989
  Increased protection and restoration of wetlands under the North American Waterfowl Management Plan. A percentage of funds were obligated to wetland projects in Canada and Mexico, with the rest in the U.S. Funded in part by taxes on hunting equipment and by hunting fines.
- 1990 - Coastal Wetlands Planning, Protection, and Restoration Act
  Provided cost-share funding for restoration of coastal wetlands and funding for North American Waterfowl Management Plan projects.

- 1990 - Food, Agriculture, Conservation and Trade Act of 1990
  Established wetlands reserve program for purchase of easements on wetlands. Included a number of provisions or amendments to existing programs that affected wetlands, such as changes to Swampbuster and Conservation Reserve Program, and creation of the President's Water Quality Initiative.
- 1990 - Water Resources Development Act
  Required federal agencies to develop action plan to achieve no-net loss of wetlands. Prohibited U.S. Army Corps of Engineers from the use of 1989 Manual for Delineation of Wetlands, resulting in standardized use of the 1987 manual.

Sources: Want 1993; Mitsch and Gosselink 1993; GAO, 1991.

WETLAND PROTECTION AT THE STATE AND LOCAL LEVELS

As described early in this section, regulatory programs have distinct limitations for overall wetland protection. We have also outlined the federal non-regulatory programs that add to wetland protection in some way. Overall, however, a number of problems exist with these wetland protection efforts. In addition to the problems with regulatory programs outlined above, permitting tends to be inconsistently executed and can be duplicative and frustrating. Moreover, it is typically handicapped by limited budgets, staff, and expertise. One result is often inadequate compliance monitoring and enforcement (see Wetlands Mitigation section). At the same time, although most regulatory programs are limited in scope, there is a tendency toward overreliance on them as the protection solution. Further, the vast majority of both regulatory and non-regulatory programs are simply not structured to consider the setting that wetlands occupy in their protection approaches. Unregulated forces operating on wetlands include man's activities in the form of surrounding land uses, and natural forces, such as hydrology, fire, species movement, and others, which are interfered with by man's activities. In addition, there are often inadequate wetland maps and other data, such as information on high quality systems in need of protection or degraded candidates for restoration, on which to prioritize protection and management efforts. Clearly, successful wetland protection must utilize a comprehensive approach. State and local governments are the entities that must address these issues.

State Wetland Protection

States occupy perhaps the best position to take the lead on wetlands protection because they are more aware of and responsive to local needs than federal agencies, and at the same time they are sufficiently removed from the influences of local politics to play a key guiding role. Like federal protections, state efforts can be grouped by type of approach: regulation; incentive/disincentive; acquisition/legal restriction; restoration; and others, including policy statements, educational efforts, inventories, and other efforts. However, in addition to the tools used at the federal level, states and local governments have the ability to use measures traditionally reserved for them, such as land use and zoning authority, to assist in the protection of wetlands.

Most states have enacted laws that offer some manner of protection specifically for wetlands. In terms of regulatory protection, many states have promulgated wetland regulations, most by including wetlands in the definition of state waters (Salvesen 1990). Regulatory programs include direct regulation of activities in wetlands or disturbance to the water table (Salvesen 1990) and indirect regulations, such as floodplain protection laws and enforcement of state water quality standards. Some states have developed wetlands-specific water quality standards to support indirect regulation through CWA Section 401 Water Quality Certification. Coastal wetlands have received the most attention. Most coastal states now have laws to protect coastal wetlands as a result of the federal Coastal Zone Management Act of 1972; the laws have significantly reduced losses of these wetland types. However, by 1990 only 14 of the 30 coastal states had freshwater wetland regulations in place, and only one non-coastal state, North Dakota, had enacted wetland regulatory powers (Salvesen 1990).

The 1988 National Wetlands Policy Forum agreed that comprehensive statewide wetland strategies were the best way to implement the no net loss policy (Conservation Foundation 1988). States have experience in managing environmental programs; they can identify local economic and geographic factors that lead to wetlands loss; they can work with local governments to integrate wetland protection into comprehensive land use plans; and they can promote private stewardship through a variety of nonregulatory measures (World Wildlife Fund 1992). States have the opportunity to obtain funding from EPA to develop comprehensive wetland protection strategies under the EPA's State Wetlands Protection Grants Program. Under this program, states develop State Wetland Conservation Plans that outline strategies to achieve no net loss and other goals using both regulatory and non-regulatory protection approaches.

State Wetland Conservation Plans can address:

- an overall goal for state wetland policy, such as no net loss and net gain over time;
- information about the state's wetlands and threats to their continued functioning, such as mapping inventories and assessments;
- an assessment of current wetlands protection efforts and their limitations;
- an action plan, including guidance and funding for local governments to support development of local wetland conservation plans;
- a funding strategy; and
- a monitoring and evaluation plan (World Wildlife Fund 1992).

Specific measures available to states to fill gaps left by permitting programs include methods of legally restricting wetland activities, such as acquisition, scenic area programs, and transfer of development rights. Acquisition can include fee-simple purchase or purchase of easements on wetlands and establishment of wildlife refuges, sanctuaries, conservation areas, or multiple recreational use areas (USEPA 1995). States can collaborate with private conservation organizations and local land trusts to complement each other's programs. Conservation easement programs, land banks, and property tax incentives are protection approaches based on tax deductions or other economic incentives. States may also offer direct payment to landowners to protect, restore, and create wetlands; citizen educational programs; and voluntary private/public stewardship programs (USEPA 1995).

Local Wetland Protection

Local governments are key players in comprehensive wetland protection. Wetland strategic plans adopted on the local government level offer advantages such as:

- more diverse protection capabilities, such as water management, land use, and zoning authority;
- prioritizion and pre-designation of protection areas;
- landscape-scale consideration of wetland functions and values, allowing prioritization of protection and restoration efforts;
- meshing with other environmental protection and efforts and local programs, such as wildlife corridors, greenway planning, riparian protection, and floodplain regulation;
- greater ability to respond to cumulative impacts than permitting programs;
- ability to plan acceptable mitigation banking activities and to coordinate with wildlife corridor and other environmental protection efforts;
- provision of greater predictability to wetland permitting programs, and, overall, a more proactive approach to wetland protection.

While some local governments have adopted wetland protection ordinances, others have developed buffer, riparian, and other land protection ordinances, zoning overlay districts, master planning efforts which include wetlands protection and development permits.

The limitations to wetland protection at the local level are that wetlands often cross local government boundaries,; activities in one jurisdiction may impact wetlands in another jurisdiction in the same watershed, economic resources are generally limited at the local level, and local politics can interfere with larger protection goals. Thus, states may wish to retain a role and work together with local governments to effectively repair the historical legacy of wetland loss and degradation.

Public-Private Sector Partnerships

In recent years, EPA; state, tribal, and local governments; private landowners; industry representatives; nonprofit organizations; and the general public have formed partnerships in order to manage whole watersheds. One goal of these partnerships has been the implementation of a comprehensive, integrated approach to wetland protection and pollution control. The watershed approach to protection of wetlands is based on the recognition that water, land, and wetland resources are intimately inter-connected within each watershed.

A task force or working group may identify the most significant threats to water quality in a watershed based on a comparative risk analysis of human health and ecological and economic impacts, and target specific problems. Once well-defined goals and objectives for chemical, physical, and biotic water quality have been established, a management plan to meet those objectives can be implemented (USEPA 1991b).

Advance Identification of Disposal Areas (ADID)

One example of a public-private sector partnership is the Advance Identification of Disposal areas (ADID) planning process (Salvesen 1990; USEPA 1995). In this program, EPA cooperates with the Corps, state and local governments, and the public to determine in advance the suitability or unsuitability of all wetlands for the discharge of dredged and fill material (i.e., development activities). The ADID process involves identification of wetlands in selected watershed(s), followed by determination of wetland functions and values which could be lost due to development activities. Often ADID goals are simply to map wetland resources as a contribution to improved local planning efforts or water quality management. The development of ADID plans is resource intensive, but the information generated can play an extremely valuable and important part in wetlands protection (Salvesen 1990; USEPA 1995)

North American Waterfowl Management Plan

In 1986, the United States and Canada continued collaboration initiated through the Ramsar Convention by developing the North American Waterfowl Management Plan. The goal of the Plan is to conserve and restore, in both countries, 2.4 million hectares of wetland habitat used by waterfowl (Mitsch and Gosselink 1993). The support and financial involvement of private conservation organizations, such as Ducks Unlimited, has been critical to the success of the Plan. Public and private partnerships in both countries will be required for successful implementation of the Plan, as there are no federal funds provided by either the United States or Canada.

VII. Regulatory Last Resort: Mitigation

Successful Mitigation

INTRODUCTION

Under the federal, and various state and local, regulatory programs, land development activities which may adversely impact wetlands require consent through permit approval from the regulating agency. At the federal level, under the Clean Water Act Section 404(b)(1) Guidelines (codified at 40 CFR 230) and U.S. Army Corps of Engineers (Corps) regulations (codified at 33 CFR 320.4(r)), the Corps is obligated to require mitigation (i.e., compensation) for any unavoidable impacts on a wetland as a condition of permit approval. The developer can be required to enhance, restore, or create wetlands on or near the development site. Mitigation projects are meant to replace, on at least a one-to-one basis, the lost functions and values of natural wetlands affected by development activities.

Although mitigation ideally provides a mechanism for accommodating both development and the protection of wetland functions and values, the low rate of success of mitigation projects is a subject of concern (Wolf et al. 1986, Kusler and Kentula 1990, Dobberteen and Nickerson 1991, Salveson 1995). The following section examines issues related to the success of mitigation projects.

REGULATORY ISSUES

As discussed in the Wetland Protection section, wetland regulation remains a contentious exercise of government authority. As a result, agencies are under substantial pressure to keep permitting requirements to the minimum necessary to ensure compliance with rules (Salveson 1990, Gannon, pers. comm). For example, according to Erwin (1990b), few permitted wetland mitigation projects follow scientific designs. Instead, projects are often negotiated between the applicant and the regulatory agency with less site assessment, or mitigation design rigor than might be necessary to guarantee success.

Permit Compliance Surveys Find Gaps

Field surveys of permitted mitigation sites have identified a number of weaknesses in the mitigation process. First, permitting agencies sometimes allow the substitution of unlike types of wetlands in mitigation or require less-than-equal quantities of mitigation. Second, permittees frequently do not construct wetlands, construct insufficient area of wetlands, or construct wetlands otherwise out-of-compliance with the design specified in their permit. Third, constructed wetlands frequently do not function as anticipated. Finally, regular agency-conducted compliance monitoring is often inconsistent or cursory.

Lack of adherence to permits and project design and lack of monitoring are pervasive across mitigation projects (Erwin 1991, King 1991, Kentula et al. 1992b). Fifty-eight permits issued in Oregon between January 1977 and January 1987 degraded 74 hectares of wetlands, yet only 42 hectares were created, resulting in a net acreage loss of 43% (Kentula et al. 1992b). The research team also found that in the state of Washington, between 1980 and 1986, 35 permits were issued allowing impact to 61 hectares, but requiring the creation or restoration of only 45 hectares. This represents a net loss of 26% of the original wetland area. The wetland types created in both states were generally not the same types as those affected by the permitted activities.

Authors of a study of 40 mitigation projects in south Florida reported the failure or incomplete creation of 24 projects (60%), causing a 50% loss of wetlands area (Erwin 1991). Failure was judged to be a result of inappropriate hydrology in all cases. Another study, conducted by the Florida Department of Environmental Regulation (DER), found that fewer than 50% of the permitted projects could be considered ecologically successful (Redmond 1992). Many mitigation projects had not been initiated, although the impacts requiring mitigation had occurred. Of the freshwater sites, only 12% were successfully restored.

Wetland creation following mining activity is economically attractive because federal law requiring mine site reclamation necessitates large-scale earthmoving that involves creation of open water bodies. Wetlands created in this process are often used in mitigation banks. The Federal Abandoned Mine lands program in Wyoming reclaimed and created 300 wetlands (McKinstry and Anderson 1994). Of 92 created wetlands investigated, 55 (60%) were smaller than indicated in engineering plans and substantially smaller in dry years, resulting in less than a 1:1 acreage replacement.

For those created wetlands that appear successful, few have been evaluated for functionality in comparison to natural wetlands, or more specifically, to the natural wetland they replace. Agencies take the position that regulatory "science" can only strive to be the lowest-cost facsimile of true science that still gives the greatest likelihood of success. In many regulatory programs, the same personnel are responsible for both permit application review and compliance monitoring. While, typically, there are explicit statutory time frames for the processing of permit applications, compliance evaluations have no statutorily mandated schedule. Under agency budget constraints, staff are often forced to simplify or neglect compliance evaluations and associated enforcement (Salveson 1990, Gannon, pers. comm.). Any compliance activities that are performed by regulatory staff are likely to be only cursory inventories for the presence of key components, such as grading, adequate hydrology, and vegetative establishment. Costly, detailed functional studies are not feasible, and must be left to other parties, within or outside the agencies, if they are conducted at all. This reliance on form vs. function is analogous to the use of technology-based vs. performance-based standards for water or air quality compliance. The first is a presumptive test, with the agency making the presumption that functions will follow appropriate form, while the latter measures the actual resource or functions. Detailed functional evaluations of a subset of all mitigation projects to test the validity of the presumption that functions follow form would provide important information regarding the probability of mitigation success and the appropriateness of regulatory assumptions.

Functional Replacement Issues

A significant problem noted in mitigation compliance surveys is that while complex wetlands may be affected, different, simpler wetland types are often created through mitigation programs

(Kentula 1992b). Permitting agencies may attempt to address the functional differences between degraded and proposed systems by requiring greater acreage of the unequal habitat. This has historically been based on regulators' hesitance to impose overly burdensome requirements on applicants and on the "bigger is better" philosophy: if more habitat is created, even if it is significantly different and attracts different species, it is equivalent to the original, natural system. However, as the understanding of wetland types and functions has increased, this practice has been recognized as potentially detrimental within a watershed. By allowing out-of-kind creation or restoration, regulatory agencies cause overall local gains of certain common, easily attained, earlier successional-stage wetland functions, while concurrent losses are of increasingly scarce, difficult to replace, more complex functions.

Out-of-kind creation can result from agency oversights or lax criteria during permitting, the first of which agencies are very reluctant to attempt redressing after the fact. In terms of lax criteria, goals of mitigation projects as submitted may be vague, unrealistic, or ecologically unsound. If the goal is defined by the applicant and accepted by the agency simply as creation of wildlife habitat, any marsh or aquatic habitat that attracts ducks may be considered successful wetland creation (IWR 1994, ELI 1992, Erwin 1990b). The presence of waterfowl may be used as the criterion for deeming a created wetland successful, although an ecosystem is made up of much more than a few duck species.

Gaps in technical understanding of ecological functions make it difficult for regulators to require applicants to quantify such functions in site assessments and mitigation designs, which can result in out-of-kind creation. Information on the roles of fish, reptiles, amphibians, nongame birds and mammals in wetlands is scarce and generally not required, or only nominally mentioned, in mitigation plans, even though such information is essential for effective mitigation (Weller 1990, IWR 1994). It could be argued that even if technical understanding of all the biotic functions of wetlands were in place, it would still be unreasonable to require exhaustive site assessments and design details on a routine basis.

It may be helpful for agencies to establish clear policy guidance to address the issue of out-of-kind creation. In some cases, such compensation can be appropriate. For example, when a wetland is significantly degraded, and the opportunity exists to create systems that are functionally similar to undisturbed wetlands in the area, out-of-kind compensation can be advantageous. However, when wetlands are not functionally impaired, out-of-kind replacement might, as a rule, be discouraged. For example, the state of Florida has a "type for type" policy for wetland mitigation that is meant to prevent such discrepancies (Erwin 1990a). To guide the process of achieving functional replacement, regulators may take the approach of requiring prioritization of functions in proposed impact wetlands. This can be a valuable tool for ordering the process, but safeguards must be maintained against losing sight of all but the highest-priority functions.

Part of the problem in obtaining type-for-type replacement can be caused by a lack of sufficient information about the impacts that will result from the permitted activity. More complex wetland ecosystems merit more involved site assessment, but applicants are concerned with minimizing costs, particularly in the uncertain realm of wetland regulation, and routinely provide less than full information. Agencies, meanwhile, are expected to avoid imposing unnecessary information requests on applicants. Such circumstances require agency staff to use professional judgment, based on field experience, experience with applicants, and time management demands, to determine when more involved site assessment and mitigation design are merited. However, regulatory programs are often understaffed, and personnel turnover can be high, yielding low experience levels. Some regulatory programs have criteria in place to guide the professional judgment process, and such criteria can provide support for harried staff people. Given all of these factors, adequate site information on which to base effective mitigation efforts is sometimes not obtained.

Location-Dependent Functions

Another question related to functional replacement involves spatial replacement of functions. Specifically, this refers to assuring that the mitigation wetland is located in a similar landscape position to or nearby the wetland affected by the permit to allow the replacement wetland to perform the functions that the original wetland did. Functions tied to landscape position include aspects of water storage and attenuation, species habitat, and nutrient cycling. In small- to medium-scale developments, position is less of an issue. However, in large developments and in mitigation banks, loss of location-driven functions can be a concern. Replication of wetland functions can be at odds with the creation of one or two large wetland systems to offset a number of small impacts. For example, small isolated wetlands in upland landscapes perform many habitat functions that would be lost in a large wetland hydrologically tied to a floodplain (Robinson 1995, Means 1990, Laney 1988, Moler 1987, Beissinger and Takekawa 1983, Kushlan 1981). The importance of this issue can be difficult to gauge in a given case, and may as a result be left behind by overburdened regulatory staff. Agencies may need to develop guidelines to facilitate evaluation of this issue.

Temporal Replacement of Functions

The standard practice of constructing mitigation areas concurrently with conducting permitted wetland impacts results in temporal loss of wetland functions while the newly created areas become established, a process that may take years, even under favorable conditions. Many regulatory programs do not attempt to offset this temporal loss of functions. One approach that can be used to do so is to require a greater ratio of mitigation-to-impact wetland acreage than one-to-one. In this case, the process of setting ratios becomes an issue, since a greater quantity of an early successional habitat does not truly replace the lost system, and amounts to trading apples and oranges, or more accurately, trading green oranges and ripe oranges. It could be argued that, given the historic losses of wetlands in the U.S. and the less-than-certain nature of mitigation technology, wetland impacts should not be allowed prior to full functional establishment of mitigation areas, or at least prior to reasonable assurance of successful establishment as indicated through monitoring. However, the planning required for such prior mitigation would, by conventional development standards, be feasible only in large, phased developments planned years into the future. One drawback to this prior mitigation approach is that it defeats the practice, encouraged by regulatory agencies, of "saving", or physically transferring and incorporating, biotic components of the wetland to be eliminated into the prepared mitigation site to seed it with local genetic stock and to facilitate its development.

ECONOMIC ISSUES

The mitigation services marketplace can affect project quality. The mitigation component of a development proposal is often subcontracted by an engineering firm to a consulting firm specializing in wetland mitigation. Subcontracting puts consulting firms in a competitive bidding process that leads to underbudgeting and an inaccurate impression of what is economically and ecologically possible (Erwin 1990b, Kentula et al. 1992a, King and Bohlen 1994). As a result, cost estimates for wetland mitigation projects listed by permit seekers are often unreasonably low, projects are underfunded, and failure rates are high (King and Bohlen 1994).

Assessments of mitigation projects in Florida, California, and mid-Atlantic states indicated that of sampled projects, over 50% failed (King and Bohlen 1994). Failures were linked not only to improper technical decisions, but to "bad planning, poor execution, and lack of monitoring and maintenance after initial construction as a result of underfunding or cost-cutting because regulatory oversight is limited."

Other financial incentives in the development realm also reward low-cost projects rather than high-quality wetland ecosystems or successful wetlands (King 1991). Costs are higher for smaller projects and for detailed grading work typically needed to emulate a natural system (King 1991). Associated development projects often require fill material, creating an impetus for over-excavated designs with greater slope and depth than the natural systems being mitigated. Thus the bias is towards creating larger wetlands in the form of ponds rather than the more complex natural systems that are being eliminated for development (Kentula et al. 1992a, King and Bohlen 1994). Furthermore, wetland mitigation projects may double as stormwater detention basins. In such cases, emulation of wetland topography with gradually sloped emergent zones above ponding elevation necessitates expansion of the basins beyond the acreage needed for stormwater purposes alone to provide equivalent stormwater storage volume. To avoid this loss of development acreage, designers often disregard environmental design issues and propose steep-sided open water bodies at the expense of functional wetland replacement (Gannon, pers. comm.).

TECHNOLOGICAL ISSUES

Successful wetland creation and major restoration projects still involve a great deal of uncertainty, particularly those that attempt to create or restore difficult wetland types (Kusler and Kentula 1990). Many types of freshwater wetlands that are slated for development are difficult or perhaps impossible to reproduce (Dahl and Johnson 1991, Kentula et al. 1992b). Bogs or fens, for instance, require hundreds or even thousands of years to mature. Soil moisture regimes and organic material accumulation also make systems such as deepwater cypress, tupelo, white cedar, or bay swamp extremely difficult to create or restore (Clewell 1990). Even "simple" ecosystems, such as marshes, have feedback loops and complex, interdependent interactions that are not fully understood (Mitsch and Gosselink 1993, Kusler and Kentula 1990). In a given permitting scenario, a decisionmaker faced with proposed wetland impacts must decide whether a functional equivalent of the wetland that will be eliminated by the permitted activity can be successfully created. Given the uncertain technology of mitigation, regulators sometimes face difficult decisions on what is too questionable, often in the face of substantial pressure to permit the activity.

Mitigation activities for forested and shrub wetlands typically result in out-of-kind creation because of the difficulty, expense, and uncertainty associated with creating such wetland systems (Kentula et al. 1992a, Bohlen and King 1994). Some forested wetlands represent advanced successional stages, and perhaps the most successful replacement efforts for these systems to-date have attempted to relocate system components intact, which has required large up-front financial expenditures (Gannon, pers. comm.). These efforts have been few in number. In a significant percentage of cases, the verdict is not yet in because of the decades-long time frames minimally required for the functional establishment of these mature systems. Efforts thus far have resulted in early successional ecosystems with the potential to develop toward the emulated wetlands over significant time spans. In some cases it may be possible to shorten successional time frames with intervention, such as planting of shade-dependent species once a canopy is developed. Certain forested wetlands are easier to construct than others; Massachusetts has been creating red maple (Acer rubrum) forested wetlands for some time with apparent structural success (Dobberteen and Nickerson 1991). This success is probably due to the early successional nature of red maple-dominated wetlands.

Mitigation or restoration of coastal habitats requires careful understanding of physical processes, ecology, and hydrology (Lewis 1994). Restoration of diked marshes requires re-establishment of tidal patterns. However, removing dikes or plugging ditches does not necessarily lead to the return of marsh vegetation (Buchsbaum 1994, Mitsch and Gosselink 1993). Diked areas may have subsided or eroded, and may become permanently flooded or remain unflooded. Establishing substrate and plantings at precisely suited elevations relative to tidal regime appears to be the most important and most challenging factor for coastal mitigation or restoration success (Broome 1990, Lewis 1990). Also very important but often technically challenging are buffering wave energy and providing adequate drainage through gradual sloping and sufficient tidal connections.

MEASURES OF SUCCESS

Scientists agree that successful mitigation is determined by the ability of a created or restored wetland to provide the biological, hydrological, and biogeochemical functions of the original wetland or a natural reference wetland (Erwin 1990a, Erwin 1990b, Kusler and Kentula 1990, Mitsch and Gosselink 1993, IWR 1994). The following characteristics can be used to judge success based on comparison to the emulated system:

- Landscape position and contour design emulating that of the affected wetland or a chosen reference system. Successful wetland creation or restoration is often determined by such basic structural considerations (Erwin 1990a).
- A self-perpetuating hydroperiod similar to that of the emulated wetland. The major determinant of success is the presence of a self-perpetuating oscillating hydrologic regime in the created or restored wetland (Niering 1990).Achieving a self-perpetuating hydroperiod in a created system requires an understanding of the geohydrology which causes the reduced conditions in which wetland species thrive (D'Avanzo 1990).An

appropriate regime should generate conditions such as those described in the 1987 Corps Delineation Manual (USACOE 1987). Colonization by wetland plants and use of the system by wetland fauna are gross indicators of an appropriate hydroperiod.

- Successful colonization and dominance of wetland plant species similar to the emulated wetland.Vegetation characteristics that can be measured include below- and above-ground biomass, plant density, and number of reproductive stalks. Metrics of success can vary. The Corps requires that 80 percent of a created marsh area be covered with grasses after three years (Erwin 1990b). The state of Massachusetts requires that a created wetland have a 75% cover of indigenous hydrophytes within two growing seasons (Jarman et al. 1991). Outcompetition by upland species, decreasing diversity, invasion of exotic species, or lack of vegetative colonization may be indicators of the need to alter the design of the system or perform selective maintenance, or of system failure.
- Chemical and physical properties characteristic of wetlands soils and similar to the emulated wetland. The 1987 Corps Delineation Manual (USACOE 1987) can be used as a guideline to determine whether the soils in the constructed or restored area display wetland characteristics. Nitrogen, phosphorus, and organic matter levels and primary productivity should increase with the age of the created site. Nitrogen and phosphorus should reach reference wetland concentrations in 15 - 30 years (D'Avanzo 1990, Craft et al. 1988).
- Diversity, density, and biomass of animal species similar to the emulated wetland. Monitoring for certain indicator species is a common method used to evaluate this characteristic (Weller 1990, Croonquist and Brooks 1991). Use of a wetland habitat value model, habitat assessment procedure, or diversity index is a method recommended by the Corps to determine similarities between the created or restored system and a natural wetland (IWR 1994). An assessment of how biotic communities develop and interact both within the created/restored wetland and between it and the surrounding landscape is more indicative of success than is an assessment of individual indicator species.

All of the above criteria for success are interdependent; a failure in one, particularly hydroperiod, can lead to a failure in others over time. It can be seen from the bullets above that the essential, requisite conditions used to identify a natural wetland (appropriate hydrology, hydrophytes, and hydric soils) can also be used to determine whether the created/restored area functions as a wetland.

External forces other than hydrologic factors can bear on the success of a mitigation project. If water quality upstream is poor or incoming runoff or ground water movement is polluted, particularly with toxic compounds, pre-treatment of these sources may be necessary for successful establishment of a mitigation wetland. Upland buffers (see Improving the Likelihood of Successful Mitigation below) and protective measures such as structural and management best management practices (BMPs)

, in the contributing watershed protect the wetland and facilitate its establishment. Many wetland-dependent animal species require upland habitat adjacent to wetlands for part of their life cycle as well. Upland buffers can thus facilitate development of a more diverse wetland ecosystem.

COMMON MITIGATION PITFALLS

Some of the most common immediate reasons for mitigation/restoration efforts to fall short of success or to be set back include:

- Inability to accurately estimate or lack of awareness of the following site features during planning
    - hydroperiod
    - water depth
    - water supply
    - substrate
    - nutrient levels
    - toxic compounds,
- Technical aspects of design are unsound,
- The project is not constructed as planned,
- Contingencies not adequately dealt with:
    - exotic species invasion
    - grazing of plantings
    - catastrophic events (floods, storms, droughts)
    - human impacts (mowing, ditching, off-road vehicles etc.)
- Insufficient follow-through:
    - inadequate monitoring,
    - maintenance is ignored.

(Kusler and Kentula 1990, Mitsch and Gosselink 1993, McKinstry and Anderson 1993):

IMPROVING THE LIKELIHOOD OF SUCCESSFUL MITIGATION

Permit-related failure of mitigation projects can be reduced by incorporating the following requirements into a regulatory program (Josselyn et al. 1990):

- Permit applicants should provide a sufficiently thorough habitat evaluation of the impact site prior to destruction to allow useful subsequent comparison of the mitigation wetland. Evaluation level of detail should be flexible and predicated on system complexity and difficulty of replacement as determined by initial site surveillance. Evaluations should address the following:
    - landscape position and landscape-related functions
    - topographic information
    - soils assessment
    - surficial geology
    - vegetation
    - fixed point panoramic photographs
    - rainfall and water level data
    - wildlife utilization
    - fish and macroinvertebrate data (Erwin 1990b).

The permit application must include design objectives, detailed design drawings, and targeted functions and values.

Use of appropriate substrate is critical in ensuring soil conditions and hydrology that emulate those of reference wetlands. Sand, for instance, is often inappropriately used as substrate. Too much sand will cause the wetland to be leakier than a natural system. Lower organic matter, and as a result, lower soil nitrogen and phosphorus levels, than in a natural system are common (D'Avanzo 1990). Applicants should be encouraged or required to transfer organic or other surface substrate from affected wetlands to mitigation sites. If organic material from a site other than the wetland affected by the permitted activity is to be used for substrate, the applicant should be required to identify the source of material and apparent floristic composition. Adequate soil rooting volume above hardpan important for successful restoration of forested wetlands (Clewell 1990).

Applicants should be required to provide a management program and long-term maintenance provisions for created wetlands, including a maintenance schedule for eradication of undesirable species; a schedule for and content of reporting; identification of a monitoring and maintenance contractor; identification of the responsible entity for mitigation areas; contingency plans should mitigation fail; demonstration of responsible entity's financial capability; details on performance bonds or other financial instruments if appropriate; an instrument establishing homeowners associations' or other responsible entity's obligations; and necessary zoning protection steps. Permits should in turn formalize all such information.

The mitigation site should be constructed prior to or concurrently with the permitted project to reduce non-compliance and to facilitate use in the created wetland of materials from the wetland affected by the permitted development activity.

Maintenance activity, largely removal of undesirable vegetation, on a frequent basis following construction, and less often as desirable species become established, is essential for achieving the desired ecological communities within a reasonable time frame.

The developer should conduct post-creation monitoring assessments once construction is completed, on a more frequent basis initially, then at larger regular intervals (at least annually) for a number of years (typically 5 to 15), depending on the system type, to document progress or the need for remedial action.

Mitigation sites frequently require buffering from adjacent human activities and sometimes from herbivores (Clewell 1990). Mitigation design should include buffering elements suited to adjacent land use activities. Such elements include a simple setback distance of vegetated area; a buffer of shrub/tree plantings on the perimeter of the wetland or setback area; informational signs at intervals around wetland perimeter; and fencing. Issued permits should include, as applicable, conditions to inform future lot owners of restrictions, such as requirements for deed restrictions on adjacent development lots or lots extending into mitigation areas; full notification to potential purchasers; and transfer of responsibilities to subsequent owners.

Successful establishment of a wetland takes time. Thus, compliance with permit conditions typically requires long-term monitoring. Natural wetlands have evolved over tens, hundreds, or thousands of years. While long-term trends in the structural establishment of herbaceous wetlands may become apparent within as little as two to three years, it may take 15 years for a carefully created forested wetland to begin to achieve canopy closure, and to begin to look and function like a natural forested system, and decades before it approximates the structure and function of the habitat that it was intended to duplicate (Craft et al. 1988, D'Avanzo 1990).

Mitigation Banking

History and Concept

Wetlands mitigation banking is the creation, restoration, or under certain circumstances the increased protection, of an area of functioning wetland in advance of, and to offset anticipated wetland impacts within the same ecoregion. This concept originated in response to the initiation of wetland regulatory programs, and was intended to expedite the regulatory approval process for allowing wetland impacts. As wetland regulations were originally implemented, developers and governmental agencies with regular construction needs, such as departments of transportation, faced recurring and unpredictable time delays and costs in obtaining permitting approval for projects that involved wetland impacts. They sought a means of advance planning that would make the permitting process more reliable and would minimize costs. From this need the concept of mitigation banking emerged. While the typical wetland bank involves creation of wetlands from upland area, banking has been expanded to include other compensatory activities. These include restoration or enhancement of degraded wetland and, in rare cases, providing more stringent protection for wetland or wetland/upland habitat associations that are otherwise threatened by human activities not subject to regulatory control. Throughout this discussion, the term "bank" will connote a unified planning effort involving any of these advance forms of wetland mitigation, singly or in combination.

Mitigation banking is different from the normal wetland permitting process in two key aspects. First, it attempts to construct mitigation areas, or bank wetlands, far enough in advance of anticipated impacts in the area to attain fully functional bank wetlands by the time impacts are contemplated, in theory allowing a simple, one-to-one acreage and functional trade in "real time". Second, banks are typically large in area to provide this trading service for numerous contemplated impacts, as opposed to the typical impact-by-impact process associated with conventional wetland permitting.

The general process occurs as follows. The need for a bank is identified by a transportation agency with road construction needs; local or state government planning agency identifying watershed restoration needs; developer planning a large, phased project; commercial enterpreneur; or other party anticipating future mitigation needs in a given area. All banks require the acquisition or possession of a long-term interest in a piece of land by such a corporate, non-profit, or government "sponsor". A site is chosen based on suitability to support the anticipated wetland functional needs. The sponsor establishes dialogue with relevant wetland permitting agencies during these early planning stages. Agencies strongly encourage or require, depending on regulatory jurisdiction, submittal of information on the character of the bank. The bank is designed, depending on its goals, to replace either the anticipated functional losses or identified historical functional losses within a specified trading area. Watershed boundaries are often used to define the trading area based on water resource replacement rationales, but ecoregional or other boundaries may also be used. Regardless of the type of bank created, its value is determined by quantifying the created or restored wetland functions in terms of "credits". Credits may be calculated simply by the amount of acreage and the wetland type, by quantifying habitat, or by quantifying physical and biological functions and social values (IWR 1992). At some point, a permit or other instrument is finalized establishing the bank's: goals, ownership, location, size, wetland and/or other resource types included, trading area, crediting methods and accounting procedures, performance and success criteria, monitoring and reporting protocol, contingency plans, financial assurances, long-term responsibility, and detailed construction plans (Federal Register 1995). Subsequent permit applicants proposing wetland impacts that meet the bank's criteria must first meet all other normal wetland permitting requirements imposed by an agency, such as avoidance and minimization of impacts prior to proposing mitigation. Such applicants can then withdraw "debits" from the bank based on anticipated wetland functional losses due to their development activities.

Federal Banking Guidelines

Final, joint federal agency guidance, effective December 28, 1995, encourages the establishment and appropriate use of mitigation banks in the Clean Water Act Section 404 and Farm Bill Swampbuster programs (Federal Register 1995). The guidance defines mitigation banking as:

wetland restoration, creation, enhancement, and in exceptional circumstances, preservation undertaken expressly for the purpose of compensating for unavoidable wetland losses in advance of development actions, when such compensation cannot be achieved at the development site or would not be as environmentally beneficial.

It further states that banking typically involves consolidation of small fragmented mitigation projects into one large contiguous site. Banks, ideally functioning in advance of development impacts, are seen as a way of reducing uncertainty in the federal permitting programs by having credit available to applicants. They can also more effectively replace lost wetland functions within a watershed by consolidating compensation requirements, and can provide economies of scale relating to planning, implementation, monitoring and management of mitigation projects. The guidelines stress that credits may only be authorized when adverse impacts are unavoidable.

Procedurally, prospective bank sponsors are encouraged to first discuss their proposal with the appropriate agencies, then to submit a prospectus to the Corps or the NRCS to initiate the formal agency review process. The prospectus should discuss the objectives of the bank and how it will be established and operated. It should include detailed physical and legal characteristics such as those identified above in the concepts sub-section. The prospectus will be reviewed by a Mitigation Bank Review Team with representatives from each relevant agency. This team and the bank sponsor will eventually agree on an "instrument" that embodies the information in the prospectus.

The sponsor will be responsible for the bank wetlands' physical success, including monitoring, reporting, and remedial action, and for successful operation of the exchange system. The expected monitoring period is five years, longer for forested and other projects. The greater the risk of bank failure, the higher the financial assurances required. The instrument should identify long-term management/ownership of the bank resources. The bank resources should be protected in perpetuity with appropriate real estate arrangements, such as conservation easements or transfer of title to an agency or non-profit conservation organization.

The guidelines identify a number of notable planning considerations. They encourage setting the objectives for a bank in advance of site selection, driven by the anticipated mitigation need. Ecological suitability of a site will be weighed by the agencies, with importance placed on size and location of the site relative to other ecological features, hydrologic sources, compatibility with adjacent land uses and watershed management plans, and other factors.

On the issue of types of acceptable compensatory mitigation, the guidelines state that, "In-kind compensation should generally be required. Out-of-kind compensation may be acceptable if it is determined to be practicable and environmentally preferable to in-kind compensation (e.g., of greater ecological value to a particular region)." As with normal compensation protocol, restoration should be the first option considered when siting a bank, since it typically has the greatest likelihood of success. Preservation of wetlands or other aquatic resources may be given credit if it is done in conjunction with restoration, creation, or enhancement of wetlands, and to the extent that such preservation augments the functions of the created, restored, or enhanced wetlands. Further, preservation of wetlands may be authorized as the sole basis for generating credits in mitigation banks only in exceptional circumstances requiring careful judgment. Two key factors to be judged are whether the wetlands proposed for preservation: perform functions important to the region; and "are under demonstrable threat of loss or substantial degradation due to human activities that might not otherwise be expected to be restricted. The existence of a demonstrable threat will be based on clear evidence of destructive land use changes which are consistent with local and regional land use trends and are not the consequence of actions under the control of the bank sponsor." Credit may be given for the inclusion of upland areas with in a bank "only to the degree that such features increase the overall ecological functioning of the bank."

The desire to withdraw credits from a bank before it "matures", or is fully functional, invariably arises in mitigation bank projects. The general approach outlined is that the number of credits available for withdrawal should be commensurate with the functional level attained by a bank at the time of withdrawal. The agencies identify minimum actions to be taken before withdrawals will be allowed, involving approval of mitigation plans, acquisition of the site, and establishment of financial assurances. In addition, they state that "initial physical and biological improvements should be completed no later than the first full growing season following initial debiting of a bank." In these circumstances, where withdrawals are made prior to construction, higher compensation ratios may be required to offset temporal loss of functions that occurs (see below).

The federal track record on mitigation bank permitting prior to formal adoption of the guidelines extends back to the early 1980's under the Clean Water Act Section 404 program (ELI 1992, Short, 1988). Approximately 100 mitigation banks are already in operation or are being constructed in 34 states across the country (IWR 1992, Salveson 1995). Most banks are owned and operated by state transportation departments, port authorities, and federal agencies. An increasing number of entrepreneurial banks, known as commercial banks, are selling mitigation credits on the market (IWR 1992, Salveson 1995). These banks offer the economy-of-scale advantages of large-scale projects and greater planning flexibility for developers (Kusler 1992).

Banking Issues

Temporal Loss of Wetland Functions:

Ideally, mitigation banks should be created in advance of proposed development activities, and should be functionally equivalent to the wetland being impacted before credits are withdrawn. In common practice, even government agencies, such as state departments of transportation, may plan and budget only a few years in advance and have only some idea of their mitigation needs (IWR 1992). Yet, bank planning and the permitting process alone may take up to a few years, while subsequent implementation and functional establishment of banks can take at least ten years, with no guarantee of success. This incompatibility raises the issues of temporal loss of wetland functions and remedial/alternative planning and responsibility, and brings into question the practice of granting credit exchanges at a one-to-one ratio in advance of the existence of a functioning bank. A bank that is not constructed in advance of wetland impacts results in temporal loss of wetland functions, and is similar in that regard to wetland mitigation that occurs under normal (non-banked) wetland permitting scenarios. Construction of bank wetlands could potentially be delayed even beyond the time of debited wetland impacts, since with the banking process, impact and mitigation are not directly coupled in the same permit application and the same development site as they are under normal permitting scenarios. One method of offsetting this temporal loss of function is to require a greater ratio of mitigation-to-impact wetland acreage than one-to-one, as recommended in the recent federal guidance. In this case, the method of quantifying ratios becomes an issue, since a greater quantity of an early successional habitat does not truly replace the lost system, and amounts to trading apples and oranges, or more appropriately, trading green oranges and ripe oranges. Some observers believe that given the historic losses of wetlands in the U.S., and the less-than-certain nature of wetland creation technology in general, wetland impacts should not be allowed prior to full functional establishment of bank wetlands, or at least prior to reasonable assurance of successful establishment based on monitoring indications. However, such a policy would be unreasonable without similarly changing normal wetland permitting criteria, which accept concurrent wetland impacts and mitigation area construction as routine. In any case, the issue of temporal loss of wetland functions offers no easy answers.

Other Functional Replacement Issues:

While financial assurances may reduce bank failure rates, they do not ensure that success will equate to type-for-type replacement. Unless bank functional criteria are established during permitting, simple, low-cost systems, such as ponds with water lilies, that may perform as wetlands in the broad sense, but are functionally unlike impacted wetlands, could become more common (Salveson 1995). Such systems are typically easier to establish and not functionally equivalent to the complex natural systems for which they are traded (see Mitigation Success section).

The issue of functional replacement must be addressed during permitting. Several questions arise here. One of these is how specific the functional replacement must be. The concept of a mitigation bank involves predicting both the types of habitat and t he proportions of those habitat types that will need to be impacted by future development within the trading area. At some level of functional specificity, there will be unavoidable inability to predict or replicate site-specific elements of lost wetland s. Agencies must perform the difficult tasks of setting defensible practical limits on the degree of functional replacement required, and of establishing protocol for situations where insufficient similarity is achieved or where unequal proportions of the different habitats are created. In these cases, criteria for the trading of "apples and oranges" must be established, or agencies may be placed in the unpopular position of requiring remedial actions on desirable but differently functioning wetland habitat.

Another question related to functional replacement involves spatial replacement of functions. The broadest issue here is establishment of the spatial applicability, or trading limits, of the bank. Wetlands perform many functions, and spatial limits set for habitat functions provided for certain species may not coincide with those set for water quality values provided to the watershed. Also, practical considerations related to including sufficient future development area to generate the acreage of impacts being offset by the bank to make the bank economically supportable arise as well. In practice, most banks use hydrologic spatial (i.e. watershed) boundaries because of their ease of definition and the relatively universal likelihood of water quality and quantity functions and values being at stake. The recent federal guidance bases limits of the bank "service area" on hydrologic and biotic criteria, and recommends using watershed or ecoregional boundaries (Federal Register 1995).

A difficult part of spatial replacement of functions stems from the effect of location or landscape position on the functions performed by wetlands. A wetland targeted for impact may provide local water storage functions, species habitat that depends on the wetland's landscape position, or local water quality functions. These functions may be lost through the banking process, since bank wetlands may be created a significant distance away from impact wetlands or in a different landscape position. Replication of such landscape position-derived functions can even be strongly at odds with the concept of creating one large wetland system to offset numerous small future impacts. For example, small isolated wetlands in upland landscapes perform many habitat functions that would be lost in a large wetland hydrologically tied into a floodplain (Robinson 1995, Means 1990, Laney 1988, Moler 1987, Beissinger and Takekawa 1983, Kushlan 1981). Regulatory agencies should be vigilant to maintain this often-overlooked but important issue in the list of considerations that go into banking negotiations. They may need to exclude the use of banks for certain types of wetland impacts, or require designs to incorporate upland areas that recreate certain landscape function s.

The recent federal guidance gives no strong direction on this issue. It recognizes that on-site mitigation may be preferable in the types of circumstances described above, but states that this should not preclude the use of a bank when there is no practicable opportunity for on-site compensation. Criteria given for choosing between the two include: the likelihood for success of the given habitat type; compatibility of the mitigation with adjacent land uses; and "practicability of long-term monitoring an d maintenance to determine whether the effort will be ecologically sustainable, as well as the relative cost of mitigation alternatives" (Federal Register 1995).

Agencies may take the approach of prioritizing wetland functions within a candidate trading area to simplify the process of bank functional design. This can be a valuable tool for ordering the process, but it also introduces the risk of losing sight of a ll but the highest-priority functions.

Long-Term Responsibility:

The difficulties involved in creating bank wetlands in advance also highlight the importance of establishing responsibility in the event of bank failure or bank wetland establishment in a functional form other than that agreed upon. If bank credits have been sold and development impacts incurred, a failed bank effort means that the functions of the original natural wetlands have been completely lost from the watershed. Examples of failed mitigation banking efforts already exist. Although all credits had been sold, the Northlakes Park Bank in Hillsborough County, Florida, did not achieve the water levels anticipated in the restoration wetland and was subsequently "abandoned" (Salveson 1995). Similarly, the Mud Lake Bank in Jefferson County, Idaho, required enough water to maintain the hydroperiod for the 150-acre site. This could not be achieved because local agriculture and development projects utilized most of the available water. The importance of clarifying responsibility up front is becoming increasingly clear from banking attempts such as these. The permitting process should require remedial plans in the event of poor bank establishment, and contingency plans in the event of bank failure, along with long-term commitments to bank establishment and protection by the appropriate parties. Another means of gaining greater assurance of responsibility for bank success is the use of performance bonds. Regulatory agencies have started requiring performance bonds, based on bank acreage, to guarantee wetland performance for at least 5 years after the last credit is sold (Salveson 1995). The recent federal guidance stresses the importance of adopting an enforceable mechanism establishing responsibility of the bank sponsor to develop and operate the bank properly, and the importance of requiring adequate financial assurances based on the risk of bank failure (Federal Register 1995).

The Role of Mitigation Banks

The most suitable role for wetland banking has been a subject of some discussion, and the issue of whether agencies should limit the application of banks to certain types of impacts has been debated. While the speculative, commercial side of banking has been contentious, it appears that banking can be especially useful for projects where individual losses are relatively small (but collectively significant) and cannot be fully mitigated on, or immediately adjacent to, the project site (Short 1988). For example, banks offer a viable alternative to the piece-by-piece mitigation needs incurred by parties seeking to widen or locate new linear facilities, such as roadways, power corridors, and other utility easements. Banking allows these applicants to conduct prior planning and to acquire property in well-suited locations, as opposed to shoehorning mitigation sites piecemeal into existing holdings, often within rights-of-way or roadway stormwater ponds.

Banking can also be more efficient in terms of the permitting process. It can be negotiated one time, up front, providing greater predictability and simplicity to the mitigation aspect of subsequent individual permit applications. This is especially attractive for government agencies seeking permits, such as transportation agencies and county road departments, that must adhere to strict budget time frames and constraints and that cannot afford uncertainties often associated with wetland mitigation permitting. Permitting agencies also benefit from the more efficient use of review time.

Economies of scale can be obtained in design, construction, monitoring, and long-term protection of banks. Banking allows the design of one mitigation site instead of many. Similar economies occur with construction costs at only one site at one time, as opposed to at numerous small sites spread out over time and space, especially since a significant part of such costs is associated with mobilization of equipment. Substantial economies of scale can occur associated with longer-term monitoring and maintenance of a single constructed wetland as opposed to many, and with remedial actions that may be needed. These economies apply to agency compliance monitoring as well as to the permittee's monitoring and reporting requirements.

The consolidation of resources associated with economies of scale allows for a better quality of work in all aspects of bank development compared to numerous small mitigation sites. For example, a more thorough evaluation of bank site features, such as hydrology, can be conducted with the same amount of resources as needed for separate sites. This focusing of resources increases the chances of bank success.

As mentioned in the introduction, properly conducted banking eliminates the temporal loss of wetland functions that occurs with normal permitting procedures. It also eliminates the uncertainty that normally occurs over whether mitigation will be successful. Even bank wetlands that have obtained only partial functions at the time of credit withdrawal provide partial offsetting of temporal loss of functions and partial elimination of uncertainty.

One philosophical concern of banking opponents has been that the use of banks may remove some of the caution with which applicants would otherwise consider proposing impacts, as well as some of the rigor with which agencies evaluate the mandatory applicant efforts to avoid and minimize impacts to wetlands in project design. In light of the variable success record of wetland mitigation to date, incentives to relax the emphasis on avoidance and minimization of impacts is of concern to some observers. However, the newly released federal guidelines make clear that the normal review process changes in no way for applicants proposing to draw on a mitigation bank (Federal Register 1995).

Perhaps the most promising use of mitigation banking is in the realm of watershed and wildlife corridor planning and protection. Here, innovative uses of banking offer the potential to complement landscape-scale environmental protection and restoration efforts. Local government planners are beginning to consider using mitigation banking as a way of increasing their ability to successfully establish greenways and wildlife corridors. The opportunity also exists to direct wetland banking efforts strategic ally within the watershed to benefit identified water quality needs at this scale. Banking in this context is being expanded to include not only wetland creation, but also restoration of degraded wetlands, re-establishment of native upland communities in association with wetlands, and placement of long-term protective restrictions on use of these areas.

VIII. Wetland Mangement: For the Preservation of an Ecosystem

OVERVIEW

Wetland management generally involves activities that can be conducted with, in, and around wetlands, both natural and man-made, to protect, restore, manipulate, or provide for their functions and values. This discussion of wetland management is divided into issues associated with: 1) natural wetland protection; 2) activities, involving natural wetlands, that are specifically exempted from regulatory requirements; 3) wetland creation and restoration; and 4) wetland construction for water quality improvement.

The values of wetlands are by now well recognized (see Introduction, Functions and Values, and Protection sections) . The stated national goal for natural wetlands in the U.S. is one of no net loss, or protection of existing functions, as well as restoration of degraded functions. This protection goal involves not only buffering wetlands from direct human pressures, but also maintaining important natural processes that operate on wetlands from the outside and that may be altered by human activities. Management toward this goal should emphasize long-term sustenance of historical, natural wetland functions and values.

To support the national "no net loss" goal, many activities affecting natural wetlands must be conducted within the framework of government regulatory and other protection programs (see Wetland Protection section) . Manipulation of natural wetlands, within regulatory jurisdiction, is typically limited to restoration of degraded habitats. The use of natural wetlands for primary water quality treatment of either point or nonpoint pollution sources is inappropriate (Fields, 1993).

Exceptions to the rule of protection at the federal level are identified by specific Section 404 regulatory exemption categories, although such exemptions generally require the maintenance of some level of function in affected wetlands. Other exceptions include activities below minimum regulatory thresholds of applicability, and activities allowed by loopholes in the Act's construction. As a result of these caveats, by most estimates, Section 404 regulates only about 20 percent of the activities that destroy wetlands (GAO, 1991).

Wetland creation by man outside of any regulatory requirements presents opportunities for development of wildlife habitat and other valued functions as well as for capitalizing on a rapidly expanding technology for water quality improvement of both point and nonpoint pollution sources within the watershed.

Effective wetland management requires knowledge on a range of wetland subjects. Other sections within this Wetlands portion of the Education component provide current wetland information and lead to other materials that can assist wetland and watershed managers. This information can help a decision-maker evaluate wetland resources in a watershed to determine their functions, values, and roles in the watershed, assess risks, and prioritize protection. See the Wetlands Information Table of Contents to locate such information.

TERMINOLOGY

The management of wetlands and their use for water quality purposes has resulted in the introduction of a number of terms. Though definitions have not been standardized, the USEPA (Fields, 1993) recently established definitions for some of these variably applied terms, which we will follow for the rest of this discussion. Other terms used in this section are also provided here:

Natural Wetlands - wetlands that do not exist as the result of man's activities.

Wetlands - those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas (40 CFR 232.2(r)).

Wetland construction - creation of wetlands built specifically for water quality improvement purposes; this typically involves controlled outflow and a design that maximizes certain treatment functions (Fields, 1993).

Wetland creation - bringing a wetland into existence, whether by accident or intentional, where none existed previously; this includes creation of wetlands for mitigation, habitat, and water quality purposes (Fields, 1993).

Wetland enhancement - the modification of a natural or created wetland to enhance one or more functions. Enhancement of some wetland functions may negatively affect other functions.

Wetland restoration - the reestablishment of a disturbed or altered wetland as one with greater function or acreage. This may involve reestablishing original vegetation, hydrology, or other parameters to reestablish original or closer-to-original wetland functions (Fields, 1993).

NATURAL WETLAND PROTECTION

The management goal for natural wetlands is generally constrained by regulatory and other government program requirements to the protection of existing functions or restoration of degraded functions. Our discussion of natural wetlands is divided into issues of protection, the role of wetlands as buffers for other receiving waters, unregulated or exempt activities, and restoration activities. For more detailed, case- specific guidelines and information on regulatory requirements, refer to the Wetland Protection section and contact the applicable regional office of the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, and state and local environmental agencies. Throughout this discussion, references to natural wetlands are assumed to apply as well to man-made wetlands created under regulatory mitigation requirements, unless specified otherwise.

The management goal for undisturbed natural wetlands is typically to perpetuate existing functions. Functions are particular to a wetland's type and its position in the landscape (see Types of Wetlands section). Two major facets of managing wetlands for protection include buffering wetlands from direct human pressures, and maintaining natural processes in surrounding lands that affect wetlands and that may be disrupted by human activities.

Protection of Wetlands through Assignment of a Designated Use

The level of protection provided should conform with the designated use established for a wetland,. for example, aquatic life support or recreation. These coincide with two basic levels of protection recognized by environmental planners, preservation and conservation. Aquatic life support and wetland preservation connote a greater degree of protection, and involve, at most, passive use by humans (e.g., aesthetic enjoyment, wildlife observation). The recreation designated use, and wetland conservation status, connote a lesser degree of protection than do aquatic life support and preservation, on the level of protecting essential functions while allowing compatible human uses, such as recreational uses.

Factors to consider in setting the designated use and developing a management strategy for a wetland include:

- wetland type and landscape position,
- surrounding land uses,
- cumulative impacts on the wetland,
- vegetation quality,
- presence or absence of rare or endangered species,
- surface water quality,
- wildlife habitat, and
- cultural values.

It is not important to protect only rural or wilderness area wetlands. Urban wetlands can provide multiple values for suburban and city dwellers (Kusler et al. 1988). The aesthetic and recreational amenities of urban wetlands, and their value as wildlife habitat, can be significant. The capacity of a functional urban wetland in flood control can also be very important.

The Challenge of Protection

The simple goal of protecting a wetland's existing functions can prove to be incredibly complex in the modern landscape. It involves minimizing the human-induced changes affecting the natural forces that shape and sustain a wetland, such as hydrology, climate, biogeochemical fluxes, fire, and species movement. Pressures created by human activities include (see the Wetland Loss and Degradation section for a fuller review):

- proposals to fragment wetlands with roads and other linear facility crossings,
- impacts from recreational uses, including off-road vehicles, especially in residential settings,
- impacts from adjacent property owners, or partial or full wetland owners,
- incursion of trampling, soil compaction, intense herbivory, and waste loading by domesticated animals, and
- pest control treatments, in urban settings, pedestrian access, mowing, landscaping, solid waste dumping, and domesticated animal activity.

Other pressures that affect wetland functions operate less directly and are less apparent. These include:

- hydrologic alterations, such as direct surface drainage by ditch-digging, impoundment, de-watering by redirection of contributing land area inflows, de- watering by consumptive use of surface water inflows, de-watering through drawdown of unconfined aquifer from either groundwater withdrawal or stream channelization, making wetter in wet season and drier in dry season by changing both quantity and timing of inflows through placement of impervious surfaces and ditch- digging, and over-inundating by increasing contributing land area and/or increasing yield from a given land area through earthmoving, ditching, drain-tiling, and/or pumping;
- increased sediment, nutrient, organic matter, metals, pathogen and other water pollutant loadings from stormwater runoff and wastewater discharges;
- changes to physical characteristics of inflows, such as temperature, dissolved oxygen, clarity, and pH resulting from a variety of activities;
- atmospheric deposition of pollutants;
- introduction of nuisance and exotic plant and animal species;
- loss of more sensitive wetland plant and animal species due to changes in adjacent land uses;
- loss of surrounding habitat for wetland-dependent species that also require upland habitat; and
- "edge effect" changes in plant and animal species due to changes in light, temperature, and moisture regimes, and from noise, pesticide drift.

The Relationship of Natural Wetlands to Water Pollution

While wetlands play a role in reducing pollutant levels of inflowing water, they also require protection as water resources. The USEPA states that the use of natural wetlands for water quality treatment for either point or nonpoint pollution sources is inappropriate (Fields, 1993). At the same time, it must be recognized that wetlands have in the past treated and continue to treat both point and nonpoint source discharges. Untreated point source discharges to wetlands have largely been eliminated through the Section 402 NPDES program. Remaining point source discharges are essentially of secondarily treated effluent, which still typically contains elevated levels of biochemical oxygen demand, suspended solids, and nutrients relative to natural inputs. Nonpoint sources have not been commensurately improved. Natural wetlands receive largely untreated runoff from much of the developed urban and agricultural area in this country. However, the USEPA (Fields, 1993) states that proper management dictates that they be protected from such inputs using water quality standards promulgated by each state. Water quality standards specifically for wetlands are gradually being adopted by states. Progress is slow in this area, but NPS pollution control is gaining momentum. Although significant NPS loading to wetlands is undesirable, it will take time to address, and measures taken to curtail it will likely result in reduced but not eliminated loadings to wetlands.

Given the potential impacts of the myriad forces acting on wetlands, it is important to develop and implement strategies for the long-term protection of these ecosystems. A key element of any protection strategy is the establishment of physical buffers to minimize edge effects and to mitigate water quality impacts.

Buffers and Other Protective Measures for Wetlands

A buffer typically consists of a band of vegetation along the perimeter of a wetland or water body, preferably natural habitat, but including previously altered, stable native or introduced species. Once the need for a buffer is recognized, establishment of a suitable width is the critical task. In reality, many government agencies establish buffer requirements based on political acceptability and/or assumed aquatic resource functional value. Nevertheless, a fully informed buffer design must consider the nature of the encroaching activity, the buffer itself, the resource to be protected, and the buffering function to be performed. Castelle et al. (1994) identify four criteria for determining adequate buffer size to protect wetlands and other aquatic resources:

- I. wetland functional value - level of disturbance, sensitivity to disturbance,
- II. intensity of adjacent land use,
- III. buffer characteristics - vegetation density and structural complexity, soil condition, and
- IV. specific buffer functions required.

Relative to the last criterion, buffers can perform the following functions:

- sediment removal and erosion control,
- nutrient transformation and removal,
- metals and other pollutant reduction,
- stormwater runoff reduction through infiltration,
- reduction of water temperature,
- reduction of human impacts by limiting easy access and by minimizing edge effects from noise, light, temperature, and other changes,
- protection for interior wetland species, and
- a barrier to invasion of nuisance and exotic species.

In addition, Brown et al. (1987) describe how the transition area or ecotone between what is characteristically identified by regulatory agencies as wetland and undisputed upland typically supports higher species diversity and is more ecologically important than either adjacent habitat. This transition zone is of great importance to many wetland-dependent species and in riverine systems serves a vital role in maintaining regional species diversity as part of a habitat corridor.

A literature search by Castelle et al. (1994) of studies on specific buffer performance found that for sediment removal, necessary widths ranged from 10 to 60 m; for nutrient and metals removal, widths ran from 4 to 85 m; for species distribution and diversity protection, from 3 to 110 m was required; and for water temperature moderation, requirements ranged from 15 to 28 m.

Castelle et al. found that buffers less than 5 to 10 m provide little protection of aquatic resources under most conditions. They recommended minimum buffer widths of 15 to 30 m under most circumstances, with the lower end of this range providing basic physical and chemical buffering, and the upper end being the minimum needed for maintenance of biological components of wetlands and streams. They noted that fixed-width buffer approaches are easier to enforce, but that variable-width buffers are more likely to provide adequate protection on a specific-case basis. States have guidelines on desirable buffer widths and a number of states have buffers that range from 45 m to 300 m (Buchsbaum, 1994). A minimum ninety-meter buffer around state and federal wildlife refuges and conservation areas has been recommended.

Modelling can be performed to determine the width of a buffer that will reduce loading of suspended solids and bacteria from stormwater. These models relate buffer soil permeability, slope characteristics, width, and surface roughness to the surface flow (Phillips and Phillips, 1988, cited in Buchsbaum, 1994).

Although a narrow buffer may provide significant water quality benefits, the capacity for a narrow buffer to provide habitat or to act as a corridor for species is negligible. Optimal corridor widths for water quality purposes vary from 50 feet (16 m) to over 100 (34 m), with the wider corridor providing better conditions for management of wildlife (Davis, 1993).

When buffer acreage is not available or greater protection is called for, other measures can be employed. Wetlands in urban areas often require a greater level of protection. Degrading activities can include: off-road vehicle use (a problem in rural areas as well); pedestrian access; mowing; landscaping; solid waste dumping; domesticated animal access and resultant wildlife decimation, herbivory, vegetation trampling, soil compaction, and waste deposition; and others. Off-road vehicle access can be prevented by using post and cable barriers (Zentner, 1994). Pedestrian and pet access can be directed, discouraged, or eliminated through placement of shrub hedges, fences, open water buffers, signs, or a combination of these measures on the perimeter of a wetland. Common use piers and boardwalks over marshes or through swamps can be used to reduce degradation from recreational activities (Buchsbaum, 1994).

The measures noted above can be implemented by a local government agency, a wetland regulatory authority, a homeowners association, a concerned citizens' group, private individuals, or others. Community support can be developed for wetland protection. Volunteers to implement protective measures can be found in conservation organizations, volunteer water quality monitoring groups, and citizens' groups (USEPA, 1993c). Schools may value the opportunity for hands-on environmental education and involvement.

Permits issued by regulatory agencies for development around wetlands should include conditions requiring the permittee to inform future lot owners of restrictions on their use of wetlands located on, partially on, or abutting their lots. Permits can explicitly require full disclosure to potential lot purchasers; deed restrictions can be placed on such lots; permit conditions can require similar disclosure of responsibilities to subsequent lot owners. See the Wetland Protection section for a full discussion of regulatory tools.

Management Issues

As outlined above, in addition to buffering wetlands from human impacts, protective management involves maintaining important natural processes that operate on wetlands from the outside and that may be altered by human activities. One of these processes is fire. Many wetland types are adapted to periodic burns, but development interrupts natural fire patterns. Controlled burning is a management strategy that mimics the natural process in developed landscapes. It promotes marsh plant diversity and eliminates undesirable vegetation (Kent 1994b). Burns result in improved feeding and nesting for a variety of species.

Construction Impacts: For unavoidable road alignments through wetlands, it is possible to reduce impacts through "end-on" construction (USDOT 1994). Instead of driving heavy equipment in the wetland or building fill causeways or embankments, equipment is placed on work platforms mounted on concrete piles. A crane drives the piles and adds the bridge viaduct bay by bay. Waterfowl species do not seem to be disturbed by this construction process.

Mosquito control: Mosquito control is one reason that wetlands have historically been drained and it remains a cause of wetlands loss today. Natural wetlands, as well as restored and created wetlands, are habitat for mosquitoes. Constructed wetlands in particular may stagnate and increase breeding of mosquitoes because they lack a hydroperiod or do not contain predatory fish species.

Mosquito control does not have to cause wetland impacts or loss. However, pesticides such as organophosphates (e.g., malathion) that are used to control mosquitoes may be toxic to wetlands fish and aquatic invertebrates. Other more natural pesticides or bacteria can provide a more directed approach to mosquito control (Buchsbaum, 1994). *Bacillus thuringiensis israelensis* (Bti) is one bacterium that is more specific and less toxic than malathion. Careful application can avoid impacting other chironomid larvae that form the base of the food web in wetlands (Buchsbaum, 1994). An Integrated Pest Management approach to mosquito control should be used rather than drainage or non IPM-application of pesticides. Allowing predators of mosquitoes such as mosquito fish (*Gambusia affinis*), and killifishes (*Fundulus spp*.) access to breeding areas or introducing these fish should be part of an IPM mosquito control program.

Another method of mosquito control is to ensure that created and restored wet meadows and marshes have a hydroperiod which includes dry conditions during the mosquito egg- laying or hatching season (Zentner, 1994). The dry conditions will prevent egg-laying and hatching.

NATURAL WETLANDS AND RIPARIAN AREAS AS BUFFERS

The Water Treatment Role of Natural Wetlands

As discussed above, while USEPA states that the use of natural wetlands for water quality treatment for either point or nonpoint pollution sources is inappropriate (Fields, 1993), it is recognized that wetlands have in the past treated and continue to treat both point and nonpoint source (NPS) discharges. It will take time to curtail NPS pollutant loading to wetlands and measures taken to do so will likely result in reduced but not eliminated loadings to wetlands. Therefore, it is important to understand not only the long-term effects of such elevated loadings on wetlands, but the ability of wetlands to further treat these loadings prior to discharge into receiving waters. This ability of wetlands and riparian areas to process NPS pollutant loads has received significant study.

The most important forested wetlands to manage and protect as stream quality buffers may be those along first- and other low-order streams (Brinson, 1993). Wetlands along first-order streams are very efficient at nitrate removal from groundwater and runoff, and sediment removal from surface water and runoff (Whigham et al., 1988); they protect streambanks from erosion, and moderate stream temperatures by shading the water, which benefits aquatic life. Wetlands (floodplains) along higher-order streams influence water quality to a much smaller degree, since the upland runoff that passes through them and joins the stream is a much smaller fraction of the total stream flow than it is for headwater wetlands. Wetlands along large streams do, however, provide water quality benefits during flood events, a function that headwater wetlands do not provide.

Effectiveness of Natural Wetlands as Treatment Features

Water quality processes in natural wetlands are much more challenging to study than those in constructed systems. One main reason is that their water sources, rainfall and runoff, are climatically driven, making them highly variable hydrologically. It is also frequently a challenge to quantify all of the input sources and output paths. As a result, researchers tend to use differing approaches to study different systems, making their results more difficult to compare than those for the more controlled environments of constructed wetlands. Treatment efficiencies measured in natural wetlands have proven to be more widely variable than those in constructed systems, probably due only in part to differences in experimental methods, and more so to the diversity in natural system structure, function, and historical loading trends.

A substantial amount of research has focused on the biogeochemical role of wetlands in undisturbed landscapes with relatively natural levels of inputs (Nixon and Lee, 1986). Of greater interest, however, is the ability of wetlands to improve the quality of waters polluted by human activity. Significant work has been done, much of it within the last 15 years, on treatment of various polluted water sources by natural wetlands. Stormwater and wastewater have received significant attention. As reported in a literature search by Phillips et al. (1993a), natural wetlands treating domestic and municipal wastewater have removed 70% to 90% of organic matter, 26% to 70% of nitrogen, 12% to 70% of phosphorus, and high percentages of some metals. Natural wetlands treating stormwater have been somewhat more variable and less efficient. Suspended solids removal has ranged from 40% to 85%, and metals removal has been somewhat lower than in wetlands treating wastewater (Carr and Rushton, 1995; Phillips et al., 1993a). However, in one case, inorganic nitrogen removals greater than 85% were reported, as well as phosphorus reductions of greater than 70% for a natural marsh treating stormwater (Carr and Rushton, 1995).

Several researchers have looked at the efficacy of natural wetlands in treating agriculturally derived nutrient, sediment, and other pollutant loads. Two coastal forested peatlands receiving pumped cropland drainage over two years differed in nitrogen removal, reducing Kjeldahl nitrogen concentrations an average of 69% and 29% from 3 and 2.2 mg/l, and lowering nitrate concentrations 71% and 100%; phosphorus concentrations were lowered 93% and 63% from .36 and .13 mg/l; sediment removal was more consistent, with reductions of 97% and 92% (Chescheir et al., 1987). An Irish peatland that had received dairy wastewater for several decades showed high levels of nitrogen and phosphorus removal, lowering ammonia levels 88% from 15 mg/l, nitrate levels 92% from 20 mg/l, and ortho-phosphorus levels 73% from 8 mg/l (Costello, 1989). A restored prairie pothole in Minnesota showed promise for cropland runoff nitrogen and sediment removal in its first years of operation, lowering nitrate levels 70% from 4 mg/l and total suspended solids levels 92% from 1036 mg/l. Phosphorus removal was not good, with a 9% reduction from .44 mg/l (Jacobson, 1994). Several agricultural operations in Florida have used natural marshes and sloughs to treat drainage from citrus, pasture, and rangeland with variable success (Fall and Hendrickson, 1988; Goldstein, 1986; Federico, 1978). Low inflow total nitrogen levels (1 to 2 mg/l) were marginally improved or contributed to net export, while phosphorus removals ranged from 2% to 72%. A coastal creek floodplain swamp in North Carolina reduced phosphorus loads derived from cropland and animal operations by 43% over two years (Kuenzler et al., 1980).

Effectiveness of Riparian Areas as Treatment Features

Riparian areas, which include floodplain uplands as well as wetlands, are considered perhaps the most important buffer areas for protecting receiving water quality (Gilliam 1994). A number of researchers have quantified the effectiveness of both forested and grassed riparian areas for removing sediment, nitrogen, phosphorus, organic matter, and some pesticides from both surface water and ground water. Much work has focused on elevated constituent levels due to agriculture. Removal processes include deposition, absorption, adsorption, plant uptake, denitrification, and others (Welsch, 1991).

In terms of sediment, riparian zones along small streams in Coastal Plain North Carolina trapped an estimated 84 to 90 % of sediment eroding from cropland over a 25-year period (Cooper et al., 1987). Much of the coarse sediment was deposited very soon after entering the riparian area, with more than 50% of deposition occurring within 100 m of field edges. Lowrance et al (1988) used radioisotope dating in the Georgia Coastal Plain to determine that more sediment was deposited in a riparian forest over the same 25-year period than left adjacent agricultural fields, the difference being attributed to upstream inputs.

Several researchers have quantified reductions in problematic nitrate-nitrogen levels carried in cropland runoff traveling in shallow ground water across riparian areas. In one experiment, nitrate was reduced from 15 mg/l to 2 mg/l in the first 10 to 15 meters (30 to 50 ft) of riparian forest as it moved from a field toward a stream (Evans et al. 1993). Similar nitrate reductions were observed in a riparian forest in Maryland, most of the removal occurring within the first 19 m of the zone (Correll and Weller, 1989; Peterjohn and Correll: 1984; 1986). Nitrate load reduction was estimated at 45.5 kg/ha/yr. A grass riparian area between 18 and 27 m wide in Pennsylvania removed about 51% of nitrate entering at 21 mg/l, while an equal width of forested riparian zone on the opposite streambank lowered nitrate concentrations 83% from 4.3 mg/l (Schnabel, 1986). Haycock and Pinay (1993) in England measured nitrate load reductions of 99% across 26 m of riparian forest and 84% across 16 m of riparian grassland during the winter. Nitrate from dairy wastewater land application averaging 8 mg/l was reduced 89% by 30 m of reforesting grass riparian area in Coastal Plain Georgia over a 3-year period (Vellidis et al., 1995). Denitrification rates over this period averaged 68 kg/ha/yr. Overall, most other researchers have had similarly positive results with nitrate, and most believe it is largely removed from the system in gaseous forms through denitrification.

Removal of phosphorus (P) from cropland runoff by riparian areas has been somewhat less extensively researched. Cooper and Gilliam (1987) measured P deposited with the sediment in North Carolina riparian areas (see above). They estimated that over a 25-year period 50% of incoming P from agricultural areas was deposited in the riparian area. Phosphorus removal required significantly more area than a similar percentage of sediment removal, since P was concentrated in the finer sediment particles that take longer to settle. Lowrance et al. (1984) estimated that 30% of incoming P was retained in a Georgia Coastal Plain riparian forest over 3 years. In Maryland, 40 to 75 m of riparian forest retained 81% of surface water P entering at 5 mg/l and was a net exporter of dissolved ground water P (Peterjohn and Correll, 1984; 1986). Gilliam (1994) stated that riparian buffers do a reasonably good job of removing P attached to sediment, but are relatively ineffective in removing dissolved P.

Little information is presently available on removal of pesticides and fecal bacteria by riparian areas. Preliminary data from research in Kentucky on fecal bacteria indicates that removals are highly variable (Gilliam, 1994). Preliminary results of atrazine and alachlor dosing studies from Coastal Plain Georgia show reductions in surface water concentrations of 84% to 87% below conservative tracer levels, while ground water atrazine concentrations were lowered 41% and ground water alachlor 6% below tracer levels (Vellidis et al., 1995).

Phillips (1989) used a model, the Riparian Buffer Delineation Equation (RBDE), to estimate buffer widths needed to effectively treat agricultural runoff in the Coastal Plain of North Carolina. The equation uses properties found in soil surveys (slope gradient, soil moisture storage capacity, surface roughness, and soil saturated hydraulic conductivity) along with proposed buffer width to assess potential treatment capacity. Phillips found a wide variation in buffer effectiveness, with widths ranging from 5 to 93 m needed to remove nitrate from runoff volumes typical of 50 acres of row crop on relatively poorly-drained soils. He found slope gradient to be the most important variable bearing on effectiveness.

Wetland and Riparian Buffer Regulatory Issues

Although wetlands and riparian areas along low-order streams can provide effective water quality improvement, as well as habitat, floodwater storage, ground and surface water recharge, and critical amphibian breeding and reproduction sites, first order streams are often not protected as rigorously as more visible, larger streams. Low order streams and their associated wetlands and riparian areas are not protected by the nationwide Permit No. 26 within the Section 404 program, which allows up to 10 acres (4.0 hectares) of wetland impact. Laney (1988) determined that losses of isolated and limited-flow wetlands due to this authorization in North Carolina were significant, both individually and cumulatively, and these losses appeared inconsistent with the objective of the Clean Water Act to maintain the physical, chemical, and biological integrity of the nation's waters, including wetlands. Therefore, wise watershed management would include the use of other means to ensure the protection of headwater wetlands (see Wetland Protection section).

MANAGEMENT OF EXEMPT WETLAND ACTIVITIES

Exceptions to the rule of protection described above for natural wetlands include specific regulatory exemption categories, which generally require the maintenance of some level of function in affected wetlands, and activities below minimum regulatory thresholds of applicability. All of these activities can significantly impact wetlands if not conducted conscientiously.

Traditional land use activities exempted from federal and many state regulations include silviculture, agriculture, ranching, and sometimes mining. Most exemption language, including that in the Clean Water Act Section 404, stipulates that such operations in wetlands must be ongoing and established in nature to qualify for exemption. Another frequent caveat in state wetland rules is that the activity must make appropriate use of best management practices, or BMPs, for the exemption to hold. Exemption language may require individuals to obtain an approved conservation compliance plan from the National Resources Conservation Service (NRCS) or other approved plan to support their activities.

Section 404(f) of the Clean Water Act describes exempt agricultural activities and BMPs required for forestry operations to prevent adverse effects (at 40 CFR 232.2). The USEPA has also published more detailed guidance on agricultural activities and Section 404 (USEPA, 1991a). State departments of forestry often publish forestry BMP manuals with detailed information.

Silvicultural Exemption

To minimize impacts to wetlands, harvesting must be managed carefully and BMPs must be implemented. "Minor drainage" is permitted under Section 404, but ditches that significantly alter the hydrology of a wetland may not be constructed.

In terms of specific practices, road and skid trails should be minimized in number, width, and length. They should be located sufficiently far from water flow, or be bridged or culverted, so as not to impede or increase water flow or contribute to stagnation (USEPA, 1993a; Siegal and Haines, 1990). Trails should be maintained to prevent erosion. Low ground pressure vehicles and aerial logging reduce the soil compaction and hydrologic modifications resulting from heavy equipment and road construction (USEPA, 1993a; Vowell and Olszewski, 1989). Pesticides with high toxicity to aquatic life should be avoided, and slow release fertilizer formulations based on soil tests should be used (USEPA, 1993).

Maintaining riparian buffers along streams will enhance forest regeneration as well as provide wildlife habitat. At least a few snags and cavity trees should be left for habitat and tree stumps should be 12 inches high or less (USEPA, 1993; Vowell and Olszewski, 1989). The same species that existed on the site prior to harvest should be replanted afterward. Changing from mixed hardwoods to pine, for example, may change site hydrology because of the differences in evapotranspiration and growth rate of the species (Richardson and McCarthy, 1994; Skaggs, 1991). Discharges related to land clearing for silviculture may be regulated and it is advisable to contact a Corps or USEPA regional office (USEPA, 1994c).

Ranching Exemption

The CWA Section 404(f)(1)(A) exempts normal ranching activities from wetland permitting.

Under the ranching exemption, controlled grazing by livestock in winter and spring can improve herbaceous wetland nesting habitat and promote plant growth and seed production (Kent, 1994b). It has been recommended that livestock be removed after 50% of forage plants have been grazed.

The Bureau of Land Management, ranchers, and private landowners are utilizing beavers to restore degraded riparian areas in the West (USEPA, 1993b; SCS, 1989; Stuebner, 1992). The beavers create ponds that raise the water table and reestablish a wetland habitat, which wetland plants re-colonize. The plants can then be grazed in late winter and early spring.

After employing beavers to restore a riparian area and instituting a managed grazing regime there, one rancher increased weaning weight of his calves by 150 lbs., and increase his cow/calf numbers by 50% (USEPA, 1993b). The restored areas provide important habitat for many game and nongame species, and recreational opportunities as a result.

Innovative Management

Degraded, prior converted wetlands may offer opportunities for innovative management approaches (which may require permitting). In the southeastern coastal plain, a mixed- use, aquaculture-silviculture (crayfish-timber) enterprise can be quite successful (Mitsch and Gosselink, 1993). The hydrologic cycle of a bottomland hardwood forest can be simulated by winter impoundment of a prior converted or degraded swamp or area planted in flood-tolerant tree species. The crayfish are harvested in the spring and summer. Such a system can restore bottomland hardwood community structure and provide water quality benefits of nutrient removal. Inflow of toxic compounds must be monitored closely, however, because crayfish accumulate them. Since timber rotations are long, generally 20 - 50 years, this system can provide wildlife habitat as well, particularly if it is not intensively managed.

It is recommended that water depths of such managed impoundments not exceed 8 inches (15 cm) (Dugger and Frederickson, 1992). Inundation adversely affects terrestrial species and flood-intolerant tree species (King 1995). The forest should not be impounded for 3 years after acorn germination so that seedlings can become established (Kent, 1994b). Drawdown must be completed prior to the beginning of the growing season as trees and plants will be adversely impacted even if artificial inundation lasts only a few days into the growing season (King, 1995). Seedlings must not be inundated. Impoundment should not be conducted where an area is an important corridor for animal movement or where rare species occur.

Some rice farmers have found that they can take advantage of the annual flooding cycle of farmed wetlands to combine rice farming with crayfish production (Mitsch and Gosselink, 1993). Crayfish forage in the rice fields when they are re-flooded after the summer-fall rice harvest; the crayfish are harvested in spring before draining and replanting of rice. Pesticides can not be used on the fields because of the crayfish; however, flooding eliminates much of the need for pesticides.

Other farmers are converting flood-prone farmland into wildlife refuges in cooperation with federal and state agencies (Deterling, 1994). The farmers receive direct payments or tax deductions. Runoff of nutrients, agrichemicals, and eroded soil into nearby water resources is minimized or eliminated, and the wetland can provide functions in the watershed again.

Contact the Ducks Unlimited Private Lands Program 1-800-453-8257

WETLAND RESTORATION AND CREATION

While an implicit part of the national goal of no-net-loss involves mitigation for unavoidable impacts to wetlands,an explicit part of the goal is the restoration of wetlands where possible to recover the historical quality of the remaining acreage base (Conservation Foundation, 1987). Restoration may be required as part of a permitting process, but restoration efforts may also be prompted by environmental resource management goals for habitat or water quality improvement in keeping with the net- recovery clause of the national no-net-loss goal. In either case, degraded wetlands present restoration opportunities for improvements to water quality, habitat, water storage and other functions, and these opportunities can be particularly useful for watershed-scale environmental planning. The goal of restoration is typically to reestablish wetland ecosystems to levels that existed prior to human influence. Wetland creation can include regulatory mitigation or commercial and private creation efforts outside of regulatory requirements. A useful volume was recently released by the National Academy of Sciences addressing restoration of wetlands and other aquatic ecosystems from a management standpoint (National Research Council, 1992).

Management for Wildlife

Wetlands are especially critical habitats for wildlife, and exceed all other land types in wildlife productivity (Payne, 1992). Historically, wetland wildlife management was overwhelmingly concerned with maximizing production of waterfowl and furbearing mammals, and was focused largely on game species. By the 1970's, scientific and public perspective had shifted and resulting laws codified a concern for managing wildlife for diversity, emphasizing non-waterfowl and non-game species (Kent, 1994c). Kent (1994c) summarized a range of approaches to managing for habitat diversity developed in response to this evolution in perspective.

During this time, the larger question of whether wetland and other habitat should be managed at all, and if so, in what sense, gained high visibility. Kent (1994c) holds that the practice of wetland habitat management in the sense of active manipulation should be limited to degraded and created wetlands, as discussed below.

"*It is vainglorious to expect that managers can improve on the complex dynamic processes of natural undisturbed wetlands. Active management will by necessity enhance habitat for some species while degrading habitat for other species. Management may fail because of inadequate or inaccurate information, imprecise water control, colonization and modification by nuisance species, or even political or public pressure to terminate or modify management techniques or goals (Fredrickson, 1985). Therefore, it seems reasonable to reserve active management for wetlands known to be degraded and created wetlands.*"

For this reason, the subject of wildlife management is located here under wetland restoration and creation. Some additional wildlife management discussion occurs under the Management of Exempt Wetlands subsection for the same reason, since exempt systems are typically degraded and offer the possibility of improvement through active management.

Marsh creation or restoration is thus a good opportunity to manage wetlands for broad wildlife habitat goals. Not only can a restored marsh provide enhanced wildlife benefits, but other functions can be improved concurrently. Whether created or restored, wetlands designed for wildlife should take into consideration: minimum habitat area of anticipated species, their tolerance for disturbance, and the system's functional relationship to other water resources and adjacent ecosystems (Kent 1994b). It should be noted that while created wetlands can be suitable for some species, such as waterfowl, other, particularly threatened and endangered, species do not colonize artificially created wetland systems as readily or consistently as they do restored natural wetlands (Kent 1994b).

While management of restored or created wetlands should as a rule emulate the functions of undisturbed marshes, there may be times when single- or priority-objective management is appropriate. For a given wetland site, a restoration or creation management strategy must involve determination of the most important values to be obtained, and of whether a single, exclusive value outweighs the suite of values to be obtained from historic restoration. If a single-purpose wildlife use is sought, such as certain fish utilization, management may result in manipulation of marsh hydrology at the expense of other species and wetland functions. For example, game fish species require consistently deep water, yet shallow, emergent-plant-depth water levels provide the highest plant species diversity and greatest overall wildlife use of marshes (Mitsch and Gosselink 1993; Kent 1994b). At the same time, waterfowl require different structural conditions depending on species needs for feeding (divers versus dabblers), nesting, or staging (Weller 1981; Kent 1994b). In general, a ratio of no more than 1:1 open water to emergent vegetation maximizes waterfowl use (Weller 1981). Thus, tradeoffs are inevitable when structural components of a wetland, such as water level, are artificially manipulated. Any management strategy beyond reestablishment of historical functions must weigh these tradeoffs in light of management goals.

Hydrologic control can involve passive, climatically driven designs that emulate some natural ecotype, or managed designs using operable weirs, control gates, and pumps. The following table illustrates general relationships between water level and marsh characteristics.

Water level management for marsh species

Summer water level	Moist soil(mudflat)	15 cm	> 30 cm
Plant species diversity	fair	excellent	fair
Wildlife use and diversity	fair	excellent	good
Fish abundance	none	good	excellent
Migratory bird use	excellent	good	fair
Invasion by nuisance species	high	low	low

adapted from Mitsch and Gosselink (1993).

In much of the continental U.S., emulating the hydrology of a natural marsh would involve drawdown of water levels in the spring and gradual re-flooding in the fall. This pattern can stimulate primary productivity (Kent 1994b). Creation of a marsh adjacent to agriculture will likely provide elevated nutrient levels that will stimulate productivity and, if not too great, facilitate establishment of the wetland community while improving downstream water quality over previous levels.

Landscape Considerations in Wetland Restoration and Creation

Created wetlands for nonpoint source pollution control are advocated as an important part of any watershed or floodplain restoration plan (Mitsch, 1994). Location of constructed wetlands in the landscape is an important factor in determining their role. As discussed in the Riparian Wetlands subsection, the most important wetlands to manage and protect as stream quality buffers may be those along first- and other low-order streams (Brinson 1993). Wetlands along first-order streams are very efficient at nitrate removal from groundwater and runoff, and sediment removal from surface water (Whigham et al., 1988). Constructed wetlands bordering agricultural fields can be designed to intercept tile drainage with high nutrient levels that otherwise often flows directly into receiving streams, bypassing even riparian areas. Placing wetlands in a distributed pattern high in the watershed may incur less total runoff and erosion for the entire watershed than the same acreage put into large wetlands low in the watershed (van der Valk and Jolly, 1993).

Mitsch (1993) observed in a comparison of experimental systems using phosphorus as an example that retention as a function of nutrient loading will generally be less efficient in downstream wetlands than in smaller upstream wetlands. Wetlands (floodplains) along higher-order streams influence water quality to a much smaller degree, since the upland runoff that passes through them and joins the stream is a much smaller fraction of the total stream flow than it is for headwater wetlands. Wetlands along large streams do, however, provide water quality benefits during flood events, a function that headwater wetlands do not provide. Mitsch (1993) cautioned that the downstream wetlands could retain more mass of nutrients than upstream systems, and that a placement tradeoff might be optimum. From a management standpoint, creating many smaller wetlands around a watershed would mean dealing with more landowners, but taking less land out of production on any one farm than creating a few large wetlands, and is more fair in terms of not asking any landowner to contribute more than what is needed to treat the runoff from their land (van der Valk and Jolly, 1993).

Hammer (1992) envisions a holistic watershed wetland management approach involving a hierarchical arrangement of restored or created wetlands within a watershed landscape. Following conventional on-farm BMP systems, first-order control involves constructed wetlands designed specifically for animal wastewater, processing facility wastewater, or septic tank effluent treatment. Second-order control also occurs at the individual farm level, and consists of constructed wetland/upland systems, such as the nutrient/sediment control system described above, for treating cropland runoff or discharge from animal wastewater treatment systems, and providing some ancillary benefits as well. Third-order control requires a larger, watershed picture, and involves nutrient/sediment control systems, constructed wetland/pond complexes, and restored or created wetlands and riparian areas along many small streams higher in the watershed, providing water quality, hydrologic buffering, life support, and other values. Finally, fourth-order control uses large wetlands low in the watershed primarily for hydrologic buffering and habitat support values in addition to limited water quality benefits. First- and second-order systems are located within the bounds of individual farms and require active operation to maintain optimum treatment performance, while third- and fourth-order elements provide water quality benefits to runoff from numerous farms or entire watersheds, and function without intervention.

Instream wetlands can be created on small streams by impounding or adding a control structure to the stream. Mitsch (1993) observed that creation of in-stream wetlands is a reasonable alternative to upland locations only in lower-order streams and that such wetlands are susceptible to reintroduction of accumulated pollutants in large flow events as well as being unpredictable in terms of stability. Such systems would also likely involve higher maintenance and management costs than off-stream designs.

Wetland creation or restoration can provide significant benefits to surrounding systems in addition to water quality improvement. Diversity of wetland structural habitat in the landscape (particularly small multiple wetlands that differ in water level, plant species, and size), tends to increase species diversity and abundance (Weller 1981; Fleming et al. 1994). Similar to natural wetlands (see Natural Wetlands as Buffers subsection above), created systems can act as buffers for wildlife habitat. They protect streambanks from erosion, and moderate stream temperatures by shading the water, which benefits aquatic life. Larger riparian wetlands further downstream provide flood control and wildlife benefits. Knight (1993) noted that wetlands placed high in the watershed are likely to have more intermittent, less reliable water supplies, and thus exhibit lower primary production and lower overall food-chain benefits than those low in the watershed with perennial water supplies.

Riparian Restoration Guidelines for Water Quality

The U.S. Forest Service has published guidance on reforesting previously cleared riparian areas and renovating degraded riparian areas for the protection of receiving water quality (Welsch, 1991). The guidance is directed toward agricultural and silvicultural land uses and emphasizes that riparian buffers are meant to be used as part of a sound land management system including upland best management practices, and can be damaged and functionally impaired otherwise.

The design of the riparian buffers described above includes three zones intended to filter surface runoff and shallow groundwater flow. Beginning at the edge of the receiving water body, the first zone is a fixed 15 ft. wide, undisturbed native forest/shrub zone to provide a stable ecosystem at the water's edge, to perform nutrient buffering, to provide shade, and to contribute detritus and large woody debris to the water body. Landward of zone 1, zone 2 is the heart of the riparian buffer. A minimum of 60 ft. wide, it is composed primarily of native trees and shrubs, and it provides contact time and carbon energy source for buffering processes and for long-term sequestering of nutrients by trees. Periodic timber harvesting and stand improvement is acceptable in this zone. Livestock are to be excluded from both zones 1 and 2. At the landward margin, zone 3, a minimum of 20 ft. wide, is a graded, dense grass/forb strip for sediment control and nutrient uptake. Shaping into diversions, basins, and level spreaders toward this end is appropriate. This zone should be actively managed; mowing is recommended, grazing is acceptable, and periodic sediment removal, reshaping, and revegetating are necessary to maintain performance. Actual zone widths beyond the minimum can be determined based on USDA-defined Hydrologic Soil Groups found in the buffer; on the ratio of buffer area to source area; or on Soil Capability Classes of the buffer as shown in soil surveys. In addition, more involved buffer width estimation models utilizing properties and data found in soil surveys are available (Phillips, 1989).

Coastal Wetland Restoration

Coastal marsh restoration and creation efforts have been more successful than similar inland attempts (Redmond, 1992). This success appears to be due largely to researchers' ability to predict more accurately the key component, hydrologic patterns, in tidally influenced areas than in freshwater settings. Also, coastal restoration efforts have perhaps had a longer history than freshwater wetland restoration.

Restoration of coastal marshes and creation of salt marshes on dredge spoil has been found to facilitate shoreline aggradation, stabilize beach erosion, and protect landowners from the impacts of storms (Mitsch and Gosselink, 1993; NOAA, 1990; NOAA, 1995a). Restoration of wetlands on eroding shorelines can protect critical habitat for marine life and freshwater aquatic life (NOAA, 1995a; NOAA, 1995b), as well as reduce land subsidence (NOAA, 1995b; Duffy and Clark, 1989).

Mine Reclamation

Many wetland creation and restoration projects have been conducted at phosphate, coal, and sand and gravel mines throughout the United States. Some of these projects include creation or restoration of riparian wetlands, including expansive bottomland hardwood swamps in the central Florida phosphate mining district (Clewell, 1990). Some reclamation has been accomplished by terracing mountainsides to control erosion and treat acid mine drainage (Mitsch and Gosselink, 1993). In the Midwest, more than 5,666 hectares of wetlands have become established through natural colonization of coal mine slurry ponds. Many mining companies are reclaiming their slurry ponds through wetland creation (Levine and Willard, 1990).

Wetlands created or restored for mine reclamation may provide habitat for birds, mammals, herpetofauna, and macroinvertebrates if water is not acidic and does not contain high levels of toxic compounds. They may be stocked with fish and used for recreational activities. Water in reclaimed wetlands has been used for crop irrigation, livestock, fire protection, industrial purposes, and even as a water supply for human use (Brooks, 1990). There is extensive literature on the subject of mine reclamation as noted in Clewell (1990) and Brooks (1990). Also, individual project reports on phosphate mine reclamation are available through inter-library loan from the Florida Institute of Phosphate Research, 1855 W. Main St., Bartow, Florida 33830; (813) 533-0983.

Urban Wetland Restoration

Wetland restoration can be an important contributor to downstream habitat and water quality recovery in urbanized landscapes. Restored urban wetlands can help protect floodplains and streambeds that are otherwise degraded by urbanization forces, and can help to minimize downstream flooding that results from urbanization. Such wetlands can also reduce sedimentation of lagoons, bays, and other downstream water resources (Williams, 1990; Gale and Williams, 1988; Marcus, 1988). Larger restoration projects are more cost effective and are typically more beneficial ecologically as well (King and Bohlen, 1994; Lewis, 1988). Larger areas may provide habitat for interior species that an equivalent acreage of smaller parcels cannot support.

Upland buffer zones adjacent to urban restoration projects are important to protect them from degrading forces and provide important habitat used by many wetland species (Lewis, 1988). Such projects require other protective measures as well to sustain their functions long-term (see the Wetland Buffers subsection above).

Restoration of urban wetlands in coastal California has been fairly successful. In an evaluation of 120 such completed projects, 65 percent functioned similarly to natural wetlands, 25 percent were functional but resulted in different habitats than were originally designed, and 10 percent were failures (Zentner, 1988).

Innovative Commercial Wetland Creation

In association with Ducks Unlimited, the Natural Resources Conservation Service, and federal or state fish and wildlife agencies, farmers throughout the South are managing their rice, corn, and soybean fields as wetland habitat for economic benefit (Deterling 1994; Muzzi 1994). By flooding fields from November through February, farmers provide winter habitat along migratory flyways. Some farmers keep fields flooded longer because flooding keeps the soil soft and kills flood-intolerant weeds, thus eliminating tillage costs. Waterfowl eat flood tolerant weeds and weed seeds. Crops can then be planted earlier and faster, since crops germinate faster because tilling is not necessary and weeds are not competing for nutrients and space. Farmers who flood their fields save from $10 -$30 per acre on herbicide and tillage costs (Muzzi 1994)and there is less chemical runoff to pollute local water resources. Farmers can also receive income by leasing access rights to hunters or hunting clubs (Deterling 1994). Ducks Unlimited provides farmers with water control structures and advice in return for a 10-year agreement to conduct winter flooding and provide waterfowl habitat.

<u>CONSTRUCTED WETLANDS</u>

Photo courtesy of USDA NRCS

Overview

Interest in the use of natural physical, biological, and chemical aquatic processes for the treatment of polluted waters has increased steadily in the United States over the last two decades. This interest has been driven by growing recognition of the natural treatment functions performed by wetlands and aquatic plants, by the escalating costs of conventional treatment methods, and by a growing appreciation for the potential ancillary benefits provided by such systems. Aquatic treatment systems have been divided into natural wetlands, constructed wetlands, and aquatic plant systems (USEPA, 1988). Of the three types, constructed wetlands have received the greatest attention for treatment of point source pollution. As discussed and defined at the beginning of the Wetlands information section, constructed wetlands are a subset of created wetlands designed and developed specifically for water treatment (Fields, 1993). They have been further defined as:

engineered systems designed to simulate natural wetlands to exploit the water purification functional value for human use and benefits. Constructed wetlands consist of former upland environments that have been modified to create poorly drained soils and wetlands flora and fauna for the primary purpose of contaminant or pollutant removal from wastewaters or runoff (Hammer, 1992).

Constructed wetlands can provide many of the water quality improvement functions of natural wetlands with the advantage of control over location, design, and management to optimize those water quality functions. Constructed wetlands are not typically intended to replace all of the functions of natural wetlands, but emphasize certain features to maximize pollutant removal efficiency and to minimize point source and nonpoint source pollution prior to its entry into streams, natural wetlands, and other receiving waters. Wetlands created for habitat, water quantity, aesthetic and other functions as well as water quality functions typically call for different design considerations than those used solely for water quality improvement.

This tailored design approach to constructed systems generally makes them less suitable as wildlife habitat than natural wetlands. Nevertheless, constructed wetlands are often designed with ancillary wildlife values in mind, for example, incorporating open water for waterfowl usage. While species diversity of vegetation and microflora and fauna are lower in treatment wetlands, bird usage can be higher than that in adjacent natural wetlands because of the more eutrophic, and hence more productive, aquatic conditions in the loaded systems (McAllister, 1993, in Kadlec, 1995). A major concern with the use of constructed wetlands for wildlife habitat is the potential for concentrating accumulated pollutants up the food chain, with deleterious effects to birds and other consumers. While wildlife impacts have been observed in several instances with wetlands created for habitat (see the Wetlands Loss and Degradation section), these appear related to agricultural irrigation return flows in the West or hazardous waste site releases (Knight, 1993). So far, no similar problems are documented for constructed treatment wetlands (Kadlec, 1995; Knight, 1993), but the potential for harm exists with some metals and other compounds (Knight, 1993), and the issue requires continued evaluation.

Constructed wetlands are becoming an increasingly common method for treatment of all forms of water pollution, including confined animal wastewater, cropland runoff, urban stormwater, septic tank effluent, municipal wastewater effluent, acid mine drainage, industrial process waters, and landfill leachate (Kadlec and Knight, 1996; Kadlec, 1995: Bastian and Hammer, 1993). The beginnings of constructed wetland technology are dated to the 1950's in Germany for municipal wastewater treatment (Brix, 1994). This use is the most established and advanced, with hundreds of systems in place in Europe and the United States (Kadlec and Knight, 1996; Kadlec, 1995; Brown and Reed, 1994; Brix, 1994; Bastian and Hammer, 1993). Most constructed wetlands installed to date are used for advanced (nutrient reduction) treatment of municipal wastewater, with a large number also in place for secondary (solids and BOD) wastewater treatment. Use of these systems for primary wastewater treatment without prior or adequate settling and solids removal quickly overloads them and degrades performance capabilities, and is largely avoided (Cronk, 1995; Reaves et al., 1994). Other than primary wastewater uses, the range of potential applications for constructed wetlands is great and the record of actual applications is rapidly expanding.

Performance of constructed wetlands is good for a number of pollutants. In general, the greatest and most consistent reductions have been those of suspended solids, BOD, and fecal coliforms, with common discharge values of 10-20 mg/l for the first two and 50-100 fecal colonies/100 ml (Hammer, 1992). Phosphorus and nitrogen reductions are typically good, but less than efficiencies in the first three categories given the same conditions, with nitrogen usually more efficiently and consistently reduced than phosphorus. Strong nutrient reductions generally require greater area or lower application rates than do the first three constituents. Metals and some synthetic organic chemicals can also be reduced effectively, but results are more variable (Kadlec and Knight, 1996; Kadlec, 1995; Brown and Reed, 1994; Brix, 1994; Bastian and Hammer, 1993; Reed and Brown, 1992).

While construction costs can vary significantly, constructed wetlands provide treatment at significantly lower installation and maintenance costs than conventional municipal wastewater treatment options (Hammer, 1992). Hammer (1992) estimates that construction costs range from 1/10 to 1/2 of the cost of comparable conventional treatment systems. Constructed wetlands do, however, typically require significantly more land than conventional facilities. The major construction costs are associated with land purchase, pumping water to the wetlands, earthwork, possible impermeable liner, and planting (Kadlec, 1995; Reed et al., 1994; USEPA, 1988). Using data from municipal systems, Kadlec (1995) cites construction costs from 18 North American surface flow wetlands ranging from $4,500 to $203,000 per hectare (1994), with a mean of $68,000. Reed et al. (1994) give a range of $75,000 to $170,000 per hectare for the same type of system. Once up and running, operation and maintenance costs for constructed wetlands can be lower than for alternative treatment options, generally less than $1,000/ha/year (Kadlec, 1995), including the cost of pumping, mechanical maintenance, and pest control.

A number of information sources on constructed wetlands for water quality purposes are available (for non-water-quality-related wetland-creation references, see the Wetland Mitigation section). The first comprehensive synthesis of information on wastewater treatment wetlands was released at the end of 1995 by Kadlec and Knight (1996). Proceedings of conferences dealing exclusively with constructed wetlands for both point and nonpoint source treatment have been produced by Moshiri (1993), Cooper and Findlater (1990), Hammer (1989), and others, providing results, experience, and guidance on all aspects of conventional and alternative design, construction, operation, maintenance, and efficiencies. Other conferences have included coverage of constructed water quality wetlands, (Ross 1995); (Steele 1995). Perhaps the first conference dealing strictly with constructed wetlands for animal waste treatment was held in 1994 (DuBowy and Reaves, 1994). Schueler (1992) produced a guidance manual for constructed stormwater wetlands. A number of texts in the water quality/treatment area have also addressed constructed wetlands, such as those by Reed et al. (1995) and Novotny and Olem (1994). The USEPA and the Water Pollution Control Federation (WPCF) have both published design manuals which provide well-rounded basic coverage of design, performance, case studies with costs, and related issues for constructed wastewater wetlands (WPCF, 1990; USEPA, 1988).

For more detailed discussion of constructed wetlands, select the Best Management Practices for Non-Agricultural Nonpoint Source Pollution Control link in the Information Component subject index. Then choose the source type of interest from: industrial stormwater; mining/acid mine drainage; point sources; roads; septic systems; and urban stormwater options.

Constructed Wetlands for Animal Wastewater Treatment

Use of constructed wetland systems for confined animal wastewater has gained momentum in recent years, yet is still largely in the experimental stages. The major treatment concerns for these systems are BOD, ammonia, suspended solids, phosphorus, fecal coliforms, and sometimes metals added to feeds. The most problematic constituent seems to be ammonia; because of very high influent BOD levels, practically the entire wetland water column is essentially anoxic, inhibiting the aerobic nitrification step that must take place before denitrification and gaseous nitrogen release can occur. Very good nitrogen removals can occur with prior dilution or some form of aeration.

Although animal wastewater systems can borrow much from the municipal wastewater experience, an important difference is the need to keep capital costs and operation requirements to a minimum on the farm compared to municipal constraints. Also, minimizing wetland acreage is not as much a driving force with animal producers, since they often have significant area dedicated to lagoon waste land application, and wetlands can replace much of that disposal need in a fraction of the area. Municipal wastewater wetland design efforts toward increasing technical sophistication to maximize efficiency and minimize land requirements are of little assistance to animal facility operators.

Constructed Wetlands for Nonpoint Source Treatment

Wetlands constructed to treat stormwater runoff must be designed somewhat differently than wastewater wetlands. These constructed nonpoint source (NPS) wetlands can provide high removal efficiencies for stormwater pollutants and can be used to reduce stormwater runoff peak discharge rates. Constructed stormwater and other NPS treatment wetlands that mimic natural systems have been successful at many sites (Bingham, 1994; Mitsch and Gosselink, 1993). Constructed wetlands can also providing a pleasing natural area. Wetlands are highly valued by many landowners and can serve as attractive centerpieces to developments and recreation areas; wetlands also typically increase property values (Shaver, 1992; Schueler, 1987). Constructed wetland systems can provide ground water recharge in the area, thus lessening the impact of impervious surfaces. This recharge can also provide a ground water subsidy to the surficial aquifer, which can benefit local vegetative communities and decrease irrigation needs.

Runoff-driven wetlands by nature experience highly variable inputs, both hydrologically and in terms of pollutant loads. As a result, pollutant removal efficiency data are challenging to collect, are often collected using varying methods, often approximate in terms of accurately representing overall loading and removal efficiency, and are ultimately highly variable both within sites and between research efforts. Overall, NPS wetlands show much more variable performance than wastewater and other constant- source constructed wetlands.

In a recent literature review of constructed systems for agricultural NPS treatment, an important information gap (common to virtually all constructed wetland studies) was a dearth of information on long-term removal efficiencies (Osmond et al., 1995). The average length of a constructed wetland study was a little more than one year, following less than a year of preliminary loading. Decreasing efficiencies with time were observed in more than one experiment, and commonly recognized as a long-term possibility.

Nutrients, sediments, pathogens, metals and organic chemicals are pollutants typically removed by NPS constructed wetlands. Suspended solids removal in NPS constructed wetlands is generally greater than 60%; total nitrogen removal ranges from 25 to 76%; metals removal is variable, but lead generally shows at least 75% reduction; and phosphorus removal ranges from 30 to 90%, with an average of 50% (Bingham, 1994; Schueler et al., 1992). NPS constructed wetlands may release dissolved phosphorus because of improper design, including reliance on biotic activity for removal of phosphorus (D'Angelo and Reddy, 1994; Oberts and Osgood, 1991).

The use of constructed wetlands for stormwater treatment is still an emerging technology, hence there are no widely accepted design criteria. However, certain general design considerations do exist. It is important to first drop stormwater inflow velocities and provide opportunity for initial sediment deposition and solids removal using facilities that can be periodically maintained and that minimize the likelihood of entraining deposited sediment in subsequent inflows (Landers and Knuth, 1991; Oberts and Osgood, 1991). It is important to provide for the removal of oil and grease and floatable debris, preferably in the pre-treatment basin. The basin's outfall can be fitted with some form of skimmer or other means to retain floating matter (Palmer and Hunt, 1989). It is important to maximize the hydraulic residence time and the distribution of inflows over the treatment area, avoiding designs that may allow for hydraulic short-circuiting. Emergent macrophytic vegetation plays a key role, intimately linked with that of the sediment biota, by providing attachment sites for periphyton, by physically filtering flows, and by serving as a major storage vector for carbon and nutrients, an energy source for sediment microbial metabolism, and a gas exchange vector between sediments and air. Thus, it is important to design for a substantial native emergent vegetative component. Anaerobic sediment conditions should be ensured to allow for long-term burial of organic matter and phosphorus. A controlled rate of discharge is the last major physical design feature. While an adjustable outfall may seem desirable for fine-tuning system performance, regulatory agencies often require a fixed design to preclude subsequent inappropriate modifications to this key feature. Plants must be chosen to withstand the pollutant loading and the frequent fluctuation in water depth associated with the design treatment volume. It is advisable to consult a wetlands botanist to choose the proper vegetation.

Florida Administrative Code 40C-42, the stormwater rule used by the St. Johns River Water Management District, recommends that a constructed wetland for stormwater have less than 70% open water, a residence time of at least 14 days, and inlet structures designed to minimize turbidity and maximize settling of sediments (Palmer and Hunt, 1989). Storage capacity should be twice the capacity of an average storm event and drawdowns should be conducted to stabilize bottom sediments and reduce the re-release of orthophosphorus from the benthic sediments (Maristany et al., 1989; Esry et al., 1989).

For agricultural NPS runoff, researchers in Maine have developed and tested a multi-step constructed "nutrient/sediment control system" for cropland runoff (Reed et al., 1995; Higgins et al., 1993), and a number of such systems have now been installed around the state. Components of the system include, in sequence: a sediment basin; a level spreader, which disperses flows across an overland grass filter; the filter, which provides fine sediment and nutrient removal; an emergent marsh that grades into open water, primarily for nutrient removal; and a final grass filter to capture solids and nutrients in the form of algae that is produced in the pond. These systems have removed 90-100% of suspended solids, 85-100% of total phosphorus, 90-100% of BOD, and 80-90% of total nitrogen from potato field runoff in northern Maine (Hammer, 1992).

Constructed Wetlands for Mine Drainage

Acid mine drainage (AMD) is a major water pollutant associated with various types of mining operations, especially coal mining. AMD characteristically has low pH and high concentrations of iron, sulfate, and trace metals. Conventional treatment of acid mine drainage with alkaline reagents is "active" in nature, costly, and must be continued indefinitely (Skouson et al., 1994; Brodie et al., 1993).

The use of constructed wetlands for treatment of AMD is a "passive" technology, and provides a potential alternative to the conventional, active methods of chemical treatment. Thriving wetland communities have been observed despite acid mine drainage inputs. Closer inspection has revealed that outflow from such wetlands was of higher pH and did not contain, or contained only low concentrations of iron, sulfate and trace metals. This rapidly led to use of constructed wetlands to treat acid mine drainage (Skousen et al., 1994). It is estimated that over 400 wetlands are now in use in the U.S. for treatment of acid mine drainage (Weider, 1994).

Wetlands treatment of AMD is still an emerging technology. Treatment effectiveness has been variable to date, and long-term treatment effectiveness data do not yet exist. Hence, there are no widely accepted design criteria. The characteristics of AMD appear to present greater design challenges than more conventional applications. Some of the AMD removal processes initially thought to occur in wetlands were not evident when detailed research was completed (Vile and Weider, 1993; Skousen et al., 1994). Nonetheless, technical understanding of AMD wetland treatment issues is improving. The two major AMD contaminants from operations that encounter pyrite, including coal mine operations, are characteristically acidity and metals, usually iron (Fe) and manganese (Mn). Significant metals removal can take place through physical/chemical cation exchange and complexation with organic matter, both of which occur in the substrate. This physical filtering function is ultimately finite, and saturation of all available sites will occur (Weider, 1994; Gambrell, 1994; Skousen et al., 1994; Stark et al., 1994; Richardson, 1985). On the other hand, oxidation/reduction reactions yielding precipitation occur in wetlands and can provide a major sink for metals. However, the biological and chemical processes that "treat" the metals and the acidity are pH dependent. If the pH of inflow is less than 3, the wetland will not function (USDI, 1990). A calcium source, such as limestone, must be added regularly to constructed wetlands to regulate pH (Weider, 1994; McMillen et al., 1994). If the pH of the acid mine drainage and the wetland can be raised to 6.0, and if loading is less than 3g/m2/day, retention of metals can remain effective (Weider, 1994; USDI, 1990).

Research shows that an aerated vertical-flow constructed wetland is very effective in manganese removal (McMillen et al., 1994). The system causes an increase in the pH of the mine drainage when the inflow water infiltrates through the soil, a filter layer, and a limestone gravel layer. Manganese precipitates with the limestone (McMillen et al., 1994; Weider, 1994), although it is not normally precipitated in natural wetland processes (McMillen et al., 1994).

If constructed wetland management goals include wildlife habitat, pH must be greater then 3.5-4.0, and the concentrations of heavy metals in the water and sediments must not be toxic (Lacki et al., 1992).

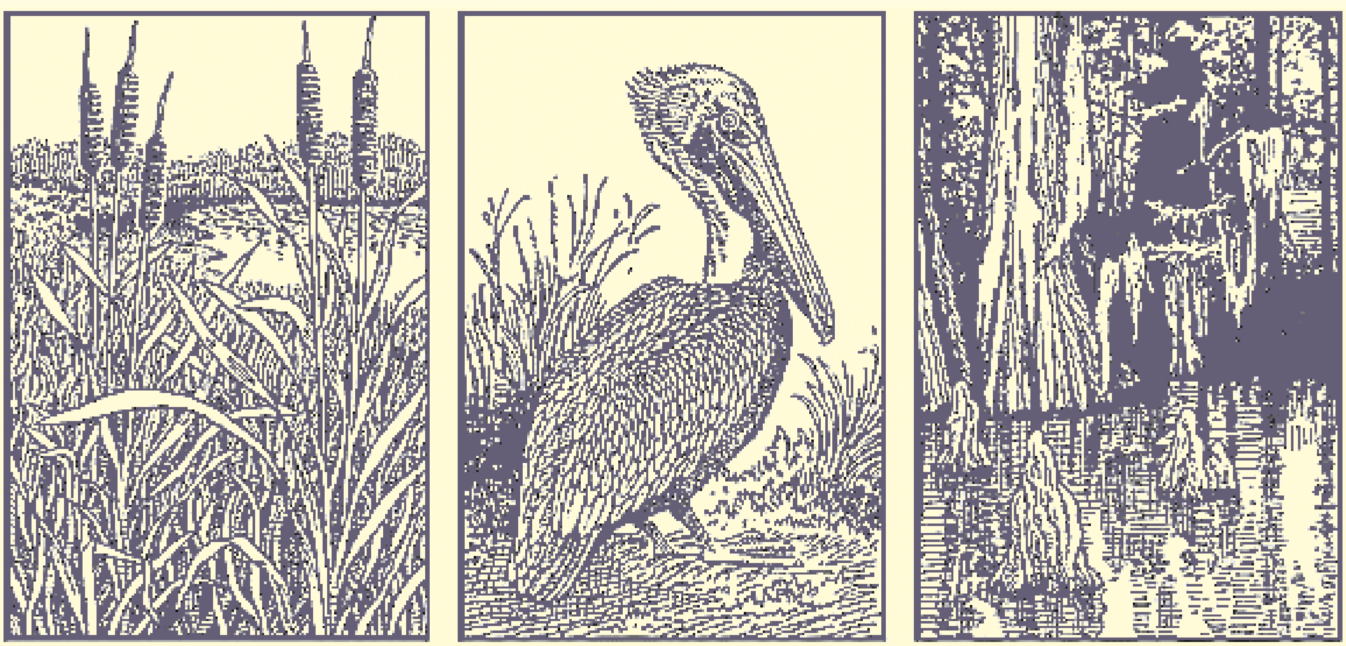
More information regarding constructed wetlands for acid mine drainage can be found through the "Best Management Practices for Non-Agricultural Nonpoint Source Pollution Control" link in the Education Component subject index. Once there, choose the mining/acid mine drainage source type option.

US Army Corps
of Engineers
Waterways Experiment
Station

Wetlands Research Program Technical Report Y-87-1 (on-line edition)

Corps of Engineers
Wetlands Delineation Manual

by Environmental Laboratory



January 1987 - Final Report

The following two letters used as part of the number designating technical reports of research published under the Wetlands Research Program identify the area under which the report was prepared:

	Task		Task
CP	Critical Processes	RE	Restoration & Establishment
DE	Delineation & Evaluation	SM	Stewardship & Management

Wetlands Research Program

Technical Report Y-87-1
January 1987

Corps of Engineers Wetlands Delineation Manual

by Environmental Laboratory

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Corps of Engineers
Washington, DC 20314-1000

Contents

List of Figures

List of Tables

Preface to the On-Line Edition

This is an electronic version of the 1987 *Corps of Engineers Wetlands Delineation Manual* (the 1987 Manual). The 1987 Manual is the current Federal delineation manual used in the Clean Water Act Section 404 regulatory program for the identification and delineation of wetlands. Except where noted in the manual, the approach requires positive evidence of hydrophytic vegetation, hydric soils, and wetland hydrology for a determination that an area is a wetland.

The original manual and this on-line edition were prepared by the Environmental Laboratory (EL) of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi. The work was sponsored by Headquarters, U.S. Army Corps of Engineers (HQUSACE), through the Wetlands Research Program.

The manual was originally published in January 1987, following several years of development and testing of draft versions. Since that time, the use and interpretation of the 1987 Manual have been clarified and updated through a series of guidance documents and memoranda from HQUSACE. This electronic edition does not change the intent or jurisdictional area of the 1987 Manual. It does, however, attempt to clarify the manual and current guidance by including a number of boxed "USER NOTES" indicating where the original manual has been augmented by more recent information or guidance. USER NOTES were written by Dr. James S. Wakeley, EL, WES. Due to re-formatting of the text and insertion of the USER NOTES, page numbers in this edition do not match those in the original edition. Some obsolete material appears in this document as struck-out text (e.g., ~~obsolete material~~), and hypertext links are provided to sources of important supplementary information (e.g., hydric soils lists, wetland plant lists). References cited in the USER NOTES refer to the following guidance documents from HQUSACE:

"Clarification of the Phrase "Normal Circumstances" as it pertains to Cropped Wetlands," Regulatory Guidance Letter (RGL) 90-7 dated 26 September 1990.

"Implementation of the 1987 Corps Wetland Delineation Manual," memorandum from John P. Elmore dated 27 August 1991.

"Questions & Answers on the 1987 Manual," memorandum from John F. Studt dated 7 October 1991.

"Clarification and Interpretation of the 1987 Manual," memorandum from Major General Arthur E. Williams dated 6 March 1992.

"Revisions to National Plant Lists," memorandum from Michael L. Davis dated 17 January 1996.

"NRCS Field Indicators of Hydric Soils," memorandum from John F. Studt dated 21 March 1997.

Copies of the original published manual are available through the National Technical Information Service (phone 703-487-4650, NTIS document number ADA 176734/2INE). The report should be cited as follows:

> Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Useful supplementary information for making wetland determinations can also be found at the following sites on the World Wide Web:

- Hydric soils definition, criteria, and lists
- National list of plant species that occur in wetlands
- Analyses of normal precipitation ranges and growing season limits
- National Wetlands Inventory maps and databases

Preface to the Original Edition

This manual is a product of the Wetlands Research Program (WRP) of the U.S. Army Engineer Waterways Experiment Station (WES), Vicksburg, MS. The work was sponsored by the Office, Chief of Engineers (OCE), U.S. Army. OCE Technical monitors for the WRP were Drs. John R. Hall and Robert J. Pierce, and Mr. Phillip C. Pierce.

The manual has been reviewed and concurred in by the Office of the Chief of Engineers and the Office of the Assistant Secretary of the Army (Civil Works) ~~as a method approved for voluntary use in the field for a trial period of 1 year~~.

~~This manual is not intended to change appreciably the jurisdiction of the Clean Water Act (CWA) as it is currently implemented. Should any District find that use of this method appreciably contracts or expands jurisdiction in their District as the District currently interprets CWA authority, the District should immediately discontinue use of this method and furnish a full report of the circumstances to the Office of the Chief of Engineers~~.

USER NOTES: Use of the 1987 Manual to identify and delineate wetlands potentially subject to regulation under Section 404 is now mandatory. (HQUSACE, 27 Aug 91)

This manual describes technical guidelines and methods using a multiparameter approach to identify and delineate wetlands for purposes of Section 404 of the Clean Water Act. Appendices of supporting technical information are also provided.

The manual is presented in four parts. Part II was prepared by Dr. Robert T. Huffman, formerly of the Environmental Laboratory (EL), WES, and Dr. Dana R. Sanders, Sr., of the Wetland and Terrestrial Habitat Group (WTHG), Environmental Resources Division (ERD), EL. Dr. Huffman prepared the original version of Part II in 1980, entitled "Multiple Parameter Approach to the Field Identification and Delineation of Wetlands." The original version was distributed to all Corps field elements, as well as other Federal resource and environmental regulatory agencies, for review and comments. Dr. Sanders revised the original version in 1982, incorporating review comments. Parts I, III, and IV

were prepared by Dr. Sanders, Mr. William B. Parker (formerly detailed to WES by the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS)) and Mr. Stephen W. Forsythe (formerly detailed to WES by the U.S. Department of the Interior, Fish and Wildlife Service (FWS)). Dr. Sanders also served as overall technical editor of the manual. The manual was edited by Ms. Jamie W. Leach of the WES Information Products Division.

The authors acknowledge technical assistance provided by: Mr. Russell F. Theriot, Mr. Ellis J. Clairain, Jr., and Mr. Charles J. Newling, all of WTHG, ERD; Mr. Phillip Jones, former SCS detail to WES; Mr. Porter B. Reed, FWS, National Wetland Inventory, St. Petersburg, Fla.; Dr. Dan K. Evans, Marshall University, Huntington, W. Va.; and the USDA-SCS. The authors also express gratitude to Corps personnel who assisted in developing the regional lists of species that commonly occur in wetlands, including Mr. Richard Macomber, Bureau of Rivers and Harbors; Ms. Kathy Mulder, Kansas City District; Mr. Michael Gilbert, Omaha District; Ms. Vicki Goodnight, Southwestern Division; Dr. Fred Weinmann, Seattle District; and Mr. Michael Lee, Pacific Ocean Division. Special thanks are offered to the CE personnel who reviewed and commented on the draft manual, and to those who participated in a workshop that consolidated the field comments.

The work was monitored at WES under the direct supervision of Dr. Hanley K. Smith, Chief, WTHG, and under the general supervision of Dr. Conrad J. Kirby, Jr., Chief, ERD. Dr. Smith, Dr. Sanders, and Mr. Theriot were Managers of the WRP. Dr. John Harrison was Chief, EL.

Director of WES during the preparation of this report was COL Allen F. Grum, USA. During publication, COL Dwayne G. Lee, CE, was Commander and Director. Technical Director was Dr. Robert W. Whalin.

This report should be cited as follows:

> Environmental Laboratory. (1987). "Corps of Engineers Wetlands Delineation Manual," Technical Report Y-87-1, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
acres	0.4047	hectares
Fahrenheit degrees	5/9	Celsius degrees[1]
feet	0.3048	metres
inches	2.54	centimetres
miles (U.S. statute)	1.6093	kilometres
square inches	6.4516	square centimetres

[1] To obtain Celsius (C) temperature readings from Fahrenheit (F) readings, use the following formula: C = (5/9) (F - 32).

Part I: Introduction

Background

1. Recognizing the potential for continued or accelerated degradation of the Nation's waters, the U.S. Congress enacted the Clean Water Act (hereafter referred to as the Act), formerly known as the Federal Water Pollution Control Act (33 U.S.C. 1344). The objective of the Act is to maintain and restore the chemical, physical, and biological integrity of the waters of the United States. Section 404 of the Act authorizes the Secretary of the Army, acting through the Chief of Engineers, to issue permits for the discharge of dredged or fill material into the waters of the United States, including wetlands.

Purpose and Objectives

Purpose

2. The purpose of this manual is to provide users with guidelines and methods to determine whether an area is a wetland for purposes of Section 404 of the Act.

Objectives

3. Specific objectives of the manual are to:

a. Present technical guidelines for identifying wetlands and distinguishing them from aquatic habitats and other nonwetlands.[1]

b. Provide methods for applying the technical guidelines.

c. Provide supporting information useful in applying the technical guidelines.

---

[1] Definitions of terms used in this manual are presented in the Glossary, Appendix A.

Scope

4. This manual is limited in scope to wetlands that are a subset of "waters of the United States" and thus subject to Section 404. The term "waters of the United States" has broad meaning and incorporates both deep-water aquatic habitats and special aquatic sites, including wetlands (*Federal Register* 1982), as follows:

a. The territorial seas with respect to the discharge of fill material.

b. Coastal and inland waters, lakes, rivers, and streams that are navigable waters of the United States, including their adjacent wetlands.

c. Tributaries to navigable waters of the United States, including adjacent wetlands.

d. Interstate waters and their tributaries, including adjacent wetlands.

e. All others waters of the United States not identified above, such as isolated wetlands and lakes, intermittent streams, prairie potholes, and other waters that are not a part of a tributary system to interstate waters or navigable waters of the United States, the degradation or destruction of which could affect interstate commerce.

Determination that a water body or wetland is subject to interstate commerce and therefore is a "water of the United States" shall be made independently of procedures described in this manual.

Special aquatic sites

5. The Environmental Protection Agency (EPA) identifies six categories of special aquatic sites in their Section 404 b.(l) guidelines (*Federal Register* 1980), including:

a. Sanctuaries and refuges.

b. Wetlands.

c. Mudflats.

d. Vegetated shallows.

e. Coral reefs.

f. Riffle and pool complexes.

Although all of these special aquatic sites are subject to provisions of the Clean Water Act, this manual considers only wetlands. By definition, wetlands are vegetated. Thus, unvegetated special aquatic sites (e.g., mudflats lacking macrophytic vegetation) are not covered in this manual.

Relationship to wetland classification systems

6. The technical guideline for wetlands does not constitute a classification system. It only provides a basis for determining whether a given area is a wetland for purposes of Section 404, without attempting to classify it by wetland type.

7. Consideration should be given to the relationship between the technical guideline for wetlands and the classification system developed for the Fish and Wildlife Service (FWS), U.S. Department of the Interior, by Cowardin et al. (1979). The FWS classification system was developed as a basis for identifying, classifying, and mapping wetlands, other special aquatic sites, and deepwater aquatic habitats. Using this classification system, the National Wetland Inventory (NWI) is mapping the wetlands, other special aquatic sites, and deepwater aquatic habitats of the United States, and is also developing both a list of plant species that occur in wetlands and an associated plant database. These products should contribute significantly to application of the technical guideline for wetlands. The technical guideline for wetlands as presented in the manual includes most, but not all, wetlands identified in the FWS system. The difference is due to two principal factors:

a. The FWS system includes all categories of special aquatic sites identified in the EPA Section 404 b.(l) guidelines. All other special aquatic sites are clearly within the purview of Section 404; thus, special methods for their delineation are unnecessary.

b. The FWS system requires that a positive indicator of wetlands be present for any one of the three parameters, while the technical guideline for wetlands requires that a positive wetland indicator be present for each parameter (vegetation, soils, and hydrology), except in limited instances identified in the manual.

Organization

8. This manual consists of four parts and four appendices. Part I presents the background, purpose and objectives, scope, organization, and use of the manual.

9. Part II focuses on the technical guideline for wetlands, and stresses the need for considering all three parameters (vegetation, soils, and hydrology) when making wetland determinations. Since wetlands occur in an intermediate posi-

tion along the hydrologic gradient, comparative technical guidelines are also presented for deepwater aquatic sites and nonwetlands.

10. Part III contains general information on hydrophytic vegetation, hydric soils, and wetland hydrology. Positive wetland indicators of each parameter are included.

11. Part IV, which presents methods for applying the technical guideline for wetlands, is arranged in a format that leads to a logical determination of whether a given area is a wetland. Section A contains general information related to application of methods. Section B outlines preliminary data-gathering efforts. Section C discusses two approaches (routine and comprehensive) for making wetland determinations and presents criteria for deciding the correct approach to use. Sections D and E describe detailed procedures for making routine and comprehensive determinations, respectively. The basic procedures are described in a series of steps that lead to a wetland determination.

12. The manual also describes (Part IV, Section F) methods for delineating wetlands in which the vegetation, soils, and/or hydrology have been altered by recent human activities or natural events, as discussed below:

a. The definition of wetlands contains the phrase "under normal circumstances," which was included because there are instances in which the vegetation in a wetland has been inadvertently or purposely removed or altered as a result of recent natural events or human activities. Other examples of human alterations that may affect wetlands are draining, ditching, levees, deposition of fill, irrigation, and impoundments. When such activities occur, an area may fail to meet the diagnostic criteria for a wetland. Likewise, positive hydric soil indicators may be absent in some recently created wetlands. In such cases, an alternative method must be employed in making wetland determinations.

> USER NOTES: "Normal circumstances" has been further defined as "the soil and hydrologic conditions that are normally present, without regard to whether the vegetation has been removed." The determination of whether normal circumstances exist in a disturbed area "involves an evaluation of the extent and relative permanence of the physical alteration of wetlands hydrology and hydrophytic vegetation" and consideration of the "purpose and cause of the physical alterations to hydrology and vegetation." (RGL 90-7, 26 Sep 90; HQUSACE, 7 Oct 91)

b. Natural events may also result in sufficient modification of an area that indicators of one or more wetland parameters are absent. For example, changes in river course may significantly alter hydrology, or beaver dams may create new wetland areas that lack hydric soil conditions. Catastrophic events (e.g., fires, avalanches, mudslides, and volcanic activities) may also alter or destroy wetland indicators on a site.

Such atypical situations occur throughout the United States, and all of these cannot be identified in this manual.

13. Certain wetland types, under the extremes of normal circumstances, may not always meet all the wetland criteria defined in the manual. Examples include prairie potholes during drought years and seasonal wetlands that may lack hydrophytic vegetation during the dry season. Such areas are discussed in Part IV, Section G, and guidance is provided for making wetland determinations in these areas. However, such wetland areas may warrant additional research to refine methods for their delineation.

14. Appendix A is a glossary of technical terms used in the manual. Definitions of some terms were taken from other technical sources, but most terms are defined according to the manner in which they are used in the manual.

15. Data forms for methods presented in Part IV are included in Appendix B. Examples of completed data forms are also provided.

16. Supporting information is presented in Appendices C and D. ~~Appendix C contains lists of plant species that occur in wetlands. Section 1 consists of regional lists developed by a Federal interagency panel. Section 2 consists of shorter lists of plant species that commonly occur in wetlands of each region.~~

> USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. (HQUSACE, 27 Aug 91)

Section 3 describes morphological, physiological, and reproductive adaptations associated with hydrophytic species, as well as a list of some species exhibiting such adaptations. Appendix D discusses procedures for examining soils for hydric soil indicators, ~~and also contains a list of hydric soils of the United States~~.

> USER NOTES: The hydric soil list published in the 1987 Corps Manual is obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

Use

17. Although this manual was prepared primarily for use by Corps of Engineers (CE) field inspectors, it should be useful to anyone who makes wetland determinations for purposes of Section 404 of the Clean Water Act. The user is

directed through a series of steps that involve gathering of information and decisionmaking, ultimately leading to a wetland determination. A general flow diagram of activities leading to a determination is presented in Figure 1. However, not all activities identified in Figure 1 will be required for each wetland determination. For example, if a decision is made to use a routine determination procedure, comprehensive determination procedures will not be employed.

Premise for use of the manual

18. Three key provisions of the CE/EPA definition of wetlands include:

a. Inundated or saturated soil conditions resulting from permanent or periodic inundation by ground water or surface water.

b. A prevalence of vegetation typically adapted for life in saturated soil conditions (hydrophytic vegetation).

c. The presence of "normal circumstances."

19. Explicit in the definition is the consideration of three environmental parameters: hydrology, soil, and vegetation. Positive wetland indicators of all three parameters are normally present in wetlands. Although vegetation is often the most readily observed parameter, sole reliance on vegetation or either of the other parameters as the determinant of wetlands can sometimes be misleading. Many plant species can grow successfully in both wetlands and nonwetlands, and hydrophytic vegetation and hydric soils may persist for decades following alteration of hydrology that will render an area a nonwetland. The presence of hydric soils and wetland hydrology indicators in addition to vegetation indicators will provide a logical, easily defensible, and technical basis for the presence of wetlands. The combined use of indicators for all three parameters will enhance the technical accuracy, consistency, and credibility of wetland determinations. Therefore, all three parameters were used in developing the technical guideline for wetlands and all approaches for applying the technical guideline embody the multiparameter concept.

Approaches

20. The approach used for wetland delineations will vary, based primarily on the complexity of the area in question. Two basic approaches described in the manual are (a) routine and (b) comprehensive.

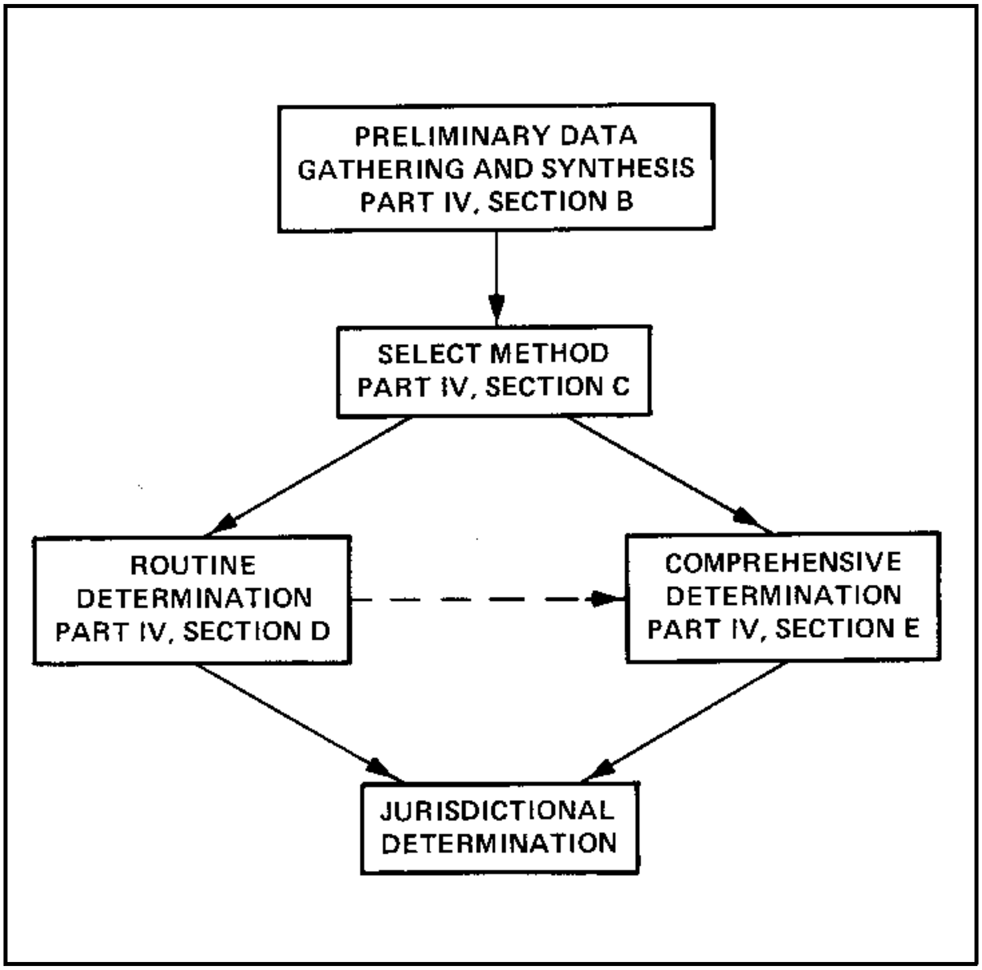


Figure 1. General schematic diagram of activities leading to a wetland/non-wetland determination

21. **Routine approach.** The routine approach normally will be used in the vast majority of determinations. The routine approach requires minimal level of effort, using primarily qualitative procedures. This approach can be further subdivided into three levels of required effort, depending on the complexity of the area and the amount and quality of preliminary data available. The following levels of effort may be used for routine determinations:

a. *Level 1 - Onsite inspection unnecessary.* (Part IV, Section D, Subsection 1).

b. *Level 2 - Onsite inspection necessary.* (Part IV, Section D, Subsection 2).

c. *Level 3 - Combination of Levels 1 and 2.* (Part IV, Section D, Subsection 3).

22. **Comprehensive approach.** The comprehensive approach requires application of quantitative procedures for making wetland determinations. It should

seldom be necessary, and its use should be restricted to situations in which the wetland is very complex and/or is the subject of likely or pending litigation. Application of the comprehensive approach (Part IV, Section E) requires a greater level of expertise than application of the routine approach, and only experienced field personnel with sufficient training should use this approach.

Flexibility

23. Procedures described for both routine and comprehensive wetland determinations have been tested and found to be reliable. However, site-specific conditions may require modification of field procedures. For example, slope configuration in a complex area may necessitate modification of the baseline and transect positions. Since specific characteristics (e.g., plant density) of a given plant community may necessitate the use of alternate methods for determining the dominant species, the user has the flexibility to employ sampling procedures other than those described. However, the basic approach for making wetland determinations should not be altered (i.e., the determination should be based on the dominant plant species, soil characteristics, and hydrologic characteristics of the area in question). The user should document reasons for using a different characterization procedure than described in the manual. *CAUTION: Application of methods described in the manual or the modified sampling procedures requires that the user be familiar with wetlands of the area and use his or her training, experience, and good judgment in making wetland determinations.*

Part II: Technical Guidelines

24. The interaction of hydrology, vegetation, and soil results in the development of characteristics unique to wetlands. Therefore, the following technical guideline for wetlands is based on these three parameters, and diagnostic environmental characteristics used in applying the technical guideline are represented by various indicators of these parameters.

25. Because wetlands may be bordered by both wetter areas (aquatic habitats) and by drier areas (nonwetlands), guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands. However, procedures for applying the technical guidelines for deepwater aquatic habitats and nonwetlands are not included in the manual.

Wetlands

26. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and delineation of wetlands:

a. *Definition.* The CE (*Federal Register* 1982) and the EPA (*Federal Register* 1980) jointly define wetlands as: Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

b. *Diagnostic environmental characteristics.* Wetlands have the following general diagnostic environmental characteristics:

(1) *Vegetation.* The prevalent vegetation consists of macrophytes that are typically adapted to areas having hydrologic and soil conditions described in *a* above. Hydrophytic species, due to morphological, physiological, and/or reproductive adaptation(s), have the ability to grow, effectively compete, reproduce, and/or persist in anaerobic

soil conditions.[1] Indicators of vegetation associated with wetlands are listed in paragraph 35.

(2) *Soil.* Soils are present and have been classified as hydric, or they possess characteristics that are associated with reducing soil conditions. Indicators of soils developed under reducing conditions are listed in paragraphs 44 and 45.

(3) *Hydrology.* The area is inundated either permanently or periodically at mean water depths $\leq$6.6 ft, or the soil is saturated to the surface at some time during the growing season of the prevalent vegetation.[2] Indicators of hydrologic conditions that occur in wetlands are listed in paragraph 49.

c. *Technical approach for the identification and delineation of wetlands.* Except in certain situations defined in this manual, evidence of a minimum of one positive wetland indicator from each parameter (hydrology, soil, and vegetation) must be found in order to make a positive wetland determination.

Deepwater Aquatic Habitats

27. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for deepwater aquatic habitats:

a. *Definition.* Deepwater aquatic habitats are areas that are permanently inundated at mean annual water depths >6.6 ft or permanently inundated areas $\leq$6.6 ft in depth that do not support rooted-emergent or woody plant species.[3]

b. *Diagnostic environmental characteristics.* Deepwater aquatic habitats have the following diagnostic environmental characteristics:

(1) *Vegetation.* No rooted-emergent or woody plant species are present in these permanently inundated areas.

(2) *Soil.* The substrate technically is not defined as a soil if the mean water depth is >6.6 ft or if it will not support rooted emergent or woody plants.

---

[1] Species (e.g., *Acer rubrum*) having broad ecological tolerances occur in both wetlands and nonwetlands.

[2] The period of inundation or soil saturation varies according to the hydrologic/soil moisture regime and occurs in both tidal and nontidal situations.

[3] Areas $\leq$6.6 ft mean annual depth that support only submergent aquatic plants are vegetated shallows, not wetlands.

(3) *Hydrology*. The area is permanently inundated at mean water depths >6.6 ft.

c. *Technical approach for the identification and delineation of deepwater aquatic habitats*. When any one of the diagnostic characteristics identified in *b* above is present, the area is a deepwater aquatic habitat.

Nonwetlands

28. The following definition, diagnostic environmental characteristics, and technical approach comprise a guideline for the identification and delineation of nonwetlands:

a. *Definition.* Nonwetlands include uplands and lowland areas that are neither deepwater aquatic habitats, wetlands, nor other special aquatic sites. They are seldom or never inundated, or if frequently inundated, they have saturated soils for only brief periods during the growing season, and, if vegetated, they normally support a prevalence of vegetation typically adapted for life only in aerobic soil conditions.

b. *Diagnostic environmental characteristics.* Nonwetlands have the following general diagnostic environmental characteristics:

(1) *Vegetation.* The prevalent vegetation consists of plant species that are typically adapted for life only in aerobic soils. These mesophytic and/or xerophytic macrophytes cannot persist in predominantly anaerobic soil conditions.[1]

(2) *Soil.* Soils, when present, are not classified as hydric, and possess characteristics associated with aerobic conditions.

(3) *Hydrology*. Although the soil may be inundated or saturated by surface water or ground water periodically during the growing season of the prevalent vegetation, the average annual duration of inundation or soil saturation does not preclude the occurrence of plant species typically adapted for life in aerobic soil conditions.

c. *Technical approach for the identification and delineation of nonwetlands.* When any one of the diagnostic characteristics identified in *b* above is present, the area is a nonwetland.

[1] Some species, due to their broad ecological tolerances, occur in both wetlands and nonwetlands (e.g., *Acer rubrum).*

Part III: Characteristics and Indicators of Hydrophytic Vegetation, Hydric Soils, and Wetland Hydrology

Hydrophytic Vegetation

Definition

29. **Hydrophytic vegetation.** Hydrophytic vegetation is defined herein as the sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. The vegetation occurring in a wetland may consist of more than one plant community (species association). The plant community concept is followed throughout the manual. Emphasis is placed on the assemblage of plant species that exert a controlling influence on the character of the plant community, rather than on indicator species. Thus, the presence of scattered individuals of an upland plant species in a community dominated by hydrophytic species is not a sufficient basis for concluding that the area is an upland community. Likewise, the presence of a few individuals of a hydrophytic species in a community dominated by upland species is not a sufficient basis for concluding that the area has hydrophytic vegetation. *CAUTION: In determining whether an area is "vegetated" for the purpose of Section 404 jurisdiction, users must consider the density of vegetation at the site being evaluated. While it is not possible to develop a numerical method to determine how many plants or how much biomass is needed to establish an area as being vegetated or unvegetated, it is intended that the predominant condition of the site be used to make that characterization. This concept applies to areas grading from wetland to upland, and from wetland to other waters. This limitation would not necessarily apply to areas which have been disturbed by man or recent natural events.*

30. **Prevalence of vegetation.** The definition of wetlands includes the phrase "prevalence of vegetation." Prevalence, as applied to vegetation, is an imprecise, seldom-used ecological term. As used in the wetlands definition, prevalence refers to the plant community or communities that occur in an area at some point in time. Prevalent vegetation is characterized by the dominant species comprising the plant community or communities. Dominant plant species are those that contribute more to the character of a plant community than other species present, as estimated or measured in terms of some ecological parameter or parameters. The two most commonly used estimates of dominance are basal area (trees) and percent areal cover (herbs). Hydrophytic vegetation is prevalent in an area when the dominant species comprising the plant community or communities are typically adapted for life in saturated soil conditions.

> USER NOTES: The "50/20 rule" is the recommended method for selecting dominant species from a plant community when quantitative data are available. The rule states that for each stratum in the plant community, dominant species are the most abundant plant species (when ranked in descending order of abundance and cumulatively totaled) that immediately exceed 50% of the total dominance measure for the stratum, plus any additional species that individually comprise 20% or more of the total dominance measure for the stratum. The list of dominant species is then combined across strata. (HQUSACE, 6 Mar 92)

31. **Typically adapted.** The term "typically adapted" refers to a species being normally or commonly suited to a given set of environmental conditions, due to some morphological, physiological, or reproductive adaptation (Appendix C, Section 3). As used in the CE wetlands definition, the governing environmental conditions for hydrophytic vegetation are saturated soils resulting from periodic inundation or saturation by surface or ground water. These periodic events must occur for sufficient duration to result in anaerobic soil conditions. When the dominant species in a plant community are typically adapted for life in anaerobic soil conditions, hydrophytic vegetation is present. Species ~~listed in Appendix C, Section 1 or 2,~~ that have an indicator status of OBL, FACW, or FAC[1] (Table 1) are considered to be typically adapted for life in anaerobic soil conditions (see paragraph 35*a*).

Influencing factors

32. Many factors (e.g., light, temperature, soil texture and permeability, man-induced disturbance, etc.) influence the character of hydrophytic vegetation. However, hydrologic factors exert an overriding influence on species that can occur in wetlands. Plants lacking morphological, physiological, and/or reproductive adaptations cannot grow, effectively compete, reproduce, and/or persist in areas that are subject to prolonged inundation or saturated soil conditions.

---

[1] Species having a FAC- indicator status are not considered to be typically adapted for life in anaerobic soil conditions.

Table 1 Plant Indicator Status Categories[1]		
Indicator Category	**Indicator Symbol**	**Definition**
Obligate Wetland Plants	OBL	Plants that occur almost always (estimated probability >99 percent) in wetlands under natural conditions, but which may also occur rarely (estimated probability <1 percent) in nonwetlands. Examples: *Spartina alterniflora, Taxodium distichum.*
Facultative Wetland Plants	FACW	Plants that occur usually (estimated probability >67 percent to 99 percent) in wetla-nds, but also occur (estimated probability 1 percent to 33 percent) in nonwetlands. Examples: *Fraxinus pennsylvanica, Cornus stolonifera.*
Facultative Plants	FAC	Plants with a similar likelihood (estimated probability 33 percent to 67 percent) of occurring in both wetlands and nonwetlands. Examples: *Gleditsia triacanthos, Smilax rotundifolia.*
Facultative Upland Plants	FACU	Plants that occur sometimes (estimated probability 1 percent to <33 percent) in wetlands, but occur more often (estimated probability >67 percent to 99 percent) in nonwetlands. Examples: *Quercus rubra, Potentilla arguta.*
Obligate Upland Plants	UPL	Plants that occur rarely (estimated probability <1 percent) in wetlands, but occur almost always (estimated probability >99 percent) in nonwetlands under natural conditions. Examples: *Pinus echinata, Bromus mollis.*
[1] Categories were originally developed and defined by the USFWS National Wetlands Inventory and subsequently modified by the National Plant List Panel. The three facultative categories are subdivided by (+) and (−) modifiers ~~(see Appendix C, Section 1)~~.		

Geographic diversity

33. Many hydrophytic vegetation types occur in the United States due to the diversity of interactions among various factors that influence the distribution of hydrophytic species. General climate and flora contribute greatly to regional variations in hydrophytic vegetation. Consequently, the same associations of hydrophytic species occurring in the southeastern United States are not found in the Pacific Northwest. In addition, local environmental conditions (e.g., local climate, hydrologic regimes, soil series, salinity, etc.) may result in broad variations in hydrophytic associations within a given region. For example, a coastal saltwater marsh will consist of different species than an inland freshwater marsh in the same region. An overview of hydrophytic vegetation occurring in each region of the Nation has been published by the CE in a series of eight preliminary wetland guides (Table 2), and a group of wetland and estuarine ecological profiles (Table 3) has been published by FWS.

Classification

34. Numerous efforts have been made to classify hydrophytic vegetation. Most systems are based on general characteristics of the dominant species occurring in each vegetation type. These range from the use of general physiognomic categories (e.g., overstory, subcanopy, ground cover, vines) to specific vegetation types (e.g., forest type numbers as developed by the Society of American Foresters). In other cases, vegetational characteristics are combined with hydrologic features to produce more elaborate systems. The most recent example of such a system was developed for the FWS by Cowardin et al. (1979).

Table 2
List of CE Preliminary Wetland Guides

Region	Publication Date	WES Report No.
Peninsular Florida	February 1978	TR Y-78-2
Puerto Rico	April 1978	TR Y-78-3
West Coast States	April 1978	TR-Y-78-4
Gulf Coastal Plain	May 1978	TR Y-78-5
Interior	May 1982	TR Y-78-6
South Atlantic States	May 1982	TR Y-78-7
North Atlantic States	May 1982	TR Y-78-8
Alaska	February 1984	TR Y-78-9

Table 3
List of Ecological Profiles Produced by the FWS Biological Services Program

Title	Publication Date	FWS Publication No.
"The Ecology of Intertidal Flats of North Carolina"	1979	79/39
"The Ecology of New England Tidal Flats"	1982	81/01
"The Ecology of the Mangroves of South Florida"	1982	81/24
"The Ecology of Bottomland Hardwood Swamps of the Southeast"	1982	81/37
"The Ecology of Southern California Coastal Salt Marshes"	1982	81/54
"The Ecology of New England High Salt Marshes"	1982	81/55
"The Ecology of Southeastern Shrub Bogs (Pocosins) and Carolina Bays"	1982	82/04
"The Ecology of the Apalachicola Bay System"	1984	82/05
"The Ecology of the Pamlico River, North Carolina"	1984	82/06
"The Ecology of the South Florida Coral Reefs"	1984	82/08
"The Ecology of the Sea Grasses of South Florida"	1982	82/25
"The Ecology of Tidal Marshes of the Pacific Northwest Coast"	1983	82/32
"The Ecology of Tidal Freshwater Marshes of the U.S. East Coast"	1984	83/17
"The Ecology of San Francisco Bay Tidal Marshes"	1983	82/23
"The Ecology of Tundra Ponds of the Arctic Coastal Plain"	1984	83/25
"The Ecology of Eelgrass Meadows of the Atlantic Coast"	1984	84/02
"The Ecology of Delta Marshes of Louisiana"	1984	84/09
"The Ecology of Eelgrass Meadows in the Pacific Northwest"	1984	84/24
"The Ecology of Irregularly Flooded Marshes of North-eastern Gulf of Mexico"	(In press)	85(7.1)
"The Ecology of Giant Kelp Forests in California"	1985	85(7.2)

Indicators of hydrophytic vegetation

35. Several indicators may be used to determine whether hydrophytic vegetation is present on a site. However, the presence of a single individual of a hydrophytic species does not mean that hydrophytic vegetation is present. The strongest case for the presence of hydrophytic vegetation can be made when

several indicators, such as those in the following list, are present. However, any one of the following is indicative that hydrophytic vegetation is present:[1]

a. More than 50 percent of the dominant species are OBL, FACW, or FAC[2] (Table 1) on lists of plant species that occur in wetlands. A national interagency panel has prepared a National List of Plant Species that occur in wetlands. This list categorizes species according to their affinity for occurrence in wetlands. ~~Regional subset lists of the national list, including only species having an indicator status of OBL, FACW, or FAC, are presented in Appendix C, Section 1. The CE has also developed regional lists of plant species that commonly occur in wetlands (Appendix C, Section 2). Either list may be used.~~

> USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. Subsequent changes to the May 1988 national plant list, or regional versions of the national list, should not be used until they receive official review and approval. (HQUSACE, 27 Aug 91 and 17 Jan 96)

Note: A District that, on a subregional basis, questions the indicator status of FAC species may use the following option: When FAC species occur as dominants along with other dominants that are not FAC (either wetter or drier than FAC), the FAC species can be considered as neutral, and the vegetation decision can be based on the number of dominant species wetter than FAC as compared to the number of dominant species drier than FAC. When a tie occurs or all dominant species are FAC, the nondominant species must be considered. The area has hydrophytic vegetation when more than 50 percent of all considered species are wetter than FAC. When either all considered species are FAC or the number of species wetter than FAC equals the number of species drier than FAC, the wetland determination will be based on the soil and hydrology parameters. Districts adopting this option should provide documented support to the Corps representative on the regional plant list panel, so that a change in indicator status of FAC species of concern can be pursued. Corps representatives on the regional and national plant list panels will continually strive to ensure that plant species are properly designated on both a regional and subregional basis.

---

[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.

[2] FAC+ species are considered to be wetter (i.e., have a greater estimated probability of occurring in wetlands) than FAC species, while FAC- species are considered to be drier (i.e., have a lesser estimated probability of occurring in wetlands) than FAC species.

USER NOTES: The FAC-neutral option can <u>not</u> be used to exclude areas as wetlands that meet the basic vegetation rule (i.e., more than 50% of dominant species are FAC, FACW, or OBL) and meet wetland hydrology and hydric soil requirements. Presence of a plant community that satisfies the FAC-neutral option may be used as a secondary indicator of wetland hydrology. (HQUSACE, 6 Mar 92)

b. *Other indicators.* Although there are several other indicators of hydrophytic vegetation, it will seldom be necessary to use them. However, they may provide additional useful information to strengthen a case for the presence of hydrophytic vegetation. Additional training and/or experience may be required to employ these indicators.

(1) *Visual observation of plant species growing in areas of prolonged inundation and/or soil saturation.* This indicator can only be applied by experienced personnel who have accumulated information through several years of field experience and written documentation (field notes) that certain species commonly occur in areas of prolonged (>10 percent) inundation and/or soil saturation during the growing season. Species such as *Taxodium distichum, Typha latifolia,* and *Spartina alterniflora* normally occur in such areas. Thus, occurrence of species commonly observed in other wetland areas provides a strong indication that hydrophytic vegetation is present. *CAUTION: The presence of standing water or saturated soil on a site is insufficient evidence that the species present are able to tolerate long periods of inundation. The user must relate the observed species to other similar situations and determine whether they are normally found in wet areas, taking into consideration the season and immediately preceding weather conditions.*

(2) *Morphological adaptations.* Some hydrophytic species have easily recognized physical characteristics that indicate their ability to occur in wetlands. A given species may exhibit several of these characteristics, but not all hydrophytic species have evident morphological adaptations. A list of such morphological adaptations and a partial list of plant species with known morphological adaptations for occurrence in wetlands are provided in Appendix C, Section 3.

(3) *Technical literature.* The technical literature may provide a strong indication that plant species comprising the prevalent vegetation are commonly found in areas where soils are periodically saturated for long periods. Sources of available literature include:

(a) *Taxonomic references.* Such references usually contain at least a general description of the habitat in which a species occurs. A habitat description such as, "Occurs in water of streams and lakes and in alluvial floodplains subject to periodic flooding," supports a conclusion that the species typically occurs in wetlands. Examples of some useful taxonomic references are provided in Table 4.

Table 4
List of Some Useful Taxonomic References

Title	Author(s)
Manual of Vascular Plants of Northeastern United States and Adjacent Canada	Gleason and Cronquist (1963)
Gray's Manual of Botany, 8th edition	Fernald (1950)
Manual of the Southeastern Flora	Small (1933)
Manual of the Vascular Flora of the Carolinas	Radford, Ahles, and Bell (1968)
A Flora of Tropical Florida	Long and Lakela (1976)
Aquatic and Wetland Plants of the Southwestern United States	Correll and Correll (1972)
Arizona Flora	Kearney and Peebles (1960)
Flora of the Pacific Northwest	Hitchcock and Cronquist (1973)
A California Flora	Munz and Keck (1959)
Flora of Missouri	Steyermark (1963)
Manual of the Plants of Colorado	Harrington (1979)
Intermountain Flora - Vascular Plants of the Intermountain West, USA - Vols I and II	Cronquist et al. (1972)
Flora of Idaho	Davis (1952)
Aquatic and Wetland Plants of the Southeastern United States - Vols I and II	Godfrey and Wooten (1979)
Manual of Grasses of the U.S.	Hitchcock (1950)

(b) *Botanical journals.* Some botanical journals contain studies that define species occurrence in various hydrologic regimes. Examples of such journals include: *Ecology, Ecological Monographs, American Journal of Botany, Journal of American Forestry, and Wetlands: The Journal of the Society of Wetland Scientists.*

(c) *Technical reports.* Governmental agencies periodically publish reports (e.g., literature reviews) that contain information on plant species occurrence in relation to hydrologic regimes. Examples of such publications include the CE preliminary regional wetland guides (Table 2) published by the U.S. Army Engineer Waterways Experiment Station (WES) and the wetland community and estuarine profiles of various habitat types (Table 3) published by the FWS.

(d) *Technical workshops, conferences, and symposia.* Publications resulting from periodic scientific meetings contain valuable information that can be used to support a decision regarding the presence of hydrophytic vegetation. These usually address specific regions or wetland types. For example, distribution of bottomland hardwood forest species in relation to hydrologic regimes was examined at a workshop on bottomland hardwood forest wetlands of the Southeastern United States (Clark and Benforado 1981).

(e) *Wetland plant database.* The NWI is producing a Plant Database that contains habitat information on approximately 5,200 plant species that occur at some estimated probability in wetlands, as compiled from the technical literature. When completed, this computerized database will be available to all governmental agencies.

(4) *Physiological adaptations.* Physiological adaptations include any features of the metabolic processes of plants that make them particularly fitted for life in saturated soil conditions. *NOTE: It is impossible to detect the presence of physiological adaptations in plant species during onsite visits.* Physiological adaptations known for hydrophytic species and species known to exhibit these adaptations are listed and discussed in Appendix C, Section 3.

(5) *Reproductive adaptations.* Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. Reproductive adaptations known for hydrophytic species are presented in Appendix C, Section 3.

Hydric Soils

Definition

36. ~~A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture (USDA) Soil Conservation Service (SCS) 1985, as amended by the National Technical Committee for Hydric Soils (NTCHS) in December 1986).~~

Criteria for hydric soils

37. ~~Based on the above definition, the NTCHS developed the following criteria for hydric soils:~~

a. ~~All Histosols[1] except Folists;~~

b. ~~Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:~~

(1) ~~Somewhat poorly drained and have a water table less than 0.5 ft[2] from the surface for a significant period (usually a week or more) during the growing season, or~~

(2) ~~Poorly drained or very poorly drained and have either:~~

(a) ~~A water table at less than 1.0 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 in/hr in all layers within 20 inches; or~~

(b) ~~A water table at less than 1.5 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/hr in any layer within 20 inches; or~~

c. ~~Soils that are ponded for long or very long duration during the growing season; or~~

d. ~~Soils that are frequently flooded for long duration or very long duration during the growing season.~~

USER NOTES: The hydric soil definition and criteria published in the 1987 Corps Manual are obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

A hydric soil may be either drained or undrained, and a drained hydric soil may not continue to support hydrophytic vegetation. Therefore, not all areas having hydric soils will qualify as wetlands. Only when a hydric soil supports hydrophytic vegetation and the area has indicators of wetland hydrology may the soil be referred to as a "wetland" soil.

38. A drained hydric soil is one in which sufficient ground or surface water has been removed by artificial means such that the area will no longer support hydrophyte vegetation. Onsite evidence of drained soils includes:

---

[1] Soil nomenclature follows USDA-SCS (1975).

[2] A table of factors for converting Non-SI Units of Measurement to SI (metric) units is presented on page x.

a. Presence of ditches or canals of sufficient depth to lower the water table below the major portion of the root zone of the prevalent vegetation.

b. Presence of dikes, levees, or similar structures that obstruct normal inundation of an area.

c. Presence of a tile system to promote subsurface drainage.

d. Diversion of upland surface runoff from an area.

Although it is important to record such evidence of drainage of an area, a hydric soil that has been drained or partially drained still allows the soil parameter to be met. However, the area will not qualify as a wetland if the degree of drainage has been sufficient to preclude the presence of either hydrophytic vegetation or a hydrologic regime that occurs in wetlands. *NOTE: The mere presence of drainage structures in an area is not sufficient basis for concluding that a hydric soil has been drained; such areas may continue to have wetland hydrology.*

General information

39. Soils consist of unconsolidated, natural material that supports, or is capable of supporting, plant life. The upper limit is air and the lower limit is either bedrock or the limit of biological activity. Some soils have very little organic matter (mineral soils), while others are composed primarily of organic matter (Histosols). The relative proportions of particles (sand, silt, clay, and organic matter) in a soil are influenced by many interacting environmental factors. As normally defined, a soil must support plant life. The concept is expanded to include substrates that could support plant life. For various reasons, plants may be absent from areas that have well-defined soils.

40. A soil profile (Figure 2) consists of various soil layers described from the surface downward. Most soils have two or more identifiable horizons. A soil horizon is a layer oriented approximately parallel to the soil surface, and usually is differentiated from contiguous horizons by characteristics that can be seen or measured in the field (e.g., color, structure, texture, etc.). Most mineral soils have A-, B-, and C-horizons, and many have surficial organic layers (O-horizon). The A-horizon, the surface soil or topsoil, is a zone in which organic matter is usually being added to the mineral soil. It is also the zone from which both mineral and organic matter are being moved slowly downward. The next major horizon is the B-horizon, often referred to as the subsoil. The B-horizon is the zone of maximum accumulation of materials. It is usually characterized by higher clay content and/or more pronounced soil structure development and lower organic matter than the A-horizon. The next major horizon is usually the C-horizon, which consists of unconsolidated parent material that has not been sufficiently weathered to exhibit characteristics of the B-horizon. Clay content and degree of soil structure development in the C-horizon are usually less than in the B-horizon. The lowest major horizon, the R-horizon, consists of consoli-

dated bedrock. In many situations, this horizon occurs at such depths that it has no significant influence on soil characteristics.

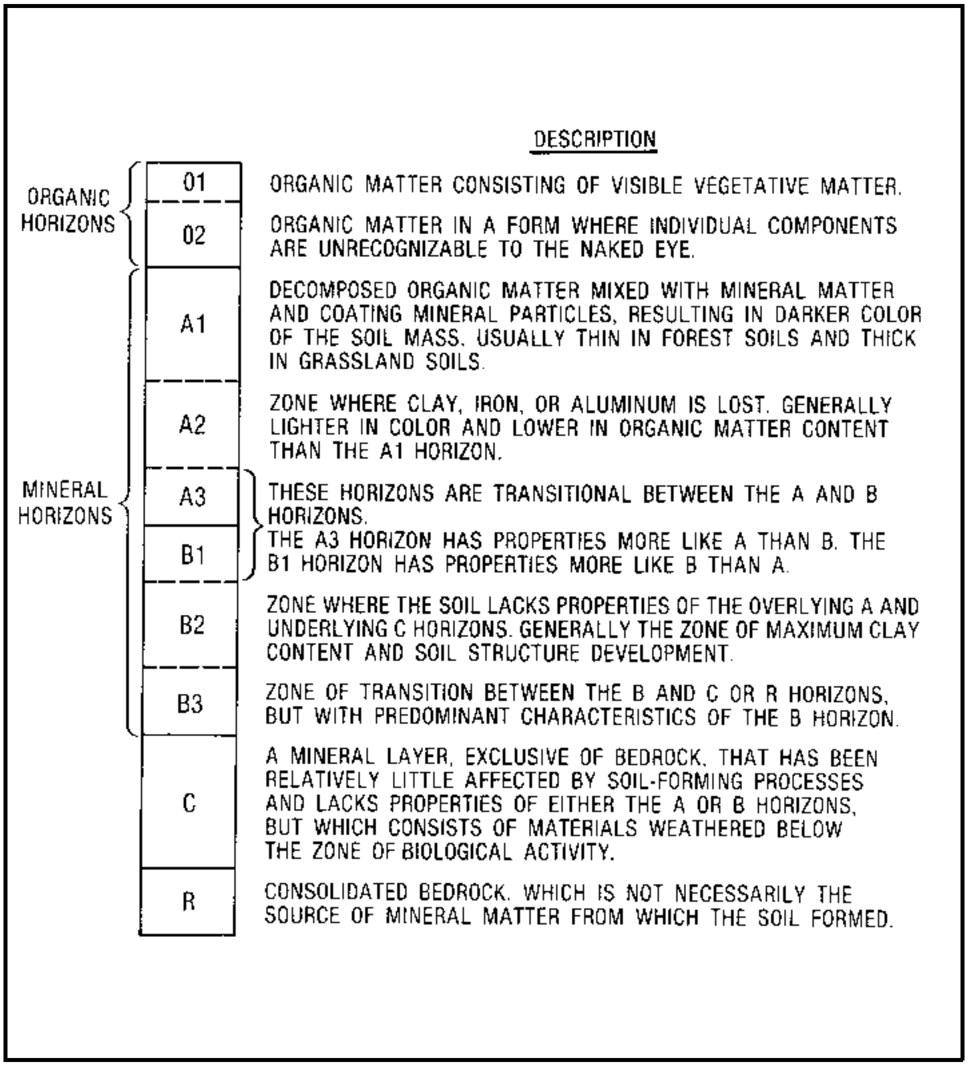


Figure 2. Generalized soil profile

Influencing factors

41. Although all soil-forming factors (climate, parent material, relief, organisms, and time) affect the characteristics of a hydric soil, the overriding influence is the hydrologic regime. The unique characteristics of hydric soils result from the influence of periodic or permanent inundation or soil saturation for sufficient duration to effect anaerobic conditions. Prolonged anaerobic soil conditions lead to a reducing environment, thereby lowering the soil redox potential. This results in chemical reduction of some soil components (e.g., iron and manganese oxides), which leads to development of soil colors and other physical characteristics that usually are indicative of hydric soils.

Classification

42. Hydric soils occur in several categories of the current soil classification system, which is published in *Soil Taxonomy* (USDA-SCS 1975). This classification system is based on physical and chemical properties of soils that can be seen, felt, or measured. Lower taxonomic categories of the system (e.g., soil series and soil phases) remain relatively unchanged from earlier classification systems.

43. Hydric soils may be classified into two broad categories: organic and mineral. Organic soils (Histosols) develop under conditions of nearly continuous saturation and/or inundation. All organic soils are hydric soils except Folists, which are freely drained soils occurring on dry slopes where excess litter accumulates over bedrock. Organic hydric soils are commonly known as peats and mucks. All other hydric soils are mineral soils. Mineral soils have a wide range of textures (sandy to clayey) and colors (red to gray). Mineral hydric soils are those periodically saturated for sufficient duration to produce chemical and physical soil properties associated with a reducing environment. They are usually gray and/or mottled immediately below the surface horizon (see paragraph 44*d*), or they have thick, dark-colored surface layers overlying gray or mottled subsurface horizons.

Wetland indicators (nonsandy soils)

44. Several indicators are available for determining whether a given soil meets the definition and criteria for hydric soils. Any one of the following indicates that hydric soils are present:[1]

Figure 3. Organic soil

a. *Organic soils (Histosols).* A soil is an organic soil when: (1) more than 50 percent (by volume) of the upper 32 inches of soil is composed of organic soil material;[2] or (2) organic soil material of any thickness rests on bedrock. Organic soils (Figure 3) are saturated for long periods and are commonly called peats or mucks.

b. *Histic epipedons.* A histic epipedon is an 8- to 16-inch layer at or near the surface of a mineral hydric soil that is saturated with

[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.
[2] A detailed definition of organic soil material is available in USDA-SCS (1975).

water for 30 consecutive days or more in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when clay content is 60 percent or greater. Soils with histic epipedons are inundated or saturated for sufficient periods to greatly retard aerobic decomposition of the organic surface, and are considered to be hydric soils.

c. *Sulfidic material.* When mineral soils emit an odor of rotten eggs, hydrogen sulfide is present. Such odors are only detected in waterlogged soils that are permanently saturated and have sulfidic material within a few centimeters of the soil surface. Sulfides are produced only in a reducing environment.

d. *Aquic or peraquic moisture regime.* An aquic moisture regime is a reducing one; i.e., it is virtually free of dissolved oxygen because the soil is saturated by ground water or by water of the capillary fringe (USDA-SCS 1975). Because dissolved oxygen is removed from ground water by respiration of microorganisms, roots, and soil fauna, it is also implicit that the soil temperature is above biologic zero (5° C) at some time while the soil is saturated. Soils with *peraquic* moisture regimes are characterized by the presence of ground water always at or near the soil surface. Examples include soils of tidal marshes and soils of closed, landlocked depressions that are fed by permanent streams.

e. *Reducing soil conditions.* Soils saturated for long or very long duration will usually exhibit reducing conditions. Under such conditions, ions of iron are transformed from a ferric valence state to a ferrous valence state. This condition can often be detected in the field by a ferrous iron test. A simple colorimetric field test kit has been developed for this purpose. When a soil extract changes to a pink color upon addition of α,α'-dipyridyl, ferrous iron is present, which indicates a reducing soil environment. *NOTE: This test cannot be used in mineral hydric soils having low iron content, organic soils, and soils that have been desaturated for significant periods of the growing season.*

f. *Soil colors.* The colors of various soil components are often the most diagnostic indicator of hydric soils. Colors of these components are strongly influenced by the frequency and duration of soil saturation, which leads to reducing soil conditions. Mineral hydric soils will be either gleyed or will have bright mottles and/or low matrix chroma. These are discussed below:

(1) *Gleyed soils (gray colors).* Gleyed soils develop when anaerobic soil conditions result in pronounced chemical reduction of iron, manganese, and other elements, thereby producing gray soil colors. Anaerobic conditions that occur in waterlogged soils result in the predominance of reduction processes, and such soils are greatly reduced. Iron is one of the most abundant elements in soils. Under anaerobic conditions, iron in converted from the oxidized (ferric)

Figure 4. Gleyed soil

Figure 5. Soil showing matrix (brown) and mottles (reddish-brown)

state to the reduced (ferrous) state, which results in the bluish, greenish, or grayish colors associated with the gleying effect (Figure 4). Gleying immediately below the A-horizon or 10 inches (whichever is shallower) is an indication of a markedly reduced soil, and gleyed soils are hydric soils. Gleyed soil conditions can be determined by using the gley page of the Munsell Color Book (Munsell Color 1975).

(2) *Soils with bright mottles and/or low matrix chroma.* Mineral hydric soils that are saturated for substantial periods of the growing season (but not long enough to produce gleyed soils) will either have bright mottles and a low matrix chroma or will lack mottles but have a low matrix chroma (see Appendix D, Section 1, for a definition and discussion of "chroma" and other components of soil color). *Mottled* means "marked with spots of contrasting color." Soils that have brightly colored mottles and a low matrix chroma are indicative of a fluctuating water table. The soil *matrix* is the portion (usually more than 50 percent) of a given soil layer that has the predominant color (Figure 5). Mineral hydric soils usually have one of the following color features in the horizon immediately below the A-horizon or 10 inches (whichever is shallower):

(a) Matrix chroma of 2 or less[1] in mottled soils.

(b) Matrix chroma of 1 or less[1] in unmottled soils.

NOTE: The matrix chroma of some dark (black) mineral hydric soils will not conform to the criteria described in (a) and (b) above; in such soils, gray mottles occurring at 10 inches or less are indicative of hydric conditions.

[1] Colors should be determined in soils that have been moistened; otherwise, state that colors are for dry soils.

CAUTION: Soils with significant coloration due to the nature of the parent material (e.g., red soils of the Red River Valley) may not exhibit the above characteristics. In such cases, this indicator cannot be used.

g. Soil appearing on hydric soils list. Using the criteria for hydric soils (paragraph 37), the NTCHS has developed a list of hydric soils.

USER NOTES: The NRCS has developed local lists of hydric soil mapping units that are available from NRCS county and area offices. These local lists are the preferred hydric soil lists to use in making wetland determinations. (HQUSACE, 6 Mar 92)

Listed soils have reducing conditions for a significant portion of the growing season in a major portion of the root zone and are frequently saturated within 12 inches of the soil surface. ~~The NTCHS list of hydric soils is presented in Appendix D, Section 2.~~ *CAUTION: Be sure that the profile description of the mapping unit conforms to that of the sampled soil.*

h. Iron and manganese concretions. During the oxidation-reduction process, iron and manganese in suspension are sometimes segregated as oxides into concretions or soft masses (Figure 6). These accumulations are usually black or dark brown. Concretions >2 mm in diameter occurring within 7.5 cm of the surface are evidence that the soil is saturated for long periods near the surface.

Figure 6. Iron and manganese concretions

Wetland indicators (sandy soils)

45. Not all indicators listed in paragraph 44 can be applied to sandy soils. *In particular, soil color should not be used as an indicator in most sandy soils.* However, three additional soil features may be used as indicators of sandy hydric soils, including:

a. High organic matter content in the surface horizon. Organic matter tends to accumulate above or in the surface horizon of sandy soils that are inundated or saturated to the surface for a significant portion of the growing season. Prolonged inundation or saturation creates anaerobic conditions that greatly reduce oxidation of organic matter.

b. *Streaking of subsurface horizons by organic matter.* Organic matter is moved downward through sand as the water table fluctuates. This often occurs more rapidly and to a greater degree in some vertical sections of a sandy soil containing high content of organic matter than in others. Thus, the sandy soil appears vertically streaked with darker areas. When soil from a darker area is rubbed between the fingers, the organic matter stains the fingers.

c. *Organic pans.* As organic matter is moved downward through sandy soils, it tends to accumulate at the point representing the most commonly occurring depth to the water table. This organic matter tends to become slightly cemented with aluminum, forming a thin layer of hardened soil (spodic horizon). These horizons often occur at depths of 12 to 30 inches below the mineral surface. Wet spodic soils usually have thick dark surface horizons that are high in organic matter with dull, gray horizons above the spodic horizon.

> USER NOTES: The NRCS has developed regional lists of "Field Indicators of Hydric Soils in the United States" (Version 3.2, July 1996, or later). Until approved, these indicators do not supersede those given in the 1987 Corps Manual and supplemental guidance but may be used as supplementary information. Several of the NRCS indicators were developed specifically to help in identifying hydric soils in certain problem soil types (e.g., sandy soils, soils derived from red parent materials, soils with thick, dark surfaces). These indicators may be used under procedures given in the Problem Area section of the 1987 Manual. (HQUSACE, 21 Mar 97)

CAUTION: In recently deposited sandy material (e.g., accreting sandbars), it may be impossible to find any of these indicators. In such cases, consider this as a natural atypical situation.

Wetland Hydrology

Definition

46. The term "wetland hydrology" encompasses all hydrologic characteristics of areas that are periodically inundated or have soils saturated to the surface at some time during the growing season. Areas with evident characteristics of wetland hydrology are those where the presence of water has an overriding influence on characteristics of vegetation and soils due to anaerobic and reducing conditions, respectively. Such characteristics are usually present in areas that

are inundated or have soils that are saturated to the surface for sufficient duration to develop hydric soils and support vegetation typically adapted for life in periodically anaerobic soil conditions. Hydrology is often the least exact of the parameters, and indicators of wetland hydrology are sometimes difficult to find in the field. However, it is essential to establish that a wetland area is periodically inundated or has saturated soils during the growing season.

> USER NOTES: The 1987 Manual (see glossary, Appendix A) defines "growing season" as the portion of the year when soil temperature (measured 20 inches below the surface) is above biological zero (5° C or 41° F). This period "can be approximated by the number of frost-free days." Estimated starting and ending dates for the growing season are based on 28° F air temperature thresholds at a frequency of 5 years in 10 (HQUSACE, 6 Mar 92). This information is available in NRCS county soil survey reports or from the NRCS Water and Climate Center in Portland, Oregon, for most weather stations in the country.

Influencing factors

47. Numerous factors (e.g., precipitation, stratigraphy, topography, soil permeability, and plant cover) influence the wetness of an area. Regardless, the characteristic common to all wetlands is the presence of an abundant supply of water. The water source may be runoff from direct precipitation, headwater or backwater flooding, tidal influence, ground water, or some combination of these sources. The frequency and duration of inundation or soil saturation varies from nearly permanently inundated or saturated to irregularly inundated or saturated. Topographic position, stratigraphy, and soil permeability influence both the frequency and duration of inundation and soil saturation. Areas of lower elevation in a floodplain or marsh have more frequent periods of inundation and/or greater duration than most areas at higher elevations. Floodplain configuration may significantly affect duration of inundation. When the floodplain configuration is conducive to rapid runoff, the influence of frequent periods of inundation on vegetation and soils may be reduced. Soil permeability also influences duration of inundation and soil saturation. For example, clayey soils absorb water more slowly than sandy or loamy soils, and therefore have slower permeability and remain saturated much longer. Type and amount of plant cover affect both degree of inundation and duration of saturated soil conditions. Excess water drains more slowly in areas of abundant plant cover, thereby increasing frequency and duration of inundation and/or soil saturation. On the other hand, transpiration rates are higher in areas of abundant plant cover, which may reduce the duration of soil saturation.

Classification

48. Although the interactive effects of all hydrologic factors produce a continuum of wetland hydrologic regimes, efforts have been made to classify wet-

land hydrologic regimes into functional categories. These efforts have focused on the use of frequency, timing, and duration of inundation or soil saturation as a basis for classification. A classification system developed for nontidal areas is presented in Table 5. This classification system was slightly modified from the system developed by the Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States (Clark and Benforado 1981). Recent research indicates that duration of inundation and/or soil saturation during the growing season is more influential on the plant community than frequency of inundation/saturation during the growing season (Theriot, in press). Thus, frequency of inundation and soil saturation are not included in Table 5. ~~The WES has developed a computer program that can be used to transform stream gage data to mean sea level elevations representing the upper limit of each hydrologic zone shown in Table 5. This program is available upon request.~~[1]

USER NOTES: Based on Table 5 and on paragraph 55, Step 8.i., an area has wetland hydrology if it is inundated or saturated to the surface continuously for at least 5% of the growing season in most years (50% probability of recurrence). These areas are wetlands if they also meet hydrophytic vegetation and hydric soil requirements. (HQUSACE, 7 Oct 91 and 6 Mar 92)

Table 5
Hydrologic Zones[1] - Nontidal Areas

Zone	Name	Duration[2]	Comments
I[3]	Permanently inundated	100 percent	Inundation >6.6 ft mean water depth
II	Semipermanently to nearly permanently inundated or saturated	>75 - <100 percent	Inundation defined as ≤6.6 ft mean water depth
III	Regularly inundated or saturated	>25 - 75 percent	
IV	Seasonally inundated or saturated	>12.5 - 25 percent	
V	Irregularly inundated or saturated	≥5 - 12.5 percent	Many areas having these hydrologic characteristics are not wetlands
VI	Intermittently or never inundated or saturated	<5 percent	Areas with these hydrologic characteristics are not wetlands

[1] Zones adapted from Clark and Benforado (1981).
[2] Refers to duration of inundation and/or soil saturation during the growing season.
[3] This defines an aquatic habitat zone.

Wetland indicators

49. Indicators of wetland hydrology may include, but are not necessarily limited to: drainage patterns, drift lines, sediment deposition, watermarks,

[1] ~~R. F. Theriot, Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station, P.O. Box 631, Vicksburg, MS 39180.~~

stream gage data and flood predictions, historic records, visual observation of saturated soils, and visual observation of inundation. Any of these indicators may be evidence of wetland hydrologic characteristics. Methods for determining hydrologic indicators can be categorized according to the type of indicator. Recorded data include stream gage data, lake gage data, tidal gage data, flood predictions, and historical records. Use of these data is commonly limited to areas adjacent to streams or other similar areas. Recorded data usually provide both short- and long-term information about frequency and duration of inundation, but contain little or no information about soil saturation, which must be gained from soil surveys or other similar sources. The remaining indicators require field observations. Field indicators are evidence of present or past hydrologic events (e.g., location and height of flooding). Indicators for recorded data and field observations include:[1]

a. *Recorded data.* Stream gage data, lake gage data, tidal gage data, flood predictions, and historical data may be available from the following sources:

(1) *CE District Offices.* Most CE Districts maintain stream, lake, and tidal gage records for major water bodies in their area. In addition, CE planning and design documents often contain valuable hydrologic information. For example, a General Design Memorandum (GDM) usually describes flooding frequencies and durations for a project area. Furthermore, the extent of flooding within a project area is sometimes indicated in the GDM according to elevation (height) of certain flood frequencies (1-, 2-, 5-, 10-year, etc.).

(2) *U.S. Geological Survey (USGS).* Stream and tidal gage data are available from the USGS offices throughout the Nation, and the latter are also available from the National Oceanic and Atmospheric Administration. CE Districts often have such records.

(3) *State, county, and local agencies.* These agencies often have responsibility for flood control/relief and flood insurance.

(4) *Soil Conservation Service Small Watershed Projects.* Planning documents from this agency are often helpful, and can be obtained from the SCS district office in the county.

(5) *Planning documents of developers.*

b. *Field data.* The following field hydrologic indicators can be assessed quickly, and although some of them are not necessarily indicative of hydrologic events that occur only during the growing season, they do provide evidence that inundation and/or soil saturation has occurred:

---

[1] Indicators are listed in order of decreasing reliability. Although all are valid indicators, some are stronger indicators than others. When a decision is based on an indicator appearing in the lower portion of the list, re-evaluate the parameter to ensure that the proper decision was reached.

(1) *Visual observation of inundation.* The most obvious and revealing hydrologic indicator may be simply observing the areal extent of inundation. However, because seasonal conditions and recent weather conditions can contribute to surface water being present on a nonwetland site, both should be considered when applying this indicator.

(2) *Visual observation of soil saturation.* Examination of this indicator requires digging a soil pit (Appendix D, Section 1) to a depth of 16 inches and observing the level at which water stands in the hole after sufficient time has been allowed for water to drain into the hole. The required time will vary depending on soil texture. In some cases, the upper level at which water is flowing into the pit can be observed by examining the wall of the hole. This level represents the depth to the water table. The depth to saturated soils will always be nearer the surface due to the capillary fringe.

For soil saturation to impact vegetation, it must occur within a *major portion of the root zone* (usually within 12 inches of the surface) of the prevalent vegetation. The major portion of the root zone is that portion of the soil profile in which more than one half of the plant roots occur. *CAUTION: In some heavy clay soils, water may not rapidly accumulate in the hole even when the soil is saturated. If water is observed at the bottom of the hole but has not filled to the 12-inch depth, examine the sides of the hole and determine the shallowest depth at which water is entering the hole. When applying this indicator, both the season of the year and preceding weather conditions must be considered.*

Figure 7. Watermark on trees

(3) *Watermarks.* Watermarks are most common on woody vegetation. They occur as stains on bark (Figure 7) or other fixed objects (e.g., bridge pillars, buildings, fences, etc.). When several watermarks are present, the highest reflects the maximum extent of recent inundation.

(4) *Drift lines.* This indicator is most likely to be found adjacent to streams or other

sources of water flow in wetlands, but also often occurs in tidal marshes. Evidence consists of deposition of debris in a line on the surface (Figure 8) or debris entangled in aboveground vegetation or other fixed objects. Debris usually consists of remnants of vegetation (branches, stems, and leaves), sediment, litter, and other waterborne materials deposited parallel to the direction of water flow. Drift lines provide an indication of the minimum portion of the area inundated during a flooding event; the maximum level of inundation is generally at a higher elevation than that indicated by a drift line.

Figure 8. Absence of leaf litter

Figure 9. Sediment deposit on plants

(5) *Sediment deposits.* Plants and other vertical objects often have thin layers, coatings, or depositions of mineral or organic matter on them after inundation (Figure 9). This evidence may remain for a considerable period before it is removed by precipitation or subsequent inundation. Sediment deposition on vegetation and other objects provides an indication of the minimum inundation level. When sediments are primarily organic (e.g., fine organic material, algae), the detritus may become encrusted on or slightly above the soil surface after dewatering occurs (Figure 10).

Figure 10. Encrusted detritus

(6) *Drainage patterns within wetlands.* This indicator, which occurs primarily in wetlands

adjacent to streams, consists of surface evidence of drainage flow into or through an area (Figure 11). In some wetlands, this evidence may exist as a drainage pattern eroded into the soil, vegetative matter (debris) piled against thick vegetation or woody stems oriented perpendicular to the direction of water flow, or the absence of leaf litter (Figure 8). Scouring is often evident around roots of persistent vegetation. Debris may be deposited in or along the drainage pattern (Figure 12).

Figure 11. Drainage pattern

Figure 12. Debris deposited in stream channel

CAUTION: Drainage patterns also occur in upland areas after periods of considerable precipitation; therefore, topographic position must also be considered when applying this indicator.

USER NOTES: The hydrology indicators described above are considered to be "primary indicators", any one of which is sufficient evidence that wetland hydrology is present when combined with a hydrophytic plant community and hydric soils. In addition, the following "secondary indicators" may also be used to determine whether wetland hydrology is present. In the absence of a primary indicator, any two secondary indicators must be present to conclude that wetland hydrology is present. Secondary indicators are: presence of oxidized rhizospheres associated with living plant roots in the upper 12 inches of the soil, presence of water-stained leaves, local soil survey hydrology data for identified soils, and the FAC-neutral test of the vegetation. (HQUSACE, 6 Mar 92)

Part IV: Methods

Section A. Introduction

50. Part IV contains sections on preliminary data gathering, method selection, routine determination procedures, comprehensive determination procedures, methods for determinations in atypical situations, and guidance for wetland determinations in natural situations where the three-parameter approach may not always apply.

51. Significant flexibility has been incorporated into Part IV. The user is presented in Section B with various potential sources of information that may be helpful in making a determination, but not all identified sources of information may be applicable to a given situation. *NOTE: The user is not required to obtain information from all identified sources.* Flexibility is also provided in method selection (Section C). Three levels of routine determinations are available, depending on the complexity of the required determination and the quantity and quality of existing information. Application of methods presented in both Section D (routine determinations) and Section E (comprehensive determinations) may be tailored to meet site-specific requirements, especially with respect to sampling design.

52. Methods presented in Sections D and E vary with respect to the required level of technical knowledge and experience of the user. Application of the qualitative methods presented in Section D (routine determinations) requires considerably less technical knowledge and experience than does application of the quantitative methods presented in Section E (comprehensive determinations). The user must at least be able to identify the dominant plant species in the project area when making a routine determination (Section D), and should have some basic knowledge of hydric soils when employing routine methods that require soils examination. Comprehensive determinations require a basic understanding of sampling principles and the ability to identify all commonly occurring plant species in a project area, as well as a good understanding of indicators of hydric soils and wetland hydrology. The comprehensive method should only be employed by experienced field inspectors.

Section B. Preliminary Data Gathering and Synthesis

53. This section discusses potential sources of information that may be helpful in making a wetland determination. When the routine approach is used, it may often be possible to make a wetland determination based on available vegetation, soils, and hydrology data for the area. However, this section deals only with identifying potential information sources, extracting pertinent data, and synthesizing the data for use in making a determination. Based on the quantity and quality of available information and the approach selected for use (Section C), the user is referred to either Section D or Section E for the actual determination. Completion of Section B is not required, but is recommended because the available information may reduce or eliminate the need for field effort and decrease the time and cost of making a determination. However, there are instances in small project areas in which the time required to obtain the information may be prohibitive. In such cases PROCEED to paragraph 55, complete STEPS 1 through 3, and PROCEED to Section D or E.

Data sources

54. Obtain the following information, when available and applicable:

a. *USGS quadrangle maps.* USGS quadrangle maps are available at different scales. When possible, obtain maps at a scale of 1:24,000; otherwise, use maps at a scale of 1:62,500. Such maps are available from USGS in Reston, VA, and Menlo Park, CA, but they may already be available in the CE District Office. These maps provide several types of information:

(1) Assistance in locating field sites. Towns, minor roads, bridges, streams, and other landmark features (e.g., buildings, cemeteries, water bodies, etc.) not commonly found on road maps are shown on these maps.

(2) Topographic details, including contour lines (usually at 5- or 10-ft contour intervals).

(3) General delineation of wet areas (swamps and marshes). *NOTE: The actual wet area may be greater than that shown on the map because USGS generally maps these areas based on the driest season of the year.*

(4) Latitude, longitude, townships, ranges, and sections. These provide legal descriptions of the area.

(5) Directions, including both true and magnetic north.

(6) Drainage patterns.

(7) General land uses, such as cleared (agriculture or pasture), forested, or urban.

CAUTION: Obtain the most recent USGS maps. Older maps may show features that no longer exist and will not show new features that have developed since the map was constructed. Also, USGS is currently changing the mapping scale from 1:24,000 to 1:25,000.

b. National Wetlands Inventory products.

(1) *Wetland maps.* The standard NWI maps are at a scale of 1:24,000 or, where USGS base maps at this scale are not available, they are at 1:62,500 (1:63,350 in Alaska). Smaller scale maps ranging from 1:100,000 to 1:500,000 are also available for certain areas. Wetlands on NWI maps are classified in accordance with Cowardin et al. (1979). *CAUTION: Since not all delineated areas on NWI maps are wetlands under Department of Army jurisdiction, NWI maps should not be used as the sole basis for determining whether wetland vegetation is present.* NWI "User Notes" are available that correlate the classification system with local wetland community types. An important feature of this classification system is the water regime modifier, which describes the flooding or soil saturation characteristics. Wetlands classified as having a temporarily flooded or intermittently flooded water regime should be viewed with particular caution since this designation is indicative of plant communities that are transitional between wetland and nonwetland. These are among the most difficult plant communities to map accurately from aerial photography. For wetlands "wetter" than temporarily flooded and intermittently flooded, the probability of a designated map unit on recent NWI maps being a wetland (according to Cowardin et al. 1979) at the time of the photography is in excess of 90 percent. *CAUTION: Due to the scale of aerial photography used and other factors, all NWI map boundaries are approximate.* The optimum use of NWI maps is to plan field review (i.e., how wet, big, or diverse is the area?) and to assist during field review, particularly by showing the approximate areal extent of the wetland and its association with other communities. NWI maps are available either as a composite with, or an overlay for, USGS base maps and may be obtained from the NWI Central Office in St. Petersburg, FL, the Wetland Coordinator at each FWS regional office, or the USGS.

USER NOTES: NWI products and information are available over the World Wide Web.

(2) *Plant database.* This database of approximately 5,200 plant species that occur in wetlands provides information (e.g., ranges, habitat, etc.) about each plant species from the technical literature. The database served as a focal point for development of a national list of plants that occur in wetlands (~~Appendix C, Section 1~~).

c. *Soil Surveys.* Soil surveys are prepared by the SCS for political units (county, parish, etc.) in a state. Soil surveys contain several types of information:

(1) General information (e.g., climate, settlement, natural resources, farming, geology, general vegetation types).

(2) Soil maps for general and detailed planning purposes. These maps are usually generated from fairly recent aerial photography. *CAUTION: The smallest mapping unit is 3 acres, and a given soil series as mapped may contain small inclusions of other series.*

(3) Uses and management of soils. Any wetness characteristics of soils will be mentioned here.

(4) Soil properties. Soil and water features are provided that may be very helpful for wetland investigations. Frequency, duration, and timing of inundation (when present) are described for each soil type. Water table characteristics that provide valuable information about soil saturation are also described. Soil permeability coefficients may also be available.

(5) Soil classification. Soil series and phases are usually provided. Published soil surveys will not always be available for the area. If not, contact the county SCS office and determine whether the soils have been mapped.

d. *Stream and tidal gage data.* These documents provide records of tidal and stream flow events. They are available from either the USGS or CE District office.

e. *Environmental impact assessments (EIAs), environmental impact statements (EISs), general design memoranda (GDM), and other similar publications.* These documents may be available from Federal agencies for an area that includes the project area. They may contain some indication of the location and characteristics of wetlands consistent with the required criteria (vegetation, soils, and hydrology), and often contain flood frequency and duration data.

f. *Documents and maps from State, county, or local governments.* Regional maps that characterize certain areas (e.g., potholes, coastal areas, or basins) may be helpful because they indicate the type and character of wetlands.

g. *Remote sensing.* Remote sensing is one of the most useful information sources available for wetland identification and delineation. Recent aerial photography, particularly color infrared, provides a detailed view of an area; thus, recent land use and other features (e.g., general type and areal extent of plant communities and degree of inundation of the area when the photography was taken) can be determined. The multiagency cooperative National High Altitude Aerial Photography Program (HAP) has 1:59,000-scale color infrared photography for approximately 85 percent (December 1985) of the coterminous United States from 1980 to 1985. This photography has excellent resolution and can be ordered enlarged to 1:24,000 scale from USGS. Satellite images provide similar information as aerial photography, although the much smaller scale makes observation of detail more difficult without sophisticated equipment and extensive training. Satellite images provide more recent coverage than aerial photography (usually at 18-day intervals). Individual satellite images are more expensive than aerial photography, but are not as expensive as having an area flown and photographed at low altitudes. However, better resolution imagery is now available with remote sensing equipment mounted on fixed-wing aircraft.

h. *Local individuals and experts.* Individuals having personal knowledge of an area may sometimes provide a reliable and readily available source of information about the area, particularly information on the wetness of the area.

i. *USGS land use and land cover maps.* Maps created by USGS using remotely sensed data and a geographical information system provide a systematic and comprehensive collection and analysis of land use and land cover on a national basis. Maps at a scale of 1:250,000 are available as overlays that show land use and land cover according to nine basic levels. One level is wetlands (as determined by the FWS), which is further subdivided into forested and nonforested areas. Five other sets of maps show political units, hydrologic units, census subdivisions of counties, Federal land ownership, and State land ownership. These maps can be obtained from any USGS mapping center.

j. *Applicant's survey plans and engineering designs.* In many cases, the permit applicant will already have had the area surveyed (often at 1-ft contours or less) and will also have engineering designs for the proposed activity.

Data synthesis

55. When employing Section B procedures, use the above sources of information to complete the following steps:

- *STEP 1 - Identify the project area on a map.* Obtain a USGS quadrangle map (1:24,000) or other appropriate map, and locate the area identified in the permit application. PROCEED TO STEP 2.

- *STEP 2 - Prepare a base map.* Mark the project area boundaries on the map. Either use the selected map as the base map or trace the area on a mylar overlay, including prominent landscape features (e.g., roads, buildings, drainage patterns, etc.). If possible, obtain diazo copies of the resulting base map. PROCEED TO STEP 3.

- *STEP 3 - Determine size of the project area.* Measure the area boundaries and calculate the size of the area. PROCEED TO STEP 4 OR TO SECTION D OR E IF SECTION B IS NOT USED.

- *STEP 4 - Summarize available information on vegetation.* Examine available sources that contain information about the area vegetation. Consider the following:

  a. USGS quadrangle maps. Is the area shown as a marsh or swamp? *CAUTION: Do not use this as the sole basis for determining that hydrophytic vegetation is present.*

  b. NWI overlays or maps. Do the overlays or maps indicate that hydrophytic vegetation occurs in the area? If so, identify the vegetation type(s).

  c. EIAs, EISs, or GDMs that include the project area. Extract any vegetation data that pertain to the area.

  d. Federal, State, or local government documents that contain information about the area vegetation. Extract appropriate data.

  e. Recent (within last 5 years) aerial photography of the area. Can the area plant community type(s) be determined from the photography? Extract appropriate data.

  f. Individuals or experts having knowledge of the area vegetation. Contact them and obtain any appropriate information. *CAUTION: Ensure that the individual providing the information has firsthand knowledge of the area.*

  g. Any published scientific studies of the area plant communities. Extract any appropriate data.

  h. Previous wetland determinations made for the area. Extract any pertinent vegetation data.

  When the above have been considered, PROCEED TO STEP 5.

- *STEP 5 - Determine whether the vegetation in the project area is adequately characterized.* Examine the summarized data (STEP 4) and determine whether the area plant communities are adequately characterized. For routine determinations, the plant community type(s) and the dominant species in each vegetation layer of each community type must be known. Dominant species are those that have the largest relative basal area (overstory),[1] height (woody understory), number of stems (woody vines), or greatest areal cover (herbaceous understory). For comprehensive determinations, each plant community type present in the project area must have been quantitatively described within the past 5 years using accepted sampling and analytical procedures, and boundaries between community types must be known. Record information on DATA FORM 1.[2] In either case, PROCEED TO Section F if there is evidence of recent significant vegetation alteration due to human activities or natural events. Otherwise, PROCEED TO STEP 6.

- *STEP 6 - Summarize available information on area soils.* Examine available information and describe the area soils. Consider the following:

  a. County soil surveys. Determine the soil series present and extract characteristics for each. *CAUTION: Soil mapping units sometimes include more than one soil series.*

  b. Unpublished county soil maps. Contact the local SCS office and determine whether soil maps are available for the area. Determine the soil series of the area, and obtain any available information about possible hydric soil indicators (paragraph 44 or 45) for each soil series.

  c. Published EIAs, EISs, or GDMs that include soils information. Extract any pertinent information.

  d. Federal, State, and/or local government documents that contain descriptions of the area soils. Summarize these data.

  e. Published scientific studies that include area soils data. Summarize these data.

  f. Previous wetland determinations for the area. Extract any pertinent soils data.

  When the above have been considered, PROCEED TO STEP 7.

---

[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

[2] A separate DATA FORM 1 must be used for each plant community type.

- *STEP 7 - Determine whether soils of the project area have been adequately characterized.* Examine the summarized soils data and determine whether the soils have been adequately characterized. For routine determinations, the soil series must be known. For comprehensive determinations, both the soil series and the boundary of each soil series must be known. Record information on DATA FORM 1. In either case, if there is evidence of recent significant soils alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO STEP 8.

- *STEP 8 - Summarize available hydrology data.* Examine available information and describe the area hydrology. Consider the following:

  a. USGS quadrangle maps. Is there a significant, well-defined drainage through the area? Is the area within a major floodplain or tidal area? What range of elevations occur in the area, especially in relation to the elevation of the nearest perennial watercourse?

  b. NWI overlays or maps. Is the area shown as a wetland or deepwater aquatic habitat? What is the water regime modifier?

  c. EIAs, EISs, or GDMs that describe the project area. Extract any pertinent hydrologic data.

  d. Floodplain management maps. These maps may be used to extrapolate elevations that can be expected to be inundated on a l-, 2-, 3-year, etc., basis. Compare the elevations of these features with the elevation range of the project area to determine the frequency of inundation.

  e. Federal, State, and local government documents (e.g., CE floodplain management maps and profiles) that contain hydrologic data. Summarize these data.

  f. Recent (within past 5 years) aerial photography that shows the area to be inundated. Record the date of the photographic mission.

  g. Newspaper accounts of flooding events that indicate periodic inundation of the area.

  h. SCS County Soil Surveys that indicate the frequency and duration of inundation and soil saturation for area soils. *CAUTION: Data provided only represent average conditions for a particular soil series in its natural undrained state, and cannot be used as a positive hydrologic indicator in areas that have significantly altered hydrology.*

i. Tidal or stream gage data for a nearby water body that apparently influences the area. Obtain the gage data and complete (1) below if the routine approach is used, or (2) below if the comprehensive approach is used (OMIT IF GAGING STATION DATA ARE UNAVAILABLE):

(1) *Routine approach.* Determine the highest water level elevation reached during the growing season for each of the most recent 10 years of gage data. Rank these elevations in descending order and select the fifth highest elevation. Combine this elevation with the mean sea level elevation of the gaging station to produce a mean sea level elevation for the highest water level reached every other year. *NOTE: Stream gage data are often presented as flow rates in cubic feet per second. In these cases, ask the CE District's Hydrology Branch to convert flow rates to corresponding mean sea level elevations and adjust gage data to the site.* Compare the resulting elevations reached biennially with the project area elevations. If the water level elevation exceeds the area elevation, the area is inundated during the growing season on average at least biennially.

(2) *Comprehensive approach.* Complete the following:

(a) *Decide whether hydrologic data reflect the apparent hydrology.* Data available from the gaging station may or may not accurately reflect the area hydrology. Answer the following questions:

- Does the water level of the area appear to fluctuate in a manner that differs from that of the water body on which the gaging station is located? (In ponded situations, the water level of the area is usually higher than the water level at the gaging station.)

- Are less than 10 years of daily readings available for the gaging station?

- Do other water sources that would not be reflected by readings at the gaging station appear to significantly affect the area? For example, do major tributaries enter the stream or tidal area between the area and gaging station?

If the answer to any of the above questions is YES, the area hydrology cannot be determined from the gaging station data. If the answer to all of the above questions is NO, PROCEED TO (b).

(b) *Analyze hydrologic data.* Subject the hydrologic data to appropriate analytical procedures. Either use duration curves or a computer program developed by WES (available from the Environmental Laboratory upon request) for determining the mean sea level elevation representing the upper limits of wetland hydrology. In the latter case, when the site elevation is lower than the mean sea level elevation representing a 5-percent duration of inundation and saturation during the growing season, the area has a hydrologic regime that may occur in wetlands. *NOTE: Duration curves do not reflect the period of soil saturation following dewatering.*

When all of the above have been considered, PROCEED TO STEP 9.

- *STEP 9 - Determine whether hydrology is adequately characterized.* Examine the summarized data and determine whether the hydrology of the project area is adequately characterized. For routine determinations, there must be documented evidence of frequent inundation or soil saturation during the growing season. For comprehensive determinations, there must be documented quantitative evidence of frequent inundation or soil saturation during the growing season, based on at least 10 years of stream or tidal gage data. Record information on DATA FORM 1. In either case, if there is evidence of recent significant hydrologic alteration due to human activities or natural events, PROCEED TO Section F. Otherwise, PROCEED TO Section C.

Section C. Selection of Method

56. All wetland delineation methods described in this manual can be grouped into two general types: routine and comprehensive. Routine determinations (Section D) involve simple, rapidly applied methods that result in sufficient qualitative data for making a determination. Comprehensive methods (Section E) usually require significant time and effort to obtain the needed quantitative data. The primary factor influencing method selection will usually be the complexity of the required determination. However, comprehensive methods may sometimes be selected for use in relatively simple determinations when rigorous documentation is required.

57. Three levels of routine wetland determinations are described below. Complexity of the project area and the quality and quantity of available information will influence the level selected for use.

a. *Level 1 - Onsite Inspection Unnecessary.* This level may be employed when the information already obtained (Section B) is sufficient for making a determination for the entire project area (see Section D, Subsection 1).

b. *Level 2 - Onsite Inspection Necessary.* This level must be employed when there is insufficient information already available to characterize the vegetation, soils, and hydrology of the entire project area (see Section D, Subsection 2).

c. *Level 3 - Combination of Levels 1 and 2.* This level should be used when there is sufficient information already available to characterize the vegetation, soils, and hydrology of a portion, but not all, of the project area. Methods described for Level 1 may be applied to portions of the area for which adequate information already exists, and onsite methods (Level 2) must be applied to the remainder of the area (see Section D, Subsection 3).

58. After considering all available information, select a tentative method (see above) for use, and PROCEED TO EITHER Section D or E, as appropriate. *NOTE: Sometimes it may be necessary to change to another method described in the manual, depending on the quality of available information and/or recent changes in the project area.*

Section D. Routine Determinations

59. This section describes general procedures for making routine wetland determinations. It is assumed that the user has already completed all applicable steps in Section B,[1] and a routine method has been tentatively selected for use (Section C). Subsections 1 through 3 describe steps to be followed when making a routine determination using one of the three levels described in Section C. Each subsection contains a flowchart that defines the relationship of steps to be used for that level of routine determinations. *NOTE: The selected method must be considered tentative because the user may be required to change methods during the determination.*

Subsection 1 - Onsite Inspection Unnecessary

60. This subsection describes procedures for making wetland determinations when sufficient information is already available (Section B) on which to base

---

[1] If it has been determined that it is more expedient to conduct an onsite inspection than to search for available information, complete STEPS 1 through 3 of Section B, and PROCEED TO Subsection 2.

the determination. A flowchart of required steps to be completed is presented in Figure 13, and each step is described below.

Equipment and materials

61. No special equipment is needed for applying this method. The following materials will be needed:

a. Map of project area (Section B, STEP 2).

b. Copies of DATA FORM 1 (Appendix B).

c. Appendices C and D to this manual.

Procedure

62. Complete the following steps, as necessary:

- *STEP 1 - Determine whether available data are sufficient for entire project area.* Examine the summarized data (Section B, STEPS 5, 7, and 9) and determine whether the vegetation, soils, and hydrology of the entire project area are adequately characterized. If so, PROCEED TO STEP 2. If all three parameters are adequately characterized for a portion, but not all, of the project area, PROCEED TO Subsection 3. If the vegetation, soils, and hydrology are not adequately characterized for any portion of the area, PROCEED TO Subsection 2.

- *STEP 2 - Determine whether hydrophytic vegetation is present.* Examine the vegetation data and list on DATA FORM 1 the dominant plant species found in each vegetation layer of each community type. *NOTE: A separate DATA FORM 1 will be required for each community type.* Record the indicator status for each dominant species ~~(Appendix C, Section 1 or 2)~~. When more than 50 percent of the dominant species in a plant community have an indicator status of OBL, FACW, and/or FAC,[1] hydrophytic vegetation is present. If one or more plant communities comprise hydrophytic vegetation, PROCEED TO STEP 3. If none of the plant communities comprise hydrophytic vegetation, none of the area is a wetland. Complete the vegetation section for each DATA FORM 1.

---

[1] For the FAC-neutral option, see paragraph 35*a*.

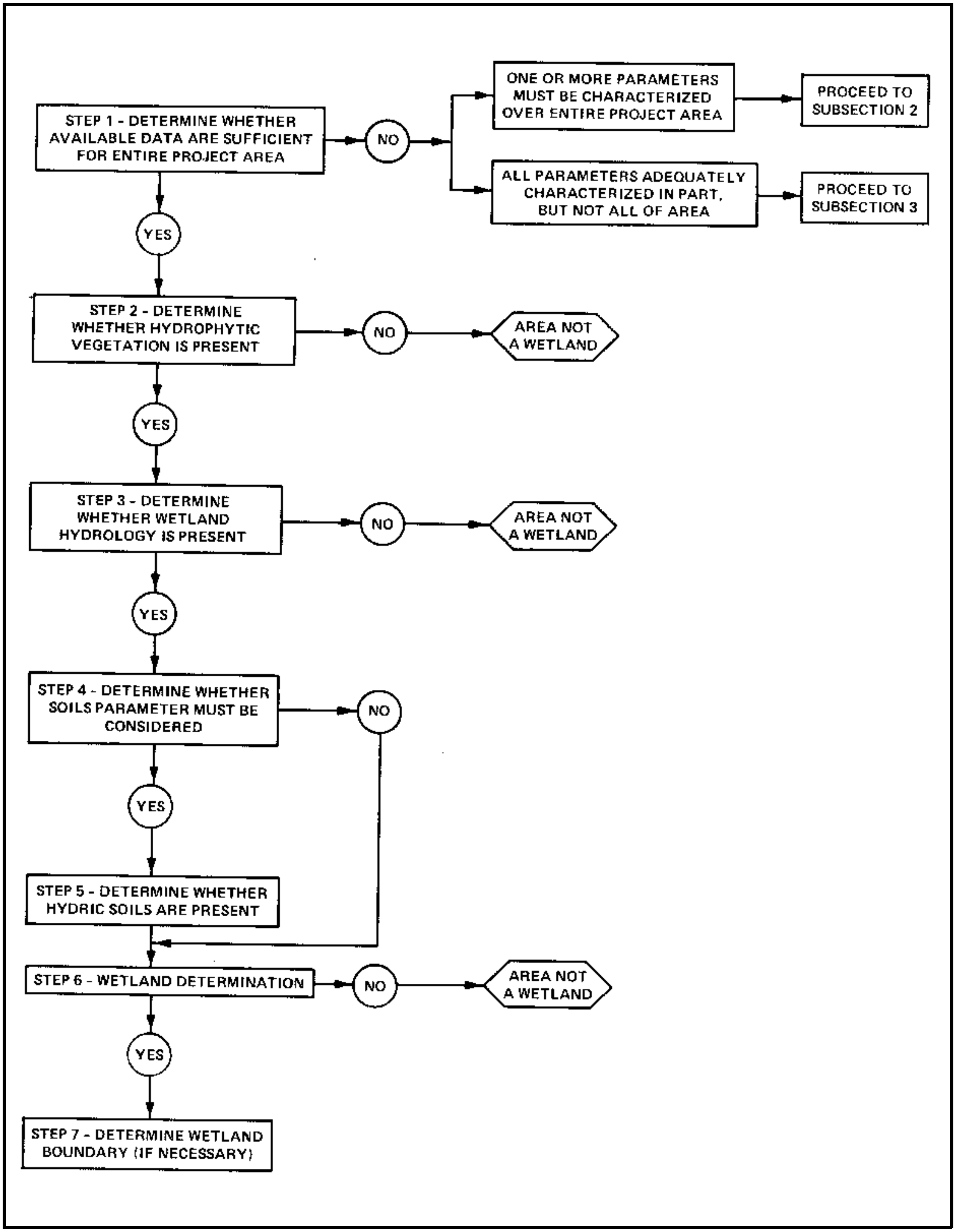


Figure 13. Flowchart of steps involved in making a wetland determination when an onsite inspection is unnecessary

- *STEP 3 - Determine whether wetland hydrology is present.* When one of the following conditions applies (STEP 2), it is only necessary to confirm that there has been no recent hydrologic alteration of the area:

  a. The entire project area is occupied by a plant community or communities in which all dominant species are OBL ~~(Appendix C, Section 1 or 2)~~.

  b. The project area contains two or more plant communities, all of which are dominated by OBL and/or FACW species, and the wetland-nonwetland boundary is abrupt[1] (e.g., a *Spartina alterniflora* marsh bordered by a road embankment).

  If either *a* or *b* applies, look for recorded evidence of recently constructed dikes, levees, impoundments, and drainage systems, or recent avalanches, mudslides, beaver dams, etc., that have significantly altered the area hydrology. If any significant hydrologic alteration is found, determine whether the area is still periodically inundated or has saturated soils for sufficient duration to support the documented vegetation (*a* or *b* above). When *a* or *b* applies and there is no evidence of recent hydrologic alteration, or when *a* or *b* do not apply and there is documented evidence that the area is periodically inundated or has saturated soils, wetland hydrology is present. Otherwise, wetland hydrology does not occur on the area. Complete the hydrology section of DATA FORM 1 and PROCEED TO STEP 4.

- *STEP 4 - Determine whether the soils parameter must be considered.* When either *a* or *b* of STEP 3 applies *and* there is either no evidence of recent hydrologic alteration of the project area or if wetland hydrology presently occurs on the area, hydric soils can be assumed to be present. If so, PROCEED TO STEP 6. Otherwise PROCEED TO STEP 5.

- *STEP 5 - Determine whether hydric soils are present.* Examine the soils data (Section B, STEP 7) and record the soil series or soil phase on DATA FORM 1 for each community type. Determine whether the soil is listed as a hydric soil ~~(Appendix D, Section 2)~~. If all community types have hydric soils, the entire project area has hydric soils. *(CAUTION: If the soil series description makes reference to inclusions of other soil types, data must be field verified).* Any portion of the area that lacks hydric soils is a nonwetland. Complete the soils section of each DATA FORM 1 and PROCEED TO STEP 6.

---

[1] There must be documented evidence of periodic inundation or saturated soils when the project area: (a) has plant communities dominated by one or more FAC species; (b) has vegetation dominated by FACW species but no adjacent community dominated by OBL species; (c) has a gradual, nondistinct boundary between wetlands and nonwetlands; and/or (d) is known to have or is suspected of having significantly altered hydrology.

- *STEP 6 - Wetland determination.* Examine the DATA FORM 1 for each community type. Any portion of the project area is a wetland that has:

  a. Hydrophytic vegetation that conforms to one of the conditions identified in STEP 3*a* or 3*b* and has either no evidence of altered hydrology or confirmed wetland hydrology.

  b. Hydrophytic vegetation that does not conform to STEP 3*a* or 3*b*, has hydric soils, and has confirmed wetland hydrology.

  If STEP 6*a* or 6*b* applies to the entire project area, the entire area is a wetland. Complete a DATA FORM 1 for all plant community types. Portions of the area not qualifying as a wetland based on an office determination might or might not be wetlands. If the data used for the determination are considered to be highly reliable, portions of the area not qualifying as wetlands may properly be considered nonwetlands. PROCEED TO STEP 7. If the available data are incomplete or questionable, an onsite inspection (Subsection 2) will be required.

- *STEP 7 - Determine wetland boundary.* Mark on the base map all community types determined to be wetlands with a W and those determined to be nonwetlands with an N. Combine all wetland community types into a single mapping unit. The boundary of these community types is the interface between wetlands and nonwetlands.

Subsection 2 - Onsite Inspection Necessary

63. This subsection describes procedures for routine determinations in which the available information (Section B) is insufficient for one or more parameters. If only one or two parameters must be characterized, apply the appropriate steps and return to Subsection 1 and complete the determination. A flowchart of steps required for using this method is presented in Figure 14, and each step is described below.

Equipment and materials

64. The following equipment and materials will be needed:

a. Base map (Section B, STEP 2).

b. Copies of DATA FORM 1 (one for each community type and additional copies for boundary determinations).

c. Appendices C and D.

d. Compass.

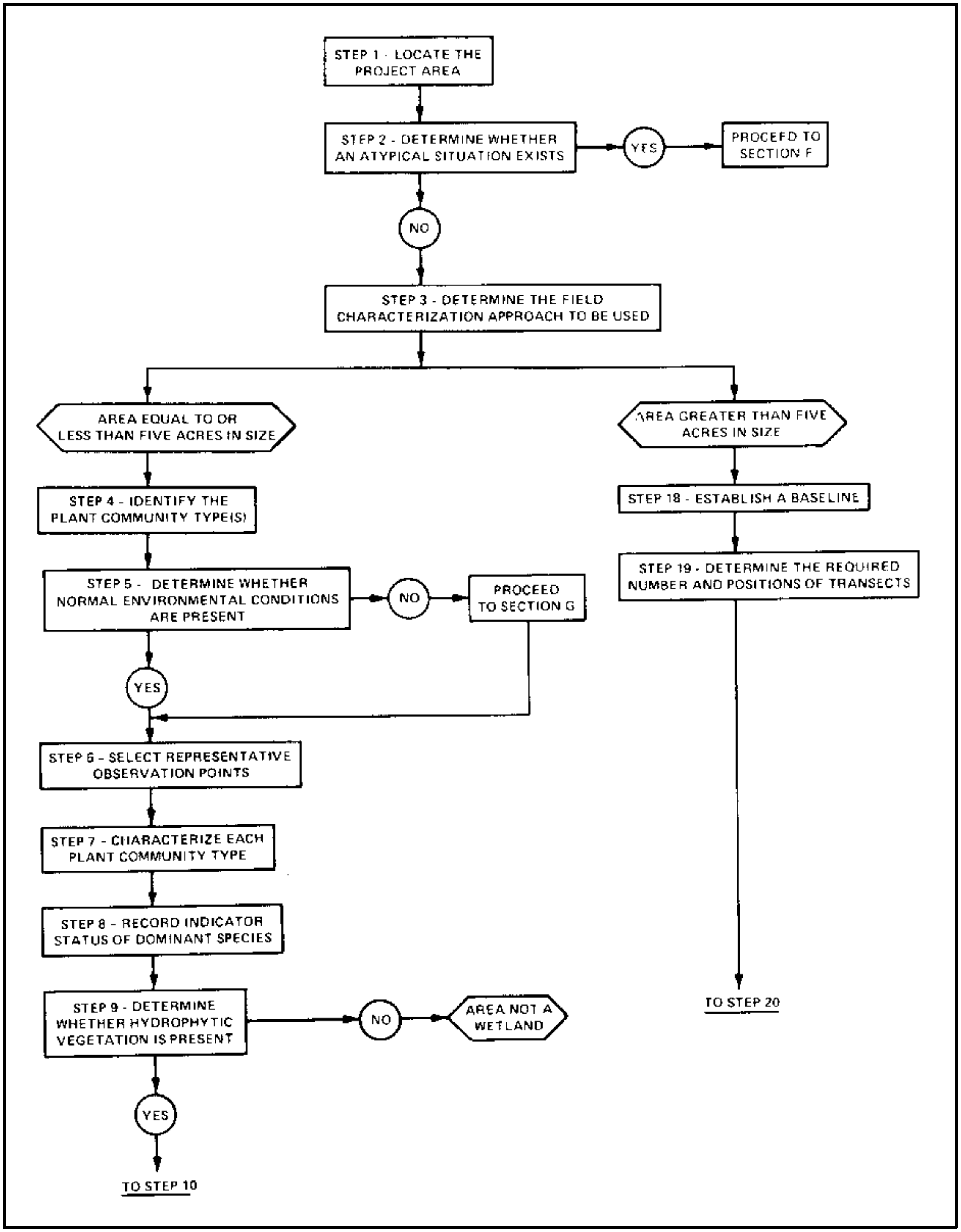


Figure 14. Flowchart of steps involved in making a routine wetland determination when an onsite visit is necessary (Continued)

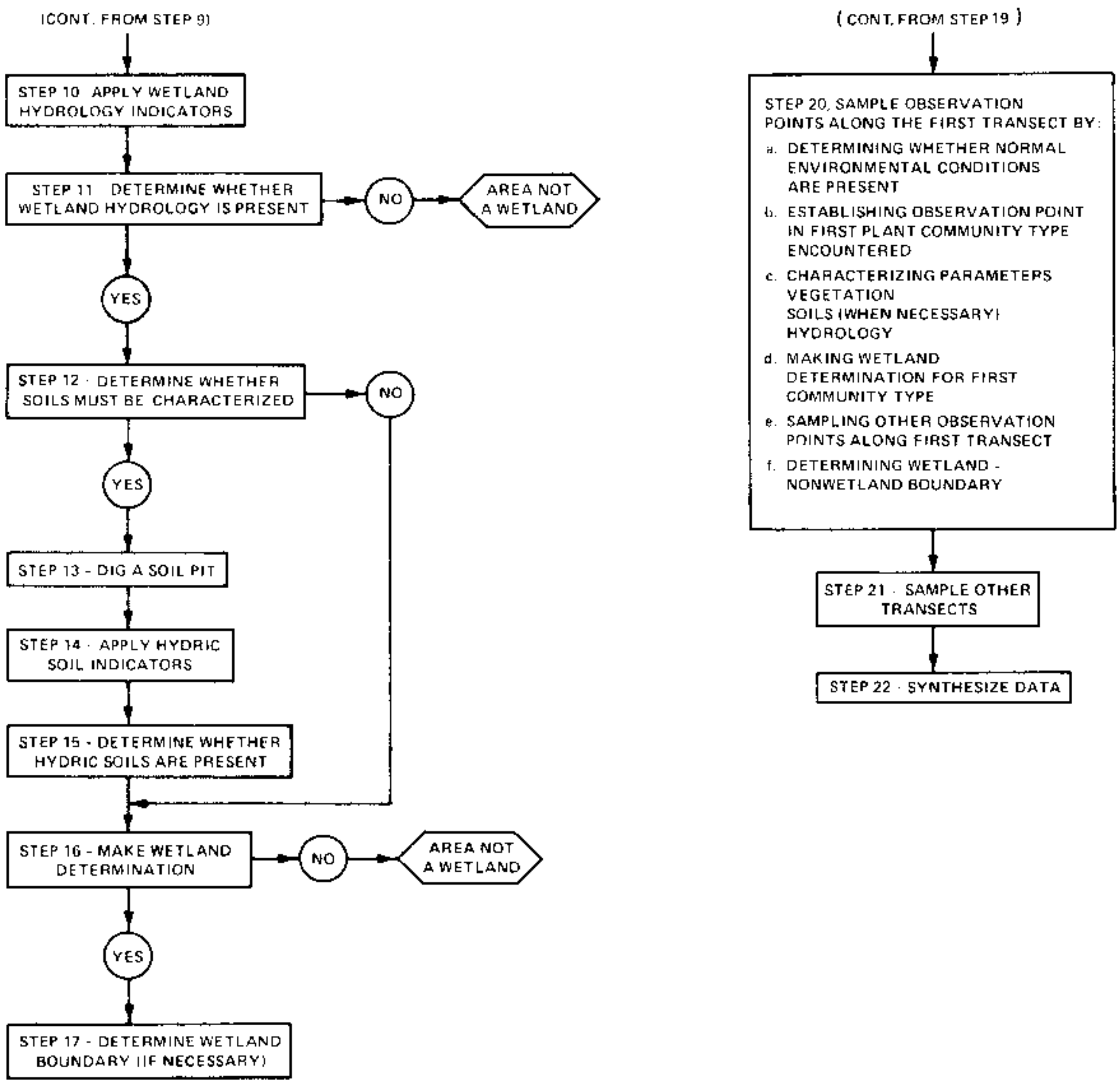


Figure 14. (Concluded)

e. Soil auger or spade (soils only).

f. Tape (300 ft).

g. Munsell Color Charts (Munsell Color 1975) (soils only).

Procedure

65. Complete the following steps, as necessary:

- *STEP 1 - Locate the project area.* Determine the spatial boundaries of the project area using information from a USGS quadrangle map or other appropriate map, aerial photography, and/or the project survey plan (when available). PROCEED TO STEP 2.

- *STEP 2 - Determine whether an atypical situation exists.* Examine the area and determine whether there is evidence of sufficient natural or human-induced alteration to significantly alter the area vegetation, soils, and/or hydrology. *NOTE: Include possible offsite modifications that may affect the area hydrology.* If not, PROCEED TO STEP 3.

  If one or more parameters have been significantly altered by an activity that would normally require a permit, PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present prior to this alteration. Then, return to this subsection and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3.

- *STEP 3 - Determine the field characterization approach to be used.* Considering the size and complexity of the area, determine the field characterization approach to be used. When the area is equal to or less than 5 acres in size (Section B, STEP 3) and the area is thought to be relatively homogeneous with respect to vegetation, soils, and/or hydrologic regime, PROCEED TO STEP 4. When the area is greater than 5 acres in size (Section B, STEP 3) or appears to be highly diverse with respect to vegetation, PROCEED TO STEP 18.

Areas Equal To or Less Than 5 Acres in Size

- *STEP 4 - Identify the plant community type(s).* Traverse the area and determine the number and locations of plant community types. Sketch the location of each on the base map (Section B, STEP 2), and give each community type a name. PROCEED TO STEP 5.

- *STEP 5 - Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present by considering the following:

  a. Is the area presently lacking hydrophytic vegetation or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?

  b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

  If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 6.

- *STEP 6 - Select representative observation points.* Select a representative observation point in each community type. A representative observation point is one in which the apparent characteristics (determine visually) best represent characteristics of the entire community. Mark on the base map the approximate location of the observation point. PROCEED TO STEP 7.

- *STEP 7 - Characterize each plant community type.* Visually determine the dominant plant species in each vegetation layer of each community type and record them on DATA FORM 1 (use a separate DATA FORM 1 for each community type). Dominant species are those having the greatest relative basal area (woody overstory),[1] greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). PROCEED TO STEP 8.

- *STEP 8 - Record indicator status of dominant species.* Record on DATA FORM 1 the indicator status ~~(Appendix C, Section 1 or 2)~~ of each dominant species in each community type. PROCEED TO STEP 9.

- *STEP 9 - Determine whether hydrophytic vegetation is present.* Examine each DATA FORM 1. When more than 50 percent of the dominant species in a community type have an indicator status (STEP 8) of OBL, FACW, and/or FAC,[2] hydrophytic vegetation is present. Complete the vegetation section of each DATA FORM 1. Portions of the area failing this test are not wetlands. PROCEED TO STEP 10.

- *STEP 10 - Apply wetland hydrologic indicators.* Examine the portion of the area occupied by each plant community type for positive indicators

---

[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To determine relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

[2] For the FAC-neutral option, see paragraph 35*a*.

of wetland hydrology (Part III, paragraph 49). Record findings on the appropriate DATA FORM 1. PROCEED TO STEP 11.

- *STEP 11 - Determine whether wetland hydrology is present.* Examine the hydrologic information on DATA FORM 1 for each plant community type. Any portion of the area having a positive wetland hydrology indicator has wetland hydrology. If positive wetland hydrology indicators are present in all community types, the entire area has wetland hydrology. If no plant community type has a wetland hydrology indicator, none of the area has wetland hydrology. Complete the hydrology portion of each DATA FORM 1. PROCEED TO STEP 12.

- *STEP 12 - Determine whether soils must be characterized.* Examine the vegetation section of each DATA FORM 1. Hydric soils are assumed to be present in any plant community type in which:

  a. All dominant species have an indicator status of OBL.

  b. All dominant species have an indicator status of OBL or FACW, and the wetland boundary (when present) is abrupt.[1]

  When either *a* or *b* occurs and wetland hydrology is present, check the hydric soils blank as positive on DATA FORM 1 and PROCEED TO STEP 16. If neither *a* nor *b* applies, PROCEED TO STEP 13.

- *STEP 13 - Dig a soil pit.* Using a soil auger or spade, dig a soil pit at the representative location in each community type. The procedure for digging a soil pit is described in Appendix D, Section 1. When completed, approximately 16 inches of the soil profile will be available for examination. PROCEED TO STEP 14.

- *STEP 14 - Apply hydric soil indicators.* Examine the soil at each location and compare its characteristics immediately below the A-horizon or 10 inches (whichever is shallower) with the hydric soil indicators described in Part III, paragraph 44 and/or 45. Record findings on the appropriate DATA FORM 1's. PROCEED TO STEP 15.

- *STEP 15 - Determine whether hydric soils are present.* Examine each DATA FORM 1 and determine whether a positive hydric soil indicator was found. If so, the area at that location has hydric soil. If soils at all sampling locations have positive hydric soil indicators, the entire area has hydric soils. If soils at all sampling locations lack positive hydric soil indicators, none of the area is a wetland. Complete the soil section of each DATA FORM 1. PROCEED TO STEP 16.

[1] The soils parameter must be considered in any plant community in which: (a) the community is dominated by one or more FAC species; (b) no community type dominated by OBL species is present; (c) the boundary between wetlands and nonwetlands is gradual or nondistinct; (d) the area is known to or is suspected of having significantly altered hydrology.

- *STEP 16 - Make wetland determination.* Examine DATA FORM 1. If the entire area presently or normally has wetland indicators of all three parameters (STEPS 9, 11, and 15), the entire area is a wetland. If the entire area presently or normally lacks wetland indicators of one or more parameters, the entire area is a nonwetland. If only a portion of the area presently or normally has wetland indicators for all three parameters, PROCEED TO STEP 17.

- *STEP 17 - Determine wetland-nonwetland boundary.* Mark each plant community type on the base map with a W if wetland or an N if nonwetland. Combine all wetland plant communities into one mapping unit and all nonwetland plant communities into another mapping unit. The wetland-nonwetland boundary will be represented by the interface of these two mapping units.

Areas Greater Than 5 Acres in Size

- *STEP 18 - Establish a baseline.* Select one project boundary as a baseline. The baseline should parallel the major watercourse through the area or should be perpendicular to the hydrologic gradient (Figure 15). Determine the approximate baseline length. PROCEED TO STEP 19.

- *STEP 19 - Determine the required number and position of transects.* Use the following to determine the required number and position of transects (specific site conditions may necessitate changes in intervals):

Baseline Length, Miles	**Number of Required Transects**
≤0.25	3
>0.25 - 0.50	3
>0.50 - 0.75	3
>0.75 - 1.00	3
>1.00 - 2.00	3-5
>2.00 - 4.00	5-8
>4.00	8 or more[1]

[1] Transect intervals should not exceed 0.5 mile.

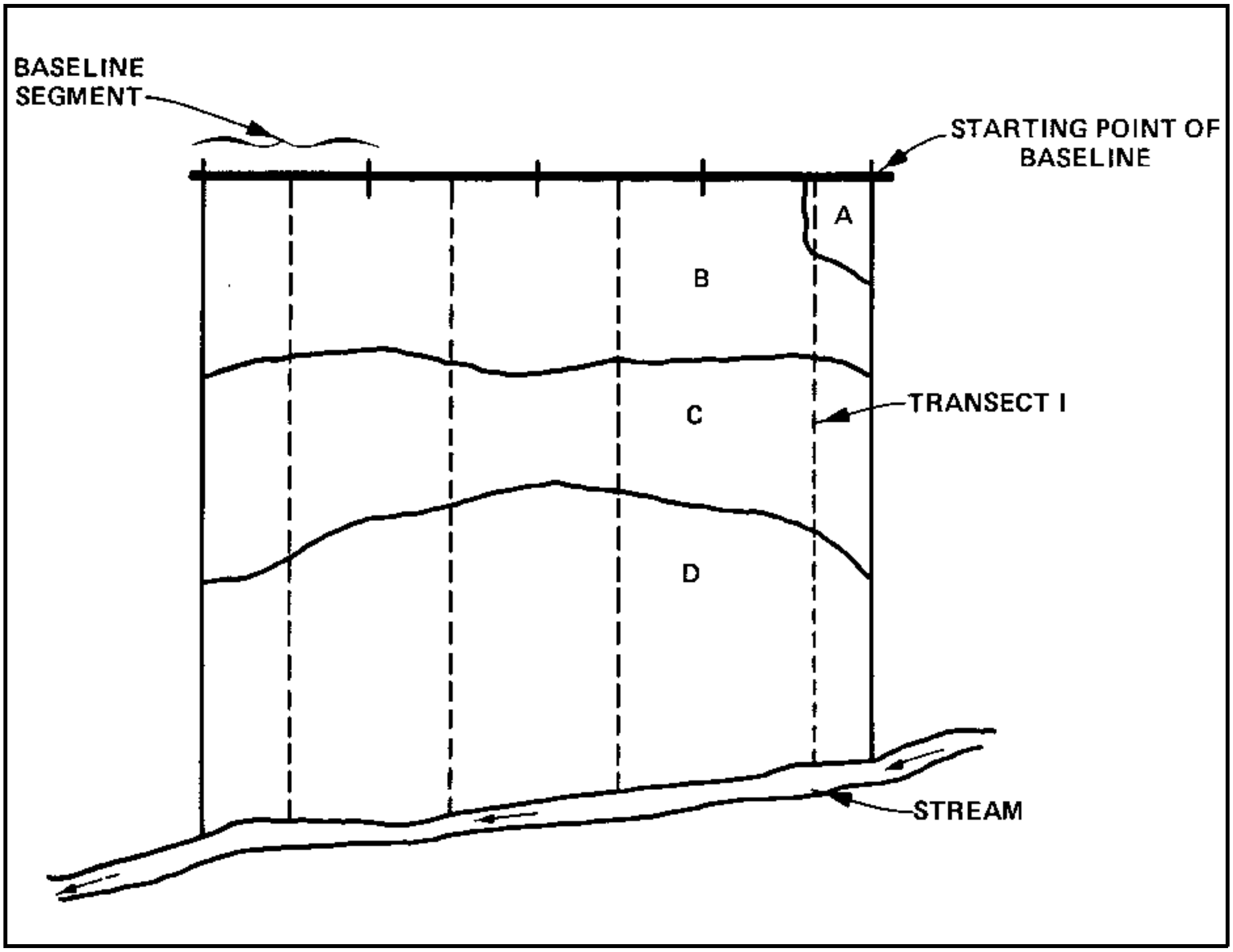


Figure 15. General orientation of baseline and transects (dotted lines) in a hypothetical project area. Alpha characters represent different plant communities. All transects start at the midpoint of a baseline segment except the first, which was repositioned to include community type A

Divide the baseline length by the number of required transects. Establish one transect in each resulting baseline increment. Use the midpoint of each baseline increment as a transect starting point. For example, if the baseline is 1,200 ft in length, three transects would be established—one at 200 ft, one at 600 ft, and one at 1,000 ft from the baseline starting point. *CAUTION: All plant community types must be included. This may necessitate relocation of one or more transect lines. PROCEED TO STEP 20.*

- *STEP 20 - Sample observation points along the first transect.* Beginning at the starting point of the first transect, extend the transect at a 90-deg angle to the baseline. Use the following procedure as appropriate to simultaneously characterize the parameters at each observation point. Combine field-collected data with information already available and make a wetland determination at each observation point. A DATA FORM 1 must be completed for each observation point.

a. *Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present by considering the following:

(1) Is the area presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or ground-water levels?

(2) Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 20*b*.

b. *Establish an observation point in the first plant community type encountered.* Select a representative location along the transect in the first plant community type encountered. When the first plant community type is large and covers a significant distance along the transect, select an area that is no closer than 300 ft to a perceptible change in plant community type. PROCEED TO STEP 20*c*.

c. *Characterize parameters.* Characterize the parameters at the observation point by completing (1), (2), and (3) below:

(1) *Vegetation.* Record on DATA FORM 1 the dominant plant species in each vegetation layer occurring in the immediate vicinity of the observation point. Use a 5-ft radius for herbs and saplings/shrubs, and a 30-ft radius for trees and woody vines (when present). Subjectively determine the dominant species by estimating those having the largest relative basal area[1] (woody overstory), greatest height (woody understory), greatest percentage of areal cover (herbaceous understory), and/or greatest number of stems (woody vines). *NOTE: Plot size may be estimated, and plot size may also be varied when site conditions warrant.* Record on DATA FORM 1 any dominant species observed to have morphological adaptations (Appendix C, Section 3) for occurrence in wetlands, and determine and record dominant species that have known physiological adaptations for occurrence in wetlands (Appendix C, Section 3). Record on DATA FORM 1 the indicator status ~~(Appendix C, Section 1 or 2)~~ of each dominant species. Hydrophytic

[1] This term is used because species having the largest individuals may not be dominant when only a few are present. To use relative basal area, consider both the size and number of individuals of a species and subjectively compare with other species present.

vegetation is present at the observation point when more than 50 percent of the dominant species have an indicator status of OBL, FACW, and/or FAC;[1] when two or more dominant species have observed morphological or known physiological adaptations for occurrence in wetlands; or when other indicators of hydrophytic vegetation (Part III, paragraph 35) are present. Complete the vegetation section of DATA FORM 1. PROCEED TO (2).

(2) *Soils.* In some cases, it is not necessary to characterize the soils. Examine the vegetation of DATA FORM 1. Hydric soils can be assumed to be present when:

(a) All dominant plant species have an indicator status of OBL.

(b) All dominant plant species have an indicator status of OBL and/or FACW (at least one dominant species must be OBL).[2]

When either (a) or (b) applies, check the hydric soils blank as positive and PROCEED TO (3). If neither (a) nor (b) applies but the vegetation qualifies as hydrophytic, dig a soil pit at the observation point using the procedure described in Appendix D, Section 1. Examine the soil immediately below the A-horizon or 10-inches (whichever is shallower) and compare its characteristics (Appendix D, Section 1) with the hydric soil indicators described in Part III, paragraph 44 and/or 45. Record findings on DATA FORM 1. If a positive hydric soil indicator is present, the soil at the observation point is a hydric soil. If no positive hydric soil indicator is found, the area at the observation point does not have hydric soils and the area at the observation point is not a wetland. Complete the soils section of DATA FORM 1 for the observation point. PROCEED TO (3) if hydrophytic vegetation (1) and hydric soils (2) are present. Otherwise, PROCEED TO STEP 20*d*.

(3) *Hydrology*. Examine the observation point for indicators of wetland hydrology (Part III, paragraph 49) and record observations on DATA FORM 1. Consider the indicators in the same sequence as presented in Part III, paragraph 49. If a positive wetland hydrology indicator

---

[1] For the FAC-neutral option, see paragraph 35*a*.
[2] Soils must be characterized when any dominant species has an indicator status of FAC.

is present, the area at the observation point has wetland hydrology. If no positive wetland hydrologic indicator is present, the area at the observation point is not a wetland. Complete the hydrology section of DATA FORM 1 for the observation point. PROCEED TO STEP 20*d*.

d. *Wetland determination.* Examine DATA FORM 1 for the observation point. Determine whether wetland indicators of all three parameters are or would normally be present during a significant portion of the growing season. If so, the area at the observation point is a wetland. If no evidence can be found that the area at the observation point normally has wetland indicators for all three parameters, the area is a nonwetland. PROCEED TO STEP 20*e.*

e. *Sample other observation points along the first transect.* Continue along the first transect until a different community type is encountered. Establish a representative observation point within this community type and repeat STEP 20*c* and 20*d*. If the areas at both observation points are either wetlands or nonwetlands, continue along the transect and repeat STEP 20*c* and 20*d* for the next community type encountered. Repeat for all other community types along the first transect. If the area at one observation point is wetlands and the next observation point is nonwetlands (or vice versa), PROCEED TO STEP 20*f*.

f. *Determine wetland-nonwetland boundary.* Proceed along the transect from the wetland observation point toward the nonwetland observation point. Look for subtle changes in the plant community (e.g., the first appearance of upland species, disappearance of apparent hydrology indicators, or slight changes in topography). When such features are noted, establish an observation point and repeat the procedures described in STEP 20*c* through 20*d*. *NOTE: A new DATA FORM 1 must be completed for this observation point, and all three parameters must be characterized by field observation.* If the area at this observation point is a wetland, proceed along the transect toward the nonwetland observation point until upland indicators are more apparent. Repeat the procedures described in STEP 20*c* through 20*d*. If the area at this observation point is a nonwetland, move halfway back along the transect toward the last documented wetland observation point and repeat the procedure described in STEP 20*c* through 20*d*. Continue this procedure until the wetland-nonwetland boundary is found. It is not necessary to complete a DATA FORM 1 for all intermediate points, but a DATA FORM 1 should be completed for the wetland-nonwetland boundary. Mark the position of the wetland boundary on the base map, and continue along the first transect until all community types have been sampled and all wetland boundaries located. *CAUTION: In areas where wetlands are interspersed among nonwetlands (or vice versa), several boundary determinations will be required.* When all necessary wetland determinations have been completed for the first transect, PROCEED TO STEP 21.

- *STEP 21 - Sample other transects.* Repeat procedures described in STEP 21 for all other transects. When completed, a wetland determination will have been made for one observation point in each community type along each transect, and all wetland-nonwetland boundaries along each transect will have been determined. PROCEED TO STEP 22.

- *STEP 22 - Synthesize data.* Examine all completed copies of DATA FORM 1, and mark each plant community type on the base map. Identify each plant community type as either a wetland (W) or nonwetland (N). If all plant community types are identified as wetlands, the entire area is wetlands. If all plant community types are identified as nonwetlands, the entire area is nonwetlands. If both wetlands and nonwetlands are present, identify observation points that represent wetland boundaries on the base map. Connect these points on the map by generally following contour lines to separate wetlands from nonwetlands. Walk the contour line between transects to confirm the wetland boundary. Should anomalies be encountered, it will be necessary to establish short transects in these areas, apply the procedures described in STEP 20*f*, and make any necessary adjustments on the base map.

Subsection 3 - Combination of Levels I and 2

66. In some cases, especially for large projects, adequate information may already be available (Section B) to enable a wetland determination for a portion of the project area, while an onsite visit will be required for the remainder of the area. Since procedures for each situation have already been described in Subsections 1 and 2, they will not be repeated. Apply the following steps:

- *STEP 1 - Make wetland determination for portions of the project area that are already adequately characterized.* Apply procedures described in Subsection 1. When completed, a DATA FORM 1 will have been completed for each community type, and a map will have been prepared identifying each community type as wetland or nonwetland and showing any wetland boundary occurring in this portion of the project area. PROCEED TO STEP 2.

- *STEP 2 - Make wetland determination for portions of the project area that require an onsite visit.* Apply procedures described in Subsection 2. When completed, a DATA FORM 1 will have been completed for each plant community type or for a number of observation points (including wetland boundary determinations). A map of the wetland (if present) will also be available. PROCEED TO STEP 3.

- *STEP 3* **-** *Synthesize data.* Using the maps resulting from STEPS 1 and 2, prepare a summary map that shows the wetlands of the entire project area. *CAUTION: Wetland boundaries for the two maps will not always match exactly. When this occurs, an additional site visit will be required to refine the wetland boundaries. Since the degree of resolution of wetland boundaries will be greater when determined onsite, it may be necessary to employ procedures described in Subsection 2 in the vicinity of the boundaries determined from Subsection 1 to refine these boundaries.*

Section E. Comprehensive Determinations

67. This section describes procedures for making comprehensive wetland determinations. Unlike procedures for making routine determinations (Section D), application of procedures described in this section will result in maximum information for use in making determinations, and the information usually will be quantitatively expressed. Comprehensive determinations should only be used when the project area is very complex and/or when the determination requires rigorous documentation. This type of determination may be required in areas of any size, but will be especially useful in large areas. There may be instances in which only one parameter (vegetation, soil, or hydrology) is disputed. In such cases, only procedures described in this section that pertain to the disputed parameter need be completed. It is assumed that the user has already completed all applicable steps in Section B. *NOTE: Depending on site characteristics, it may be necessary to alter the sampling design and/or data collection procedures.*

68. This section is divided into five basic types of activities. The first consists of preliminary field activities that must be completed prior to making a determination (STEPS 1 through 5). The second outlines procedures for determining the number and locations of required determinations (STEPS 6 through 8). The third describes the basic procedure for making a comprehensive wetland determination at any given point (STEPS 9 through 17). The fourth describes a procedure for determining wetland boundaries (STEP 18). The fifth describes a procedure for synthesizing the collected data to determine the extent of wetlands in the area (STEPS 20 and 21). A flowchart showing the relationship of various steps required for making a comprehensive determination is presented in Figure 16.

Equipment and materials

69. Equipment and materials needed for making a comprehensive determination include:

a. Base map (Section B, STEP 2).

b. Copies of DATA FORMS 1 and 2.

c. Appendices C and D.

d. Compass.

e. Tape (300 ft).

f. Soil auger or spade.

g. Munsell Color Charts (Munsell Color 1975).

h. Quadrat (3.28 ft by 3.28 ft).

i. Diameter or basal area tape (for woody overstory).

Field procedures

70. Complete the following steps:

- *STEP 1 - Identify the project area.* Using information from the USGS quadrangle or other appropriate map (Section B), locate and measure the spatial boundaries of the project area. Determine the compass heading of each boundary and record on the base map (Section B, STEP 2). The applicant's survey plan may be helpful in locating the project boundaries. PROCEED TO STEP 2.

- *STEP 2 - Determine whether an atypical situation exists.* Examine the area and determine whether there is sufficient natural or human-induced alteration to significantly change the area vegetation, soils, and/or hydrology. If not, PROCEED TO STEP 3. If one or more parameters have been recently altered significantly, PROCEED TO Section F and determine whether there is sufficient evidence that hydrophytic vegetation, hydric soils, and/or wetland hydrology were present on the area prior to alteration. Then return to this section and characterize parameters not significantly influenced by human activities. PROCEED TO STEP 3.

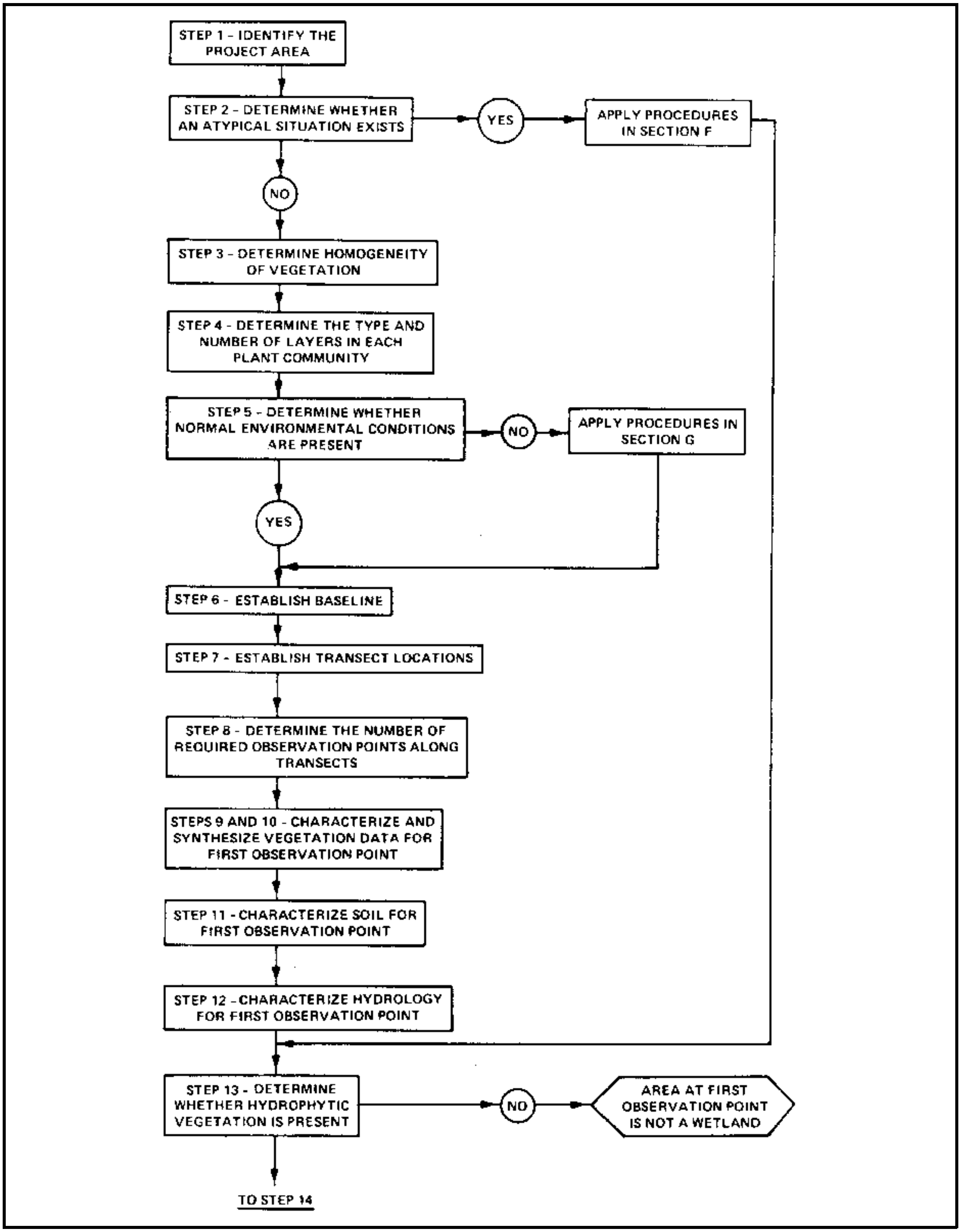


Figure 16. Flowchart of steps involved in making a comprehensive wetland determination (Section E) (Continued)

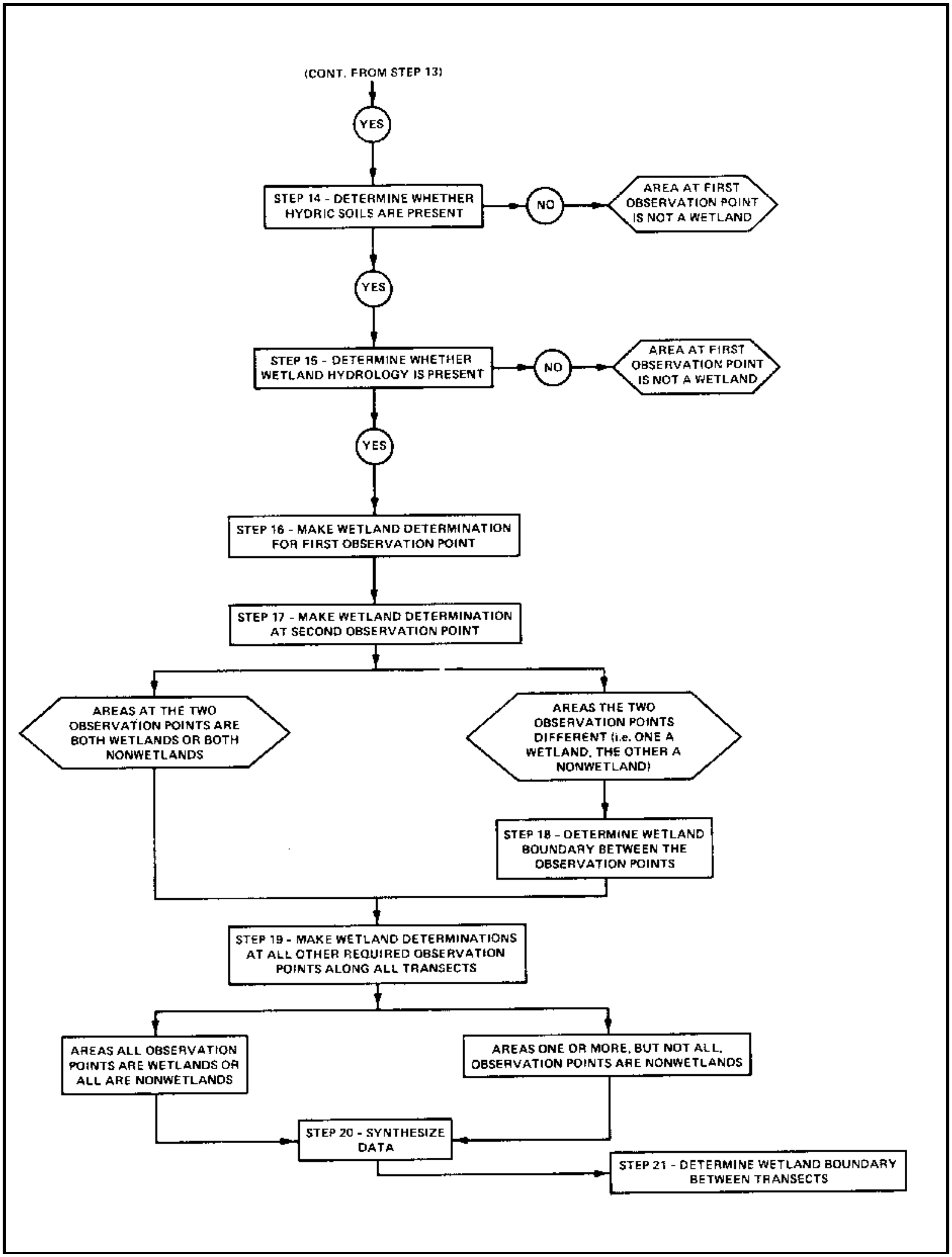


Figure 16. (Concluded)

- *STEP 3 - Determine homogeneity of vegetation.* While completing STEP 2, determine the number of plant community types present. Mark the approximate location of each community type on the base map. The number and locations of required wetland determinations will be strongly influenced by both the size of the area and the number and distribution of plant community types; the larger the area and greater the number of plant community types, the greater the number of required wetland determinations. It is imperative that all plant community types occurring in all portions of the area be included in the investigation. PROCEED TO STEP 4.

- *STEP 4 - Determine the type and number of layers in each plant community.* Examine each identified plant community type and determine the type(s) and number of layers in each community. Potential layers include trees (woody overstory), saplings/shrubs (woody understory), herbs (herbaceous understory), and/or woody vines. PROCEED TO STEP 5.

- *STEP 5 - Determine whether normal environmental conditions are present.* Determine whether normal environmental conditions are present at the observation point by considering the following:

  a. Is the area at the observation point presently lacking hydrophytic vegetation and/or hydrologic indicators due to annual or seasonal fluctuations in precipitation or groundwater levels?

  b. Are hydrophytic vegetation indicators lacking due to seasonal fluctuations in temperature?

  If the answer to either of these questions is thought to be YES, PROCEED TO Section G. If the answer to both questions is NO, PROCEED TO STEP 6.

- *STEP 6 - Establish a baseline.* Select one project boundary area as a baseline. The baseline should extend parallel to any major watercourse and/or perpendicular to a topographic gradient (see Figure 17). Determine the baseline length and record on the base map both the baseline length and its compass heading. PROCEED TO STEP 7.

- *STEP 7 - Establish transect locations.* Divide the baseline into a number of equal segments (Figure 17). Use the following as a guide to determine the appropriate number of baseline segments:

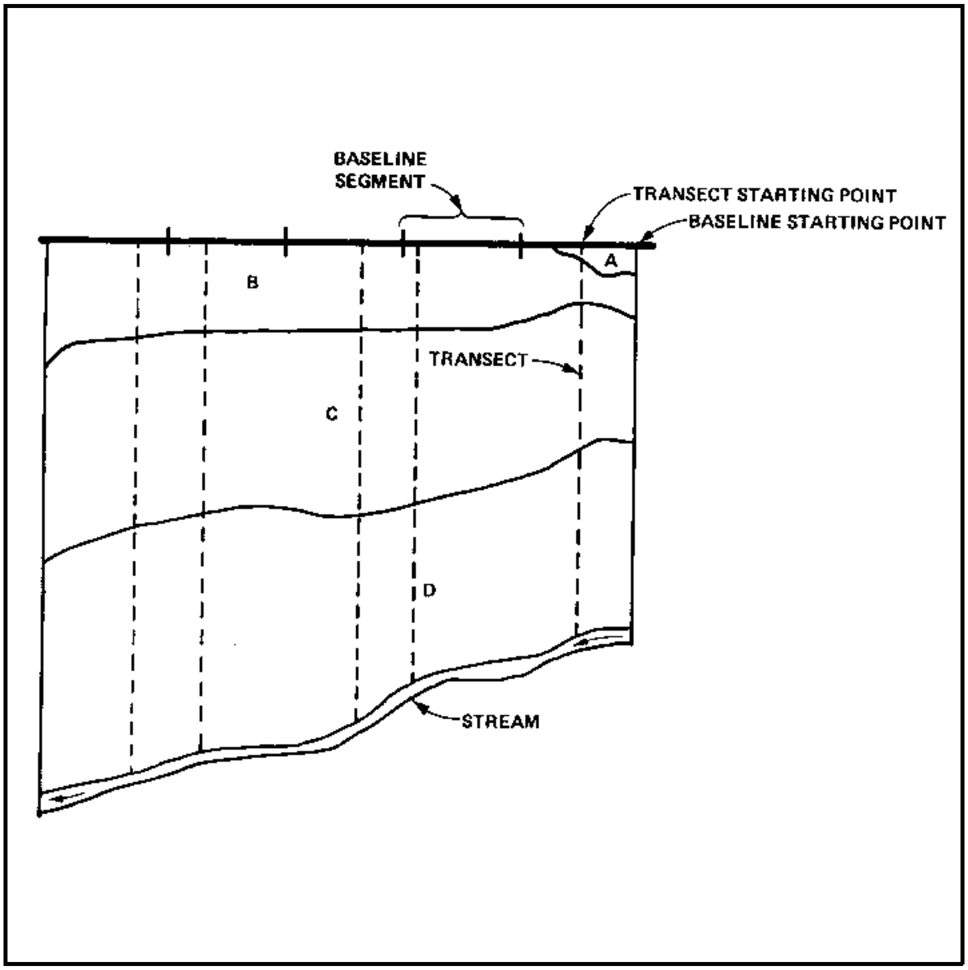


Figure 17. General orientation of baseline and transects in a hypothetical project area. Alpha characters represent different plant communities. Transect positions were determined using a random numbers table

Baseline Length, ft	Number of Segments	Length of Baseline Segment, ft
>50 - 500	3	18 - 167
>500 - 1,000	3	167 - 333
>1,000 - 5,000	5	200 - 1,000
>5,000 - 10,000	7	700 - 1,400
>10,000[1]	Variable	2,000

[1] If the baseline exceeds 5 miles, baseline segments should be 0.5 mile in length.

Use a random numbers table or a calculator with a random numbers generation feature to determine the position of a transect starting point within each baseline segment. For example, when the baseline is 4,000 ft, the number of baseline segments will be five, and the baseline segment length will be 4,000/5 = 800 ft. Locate the first transect within the first 800 ft of the baseline. If the random numbers table yields 264 as the distance from the baseline starting point, measure 264 ft from the baseline starting point and establish the starting point of the first transect. If the second random number selected is 530, the starting point of the second transect will be located at a distance of 1,330 ft (800 + 530 ft) from the baseline starting point. *CAUTION: Make sure that each plant community type is included in at least one transect. If not, modify the sampling design accordingly.* When the starting point locations for all required transects have been determined, PROCEED TO STEP 8.

- *STEP 8 - Determine the number of required observation points along transects.* The number of required observation points along each transect will be largely dependent on transect length. Establish observation points along each transect using the following as a guide:

Transect Length, ft	Number of Observation Points	Interval Between Observation Points, ft
<1,000	2-10	100
1,000 - <5,000	10	100 - 500
5,000 - <10,000	10	500 - 1,000
≥10,000	>10	1,000

Establish the first observation point at a distance of 50 ft from the baseline (Figure 17). When obvious nonwetlands occupy a long portion of the transect from the baseline starting point, establish the first observation point in the obvious nonwetland at a distance of approximately 300 ft from the point that the obvious nonwetland begins to intergrade into a potential wetland community type. Additional observation points must also be established to determine the wetland boundary between successive regular observation points when one of the points is a wetland and the other is a nonwetland. *CAUTION: In large areas having a mosaic of plant community types, several wetland boundaries may occur along the same transect.* PROCEED TO STEP 9 and apply the comprehensive wetland determination procedure at each required observation point. Use the described procedure to simultaneously characterize the vegetation, soil, and hydrology at each required observation point along each transect, and use the resulting characterization to make a wetland determination at each point. *NOTE: ALL required wetland boundary determinations should be made while proceeding along a transect.*

- *STEP 9 - Characterize the vegetation at the first observation point along the first transect.*[1] Record on DATA FORM 2 the vegetation occurring

[1] There is no single best procedure for characterizing vegetation. Methods described in STEP 9 afford standardization of the procedure. However, plot size and descriptors for determining dominance may vary.

at the first observation point along the first transect by completing the following (as appropriate):

a. *Trees.* Identify each tree occurring within a 30-ft radius[1] of the observation point, measure its basal area (square inches) or diameter at breast height (DBH) using a basal area tape or diameter tape, respectively, and record. *NOTE: If DBH is measured, convert values to basal area by applying the formula* $A = \pi r^2$*. This must be done on an individual basis.* A tree is any nonclimbing, woody plant that has a DBH of $\geq$3.0 in., regardless of height.

b. *Saplings/shrubs.* Identify each sapling/shrub occurring within a 10-ft radius of the observation point, estimate its height, and record the midpoint of its class range using the following height classes (height is used as an indication of dominance; taller individuals exert a greater influence on the plant community):

Height Class	**Height Class Range, ft**	**Midpoint of Range, ft**
1	1-3	2
2	3-5	4
3	5-7	6
4	7-9	8
5	9-11	10
6	>11	12

A sapling/shrub is any woody plant having a height >3.2 ft but a stem diameter of <3.0 in., exclusive of woody vines.

c. *Herbs.* Place a 3.28- by 3.28-ft quadrat with one corner touching the observation point and one edge adjacent to the transect line. As an alternative, a 1.64-ft-radius plot with the center of the plot representing the observation point position may be used. Identify each plant species with foliage extending into the quadrat and estimate its percent cover by applying the following cover classes:

[1] A larger sampling plot may be necessary when trees are large and widely spaced.

Cover Class	Class Range, Percent	Midpoint of Class Range, Percent
1	0-5	2.5
2	>5-25	15.0
3	>25-50	37.5
4	>50-75	62.5
5	>75-95	85.0
6	>95-100	97.5

Include all nonwoody plants and woody plants <3.2 ft in height. *NOTE: Total percent cover for all species will often exceed 100 percent.*

d. *Woody vines (lianas).* Identify species of woody vines climbing each tree and sapling/shrub sampled in STEPS 9*a* and 9*b* above, and record the number of stems of each. Since many woody vines branch profusely, count or estimate the number of stems at the ground surface. Include only individuals rooted in the 10-ft radius plot. Do not include individuals <3.2 ft in height. PROCEED TO STEP 10.

- *STEP 10 - Analyze field vegetation data.* Examine the vegetation data (STEP 9) and determine the dominant species in each vegetation layer[1] by completing the following:

a. *Trees.* Obtain the total basal area (square inches) for each tree species identified in STEP 9*a* by summing the basal area of all individuals of a species found in the sample plot. Rank the species in descending order of dominance based on total basal area. Complete DATA FORM 2 for the tree layer.

b. *Saplings/shrubs.* Obtain the total height for each sapling/shrub species identified in STEP 9*b*. Total height, which is an estimate of dominance, is obtained by summing the midpoints of height classes for all individuals of a species found in the sample plot. Rank the species in descending order of dominance based on sums of midpoints of height class ranges. Complete DATA FORM 2 for the sapling/shrub layer.

c. *Herbs.* Obtain the total cover for each herbaceous and woody seedling species identified in STEP 9*c*. Total cover is obtained by using the midpoints of the cover class range as-

[1] The same species may occur as a dominant in more than one vegetation layer.

signed to each species (only one estimate of cover is made for a species in a given plot). Rank herbs and woody seedlings in descending order of dominance based on percent cover. Complete DATA FORM 2 for the herbaceous layer.

d. *Woody vines (lianas).* Obtain the total number of individuals of each species of woody vine identified in STEP 9*d*. Rank the species in descending order of dominance based on number of stems. Complete DATA FORM 2 for the woody vine layer. PROCEED TO STEP 11.

- *STEP 11 - Characterize soil.* If a soil survey is available (Section B), the soil type may already be known. Have a soil scientist confirm that the soil type is correct, and determine whether the soil series is a hydric soil ~~(Appendix D, Section 2)~~. *CAUTION: Mapping units on soil surveys sometimes have inclusions of soil series or phases not shown on the soil survey map.* If a hydric soil type is confirmed, record on DATA FORM 1 and PROCEED TO STEP 12. If not, dig a soil pit using a soil auger or spade (See Appendix D, Section 1) and look for indicators of hydric soils immediately below the A-horizon or 10 inches (whichever is shallower) (Part III, paragraphs 44 and/or 45). Record findings on DATA FORM 1. PROCEED TO STEP 12.

- *STEP 12 - Characterize hydrology.* Examine the observation point for indicators of wetland hydrology (Part III, paragraph 49) and record observations on DATA FORM 1. Consider indicators in the same sequence as listed in paragraph 49. PROCEED TO STEP 13.

- *STEP 13 - Determine whether hydrophytic vegetation is present.* Record the three dominant species from each vegetation layer (five species if only one or two layers are present) on DATA FORM 1.[1] Determine whether these species occur in wetlands by considering the following:

a. *More than 50 percent of the dominant plant species are OBL, FACW, and/or FAC*[2] *on lists of plant species that occur in wetlands.* Record the indicator status of all dominant species ~~(Appendix C, Section 1 or 2)~~ on DATA FORM 1. Hydrophytic vegetation is present when the majority of the dominant species have an indicator status of OBL, FACW, or FAC. *CAUTION: Not necessarily all plant communities composed of only FAC species are hydrophytic communities. They are hydrophytic communities only when positive indicators of hydric soils and wetland hydrology are also found.* If this indicator is satisfied, complete the vegetation portion of

---

[1] Record all dominant species when less than three are present in a vegetation layer.
[2] For the FAC-neutral option, see paragraph 35*a*.

DATA FORM 1 and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

b. *Presence of adaptations for occurrence in wetlands.* Do any of the species listed on DATA FORM 1 have observed morphological or known physiological adaptations (Appendix C, Section 3) for occurrence in wetlands? If so, record species having such adaptations on DATA FORM 1. When two or more dominant species have observed morphological adaptations or known physiological adaptations for occurrence in wetlands, hydrophytic vegetation is present. If so, complete the vegetation portion of DATA FORM 1 and PROCEED TO STEP 14. If not, consider other indicators of hydrophytic vegetation.

c. *Other indicators of hydrophytic vegetation.* Consider other indicators (see Part III, paragraph 35) that the species listed on DATA FORM 1 are commonly found in wetlands. If so, complete the vegetation portion of DATA FORM 1 by recording sources of supporting information, and PROCEED TO STEP 14. If no indicator of hydrophytic vegetation is present, the area at the observation point is not a wetland. In such cases, it is unnecessary to consider soil and hydrology at that observation point. PROCEED TO STEP 17.

- *STEP 14 - Determine whether hydric soils are present.* Examine DATA FORM 1 and determine whether any indicator of hydric soils is present. If so, complete the soils portion of DATA FORM 1 and PROCEED TO STEP 15. If not, the area at the observation point is not a wetland. PROCEED TO STEP 17.

- *STEP 15 - Determine whether wetland hydrology is present.* Examine DATA FORM 1 and determine whether any indicator of wetland hydrology is present. Complete the hydrology portion of DATA FORM 1 and PROCEED TO STEP 16.

- *STEP 16 - Make wetland determination.* When the area at the observation point presently or normally has wetland indicators of all three parameters, it is a wetland. When the area at the observation point presently or normally lacks wetland indicators of one or more parameters, it is a nonwetland. PROCEED TO STEP 17.

- *STEP 17 - Make wetland determination at second observation point.* Locate the second observation point along the first transect and make a wetland determination by repeating procedures described in STEPS 9 through 16. When the area at the second observation point is the same as the area at the first observation point (i.e., both wetlands or both nonwetlands), PROCEED TO STEP 19. When the areas at the two observation points are different (i.e., one wetlands, the other nonwetlands), PROCEED TO STEP 18.

- *STEP 18 - Determine the wetland boundary between observation points.* Determine the position of the wetland boundary by applying the following procedure:

  a. Look for a change in vegetation or topography. *NOTE: The changes may sometimes be very subtle.* If a change is noted, establish an observation point and repeat STEPS 9 through 16. Complete a DATA FORM 1. If the area at this point is a wetland, proceed toward the nonwetland observation point until a more obvious change in vegetation or topography is noted and repeat the procedure. If there is no obvious change, establish the next observation point approximately halfway between the last observation point and the nonwetland observation point and repeat STEPS 9 through 16.

  b. Make as many additional wetland determinations as necessary to find the wetland boundary. *NOTE: The completed DATA FORM 1's for the original two observation points often will provide a clue as to the parameters that change between the two points.*

  c. When the wetland boundary is found, mark the boundary location on the base map and indicate on the DATA FORM 1 that this represents a wetland boundary. Record the distance of the boundary from one of the two regular observation points. Since the regular observation points represent known distances from the baseline, it will be possible to accurately pinpoint the boundary location on the base map. PROCEED TO STEP 19.

- *STEP 19 - Make wetland determinations at all other required observation points along all transects.* Continue to locate and sample all required observation points along all transects. *NOTE: The procedure described in STEP 18 must be applied at every position where a wetland boundary occurs between successive observation points.* Complete a DATA FORM 1 for each observation point and PROCEED TO STEP 20.

- *STEP 20 - Synthesize data to determine the portion of the area containing wetlands.* Examine all completed copies of DATA FORM 1 (STEP 19), and mark on a copy of the base map the locations of all observation points that are wetlands with a W and all observation points that are nonwetlands with an N. Also, mark all wetland boundaries occurring along transects with an X. If all the observation points are wetlands, the entire area is wetlands. If all observation points are nonwetlands, none of the area is wetlands. If some wetlands and some nonwetlands are present, connect the wetland boundaries (X) by following contour lines between transects. *CAUTION: If the determination is considered to be* *highly controversial, it may be necessary to be more precise in determining the wetland boundary between transects. This is also true for very large areas where the distance between transects is greater. If this is necessary, PROCEED TO STEP 21.*

- *STEP 21 - Determine wetland boundary between transects.* Two procedures may be used to determine the wetland boundary between transects, both of which involve surveying:

  a. *Survey contour from wetland boundary along transects.* The first method involves surveying the elevation of the wetland boundaries along transects and then extending the survey to determine the same contour between transects. This procedure will be adequate in areas where there is no significant elevational change between transects. However, if a significant elevational change occurs between transects, either the surveyor must adjust elevational readings to accommodate such changes or the second method must be used. *NOTE: The surveyed wetland boundary must be examined to ensure that no anomalies exist. If these occur, additional wetland determinations will be required in the portion of the area where the anomalies occur, and the wetland boundary must be adjusted accordingly.*

  b. *Additional wetland determinations between transects.* This procedure consists of traversing the area between transects and making additional wetland determinations to locate the wetland boundary at sufficiently close intervals (not necessarily standard intervals) so that the area can be surveyed. Place surveyor flags at each wetland boundary location. Enlist a surveyor to survey the points between transects. From the resulting survey data, produce a map that separates wetlands from nonwetlands.

Section F. Atypical Situations

71. Methods described in this section should be used only when a determination has already been made in Section D or E that positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology could not be found due to effects of recent human activities or natural events. This section is applicable to delineations made in the following types of situations:

a. *Unauthorized activities.* Unauthorized discharges requiring enforcement actions may result in removal or covering of indicators of one or more wetland parameters. Examples include, but are not limited to: (1) alteration or removal of vegetation; (2) placement of dredged or fill material over hydric soils; and/or (3) construction of levees, drainage systems, or dams that significantly alter the area hydrology. NOTE: This section should not be used for activities that have been previously authorized or those that are exempted from CE regulation. For example, this section is not applicable to areas that have been drained under CE authorization or that did not require CE authorization. Some of these areas may still be wetlands, but procedures described in Section D or E must be used in these cases.

b. *Natural events.* Naturally occurring events may result in either creation or alteration of wetlands. For example, recent beaver dams may impound water, thereby resulting in a shift of hydrology and vegetation to wetlands. However, hydric soil indicators may not have developed due to insufficient time having passed to allow their development. Fire, avalanches, volcanic activity, and changing river courses are other examples. *NOTE: It is necessary to determine whether alterations to an area have resulted in changes that are now the "normal circumstances."* The relative permanence of the change and whether the area is now functioning as a wetland must be considered.

c. *Man-induced wetlands.* Procedures described in Subsection 4 are for use in delineating wetlands that have been purposely or incidentally created by human activities, but in which wetland indicators of one or more parameters are absent. For example, road construction may have resulted in impoundment of water in an area that previously was nonwetland, thereby effecting hydrophytic vegetation and wetland hydrology in the area. However, the area may lack hydric soil indicators. *NOTE: Subsection D is not intended to bring into CE jurisdiction those manmade wetlands that are exempted under CE regulations or policy.* It is also important to consider whether the man-induced changes are now the "normal circumstances" for the area. Both the relative permanence of the change and the functioning of the area as a wetland are implied.

72. When any of the three types of situations described in paragraph 71 occurs, application of methods described in Sections D and/or E will lead to the conclusion that the area is not a wetland because positive wetland indicators for at least one of the three parameters will be absent. Therefore, apply procedures described in one of the following subsections (as appropriate) to determine whether positive indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology existed prior to alteration of the area. Once these procedures have been employed, RETURN TO Section D or E to make a wetland determination. PROCEED TO the appropriate subsection.

Subsection 1 - Vegetation

73. Employ the following steps to determine whether hydrophytic vegetation previously occurred:

- *STEP 1 - Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of selective harvesting, clear cutting, bulldozing, recent conversion to agriculture, or other activities (e.g., burning, discing, or presence of buildings, dams, levees, roads, parking lots, etc.). Determine the approximate date[1] when the alteration occurred. Record observations on DATA FORM 3, and PROCEED TO STEP 2.

- *STEP 2 - Describe effects on vegetation.* Record on DATA FORM 3 a general description of how the activities (STEP 1) have affected the plant communities. Consider the following:

  a. Has all or a portion of the area been cleared of vegetation?

  b. Has only one layer of the plant community (e.g., trees) been removed?

  c. Has selective harvesting resulted in removal of some species?

  d. Has all vegetation been covered by fill, dredged material, or structures?

  e. Have increased water levels resulted in the death of some individuals?

  PROCEED TO STEP 3.

- *STEP 3 - Determine the type of vegetation that previously occurred.* Obtain all possible evidence of the type of plant communities that occurred in the area prior to alteration. Potential sources of such evidence include:

  a. *Aerial photography*. Recent (within 5 years) aerial photography can often be used to document the type of previous vegetation. The general type of plant communities formerly present can usually be determined, and species identification is sometimes possible.

  b. *Onsite inspection.* Many types of activities result in only partial removal of the previous plant communities, and remaining species may be indicative of hydrophytic vegetation. In other cases, plant fragments (e.g., stumps, roots) may be used to reconstruct the plant community types that occurred prior to site alteration. Sometimes, this can be determined by examining piles of debris resulting from land-clearing opera-

---

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

tions or excavation to uncover identifiable remains of the previous plant community.

c. *Previous site inspections.* Documented evidence from previous inspections of the area may describe the previous plant communities, particularly in cases where the area was altered after a permit application was denied.

d. *Adjacent vegetation.* Circumstantial evidence of the type of plant communities that previously occurred may sometimes be obtained by examining the vegetation in adjacent areas. If adjacent areas have the same topographic position, soils, and hydrology as the altered area, the plant community types on the altered area were probably similar to those of the adjacent areas.

e. *SCS records.* Most SCS soil surveys include a description of the plant community types associated with each soil type. If the soil type on the altered area can be determined, it may be possible to generally determine the type of plant communities that previously occurred.

f. *Permit applicant.* In some cases, the permit applicant may provide important information about the type of plant communities that occurred prior to alteration.

g. *Public.* Individuals familiar with the area may provide a good general description of the previously occurring plant communities.

h. *NWI wetland maps.* The NWI has developed wetland type maps for many areas. These may be useful in determining the type of plant communities that occurred prior to alteration.

To develop the strongest possible record, all of the above sources should be considered. If the plant community types that occurred prior to alteration can be determined, record them on DATA FORM 3 and also record the basis used for the determination. PROCEED TO STEP 4. If it is impossible to determine the plant community types that occurred on the area prior to alteration, a determination cannot be made using all three parameters. In such cases, the determination must be based on the other two parameters. PROCEED TO Subsection 2 or 3 if one of the other parameters has been altered, or return to the appropriate Subsection of Section D or to Section E, as appropriate.

- *STEP 4 - Determine whether plant community types constitute hydrophytic vegetation.* Develop a list of species that previously occurred on the site (DATA FORM 3). Subject the species list to applicable indicators of hydrophytic vegetation (Part III, paragraph 35). If none of the indicators are met, the plant communities that previously occurred did not constitute hydrophytic vegetation. If hydrophytic vegetation was present and no other parameter was in question, record appropriate data on the vegetation portion of DATA FORM 3, and return to either the appropriate subsection of Section D or to Section E. If either of the other parameters was also in question, PROCEED TO Subsection 2 or 3.

Subsection 2 - Soils

74. Employ the following steps to determine whether hydric soils previously occurred:

- *STEP 1* **-** *Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of:

    a. *Deposition of dredged or fill material or natural sedimentation.* In many cases the presence of fill material will be obvious. If so, it will be necessary to dig a hole to reach the original soil (sometimes several feet deep). Fill material will usually be a different color or texture than the original soil (except when fill material has been obtained from like areas onsite). Look for decomposing vegetation between soil layers and the presence of buried organic or hydric soil layers. In accreting or recently formed sandbars in riverine situations, the soils may support hydrophytic vegetation but lack hydric soil characteristics.

    b. *Presence of nonwoody debris at the surface.* This can only be applied in areas where the original soils do not contain rocks. Nonwoody debris includes items such as rocks, bricks, and concrete fragments.

    c. *Subsurface plowing.* Has the area recently been plowed below the A-horizon or to depths of greater than 10 in.?

    d. *Removal of surface layers.* Has the surface soil layer been removed by scraping or natural landslides? Look for bare soil surfaces with exposed plant roots or scrape scars on the surface.

    e. *Presence of man-made structures.* Are buildings, dams, levees, roads, or parking lots present?

Determine the approximate date[1] when the alteration occurred. This may require checking aerial photography, examining building permits, etc. Record on DATA FORM 3, and PROCEED TO STEP 2.

- *STEP 2 - Describe effects on soils.* Record on DATA FORM 3 a general description of how identified activities in STEP 1 have affected the soils. Consider the following:

  a. Has the soil been buried? If so, record the depth of fill and determine whether the original soil is intact.

  b. Has the soil been mixed at a depth below the A-horizon or 10 inches? If so, it will be necessary to examine soil at a depth immediately below the plowed zone. Record supporting evidence.

  c. Has the soil been sufficiently altered to change the soil phase? Describe these changes.

  PROCEED TO STEP 3.

- *STEP 3 - Characterize soils that previously occurred.* Obtain all possible evidence that may be used to characterize soils that previously occurred on the area. Consider the following potential sources of information:

  a. *Soil surveys.* In many cases, recent soil surveys will be available. If so, determine the soil series that were mapped for the area, and compare these soil series with the list of hydric soils ~~(Appendix D, Section 2)~~. If all soil series are listed as hydric soils, the entire area had hydric soils prior to alteration.

  b. *Characterization of buried soils.* When fill material has been placed over the original soil without physically disturbing the soil, examine and characterize the buried soils. To accomplish this, dig a hole through the fill material until the original soil is encountered. Determine the point at which the original soil material begins. Remove 12 inches of the original soil from the hole and look for indicators of hydric soils (Part III, paragraphs 44 and/or 45) immediately below the A-horizon or 10 inches (whichever is shallower). Record on DATA FORM 3 the color of the soil matrix, presence of an organic layer, presence of mottles or gleying, and/or presence of iron and manganese concretions. If the original soil is mottled and the

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

chroma of the soil matrix is 2 or less,[1] a hydric soil was formerly present on the site. If any of these indicators are found, the original soil was a hydric soil. *(NOTE: When the fill material is a thick layer, it might be necessary to use a backhoe or posthole digger to excavate the soil pit.)* If USGS quadrangle maps indicate distinct variation in area topography, this procedure must be applied in each portion of the area that originally had a different surface elevation. Record findings on DATA FORM 3.

c. *Characterization of plowed soils.* Determine the depth to which the soil has been disturbed by plowing. Look for hydric soil characteristics (Part III, paragraphs 44 and/or 45) immediately below this depth. Record findings on DATA FORM 3.

d. *Removal of surface layers.* Dig a hole (Appendix D, Section 1) and determine whether the entire surface layer (A-horizon) has been removed. If so, examine the soil immediately below the top of the subsurface layer (B-horizon) for hydric soil characteristics. As an alternative, examine an undisturbed soil of the same soil series occurring in the same topographic position in an immediately adjacent area that has not been altered. Look for hydric soil indicators immediately below the A-horizon or 10 inches (whichever is shallower), and record findings on DATA FORM 3.

If sufficient data on soils that existed prior to alteration can be obtained to determine whether a hydric soil was present, PROCEED TO STEP 4. If not, a determination cannot be made using soils. Use the other parameters (Subsections 1 and 3) for the determination.

- *STEP 4 - Determine whether hydric soils were formerly present.* Examine the available data and determine whether indicators of hydric soils (Part III, paragraphs 44 and/or 45) were formerly present. If no indicators of hydric soils were found, the original soils were not hydric soils. If indicators of hydric soils were found, record the appropriate indicators on DATA FORM 3 and PROCEED TO Subsection 3 if the hydrology of the area has been significantly altered or return either to the appropriate subsection of Section D or to Section E and characterize the area hydrology.

---

[1] The matrix chroma must be 1 or less if no mottles are present. The soil must be moist when colors are determined.

Subsection 3 - Hydrology

75. Apply the following steps to determine whether wetland hydrology previously occurred:

- *STEP 1 - Describe the type of alteration.* Examine the area and describe the type of alteration that occurred. Look for evidence of:

  a. *Dams.* Has recent construction of a dam or some natural event (e.g., beaver activity or landslide) caused the area to become increasingly wetter or drier? *NOTE: This activity could have occurred a considerable distance away from the site in question.*

  b. *Levees, dikes, and similar structures.* Have levees or dikes recently been constructed that prevent the area from becoming periodically inundated by overbank flooding?

  c. *Ditching.* Have ditches been constructed recently that cause the area to drain more rapidly following inundation?

  d. *Filling of channels or depressions (land-leveling).* Have natural channels or depressions been recently filled?

  e. *Diversion of water.* Has an upstream drainage pattern been altered that results in water being diverted from the area?

  f. *Ground-water extraction.* Has prolonged and intensive pumping of ground water for irrigation or other purposes significantly lowered the water table and/or altered drainage patterns?

  g. *Channelization.* Have feeder streams recently been channelized sufficiently to alter the frequency and/or duration of inundation?

  Determine the approximate date[1] when the alteration occurred. Record observations on DATA FORM 3 and PROCEED TO STEP 2.

- *STEP 2 - Describe effects of alteration on area hydrology.* Record on DATA FORM 3 a general description of how the observed alteration (STEP 1) has affected the area. Consider the following:

  a. Is the area more frequently or less frequently inundated than prior to alteration? To what degree and why?

---

[1] It is especially important to determine whether the alteration occurred prior to implementation of Section 404.

b. Is the duration of inundation and soil saturation different than prior to alteration? How much different and why?

PROCEED TO STEP 3.

- *STEP 3 - Characterize the hydrology that previously existed in the area.* Obtain all possible evidence that may be used to characterize the hydrology that previously occurred. Potential sources of information include:

  a. *Stream or tidal gage data.* If a stream or tidal gaging station is located near the area, it may be possible to calculate elevations representing the upper limit of wetlands hydrology based on duration of inundation. Consult hydrologists from the local CE District Office for assistance. The resulting mean sea level elevation will represent the upper limit of inundation for the area in the absence of any alteration. If fill material has not been placed on the area, survey this elevation from the nearest USGS benchmark. Record elevations representing zone boundaries on DATA FORM 3. If fill material has been placed on the area, compare the calculated elevation with elevations shown on a USGS quadrangle or any other survey map that predated site alteration.

  b. *Field hydrologic indicators.* Certain field indicators of wetland hydrology (Part III, paragraph 49) may still be present. Look for watermarks on trees or other structures, drift lines, and debris deposits. Record these on DATA FORM 3. If adjacent undisturbed areas are in the same topographic position and are similarly influenced by the same sources of inundation, look for wetland indicators in these areas.

  c. *Aerial photography.* Examine any available aerial photography and determine whether the area was inundated at the time of the photographic mission. Consider the time of the year that the aerial photography was taken and use only photography taken during the growing season and prior to site alteration.

  d. *Historical records.* Examine any available historical records for evidence that the area has been periodically inundated. Obtain copies of any such information and record findings on DATA FORM 3.

  e. *Floodplain management maps.* Determine the previous frequency of inundation of the area from Floodplain Management Maps (if available). Record flood frequency on DATA FORM 3.

f. *Public or local government officials.* Contact individuals who might have knowledge that the area was periodically inundated.

If sufficient data on hydrology that existed prior to site alteration can be obtained to determine whether wetland hydrology was previously present, PROCEED TO STEP 4. If not, a determination involving hydrology cannot be made. Use other parameters (Subsections 1 and 2) for the wetland determination. Return to either the appropriate subsection of Section D or to Section E and complete the necessary data forms. PROCEED TO STEP 4 if the previous hydrology can be characterized.

- *STEP 4 - Determine whether wetland hydrology previously occurred.* Examine the available data and determine whether indicators of wetland hydrology (Part III, paragraph 49) were present prior to site alteration. If no indicators of wetland hydrology were found, the original hydrology of the area was not wetland hydrology. If indicators of wetland hydrology were found, record the appropriate indicators on DATA FORM 3 and return either to the appropriate subsection of Section D or to Section E and complete the wetland determination.

Subsection 4 - Man-Induced Wetlands

76. A man-induced wetland is an area that has developed at least some characteristics of naturally occurring wetlands due to either intentional or incidental human activities. Examples of man-induced wetlands include irrigated wetlands, wetlands resulting from impoundment (e.g., reservoir shorelines), wetlands resulting from filling of formerly deepwater habitats, dredged material disposal areas, and wetlands resulting from stream channel realignment. Some man-induced wetlands may be subject to Section 404. In virtually all cases, man-induced wetlands involve a significant change in the hydrologic regime, which may either increase or decrease the wetness of the area. Although wetland indicators of all three parameters (i.e., vegetation, soils, and hydrology) may be found in some man-induced wetlands, indicators of hydric soils are usually absent. Hydric soils require long periods (hundreds of years) for development of wetness characteristics, and most man-induced wetlands have not been in existence for a sufficient period to allow development of hydric soil characteristics. Therefore, application of the multiparameter approach in making wetland determinations in man-induced wetlands must be based on the presence of hydrophytic vegetation and wetland hydrology.[1] There must also be documented evidence that the wetland resulted from human activities. Employ the following steps to determine whether an area consists of wetlands resulting from human activities:

---

[1] Uplands that support hydrophytic vegetation due to agricultural irrigation and that have an obvious hydrologic connection to other "waters of the United States" should not be delineated as wetlands under this subsection.

- *STEP 1 - Determine whether the area represents a potential man-induced wetland.* Consider the following questions:

  a. Has a recent man-induced change in hydrology occurred that caused the area to become significantly wetter?

  b. Has a major man-induced change in hydrology that occurred in the past caused a former deepwater aquatic habitat to become significantly drier?

  c. Has man-induced stream channel realignment significantly altered the area hydrology?

  d. Has the area been subjected to long-term irrigation practices?

  If the answer to any of the above questions is YES, document the approximate time during which the change in hydrology occurred, and PROCEED TO STEP 2. If the answer to all of the questions is NO, procedures described in Section D or E must be used.

- *STEP 2 - Determine whether a permit will be needed if the area is found to be a wetland.* Consider the current CE regulations and policy regarding man-induced wetlands. If the type of activity resulting in the area being a potential man-induced wetland is exempted by regulation or policy, no further action is needed. If not exempt, PROCEED TO STEP 3.

- *STEP 3 - Characterize the area vegetation, soils, and hydrology.* Apply procedures described in Section D (routine determinations) or Section E (comprehensive determinations) to the area. Complete the appropriate data forms and PROCEED TO STEP 4.

- *STEP 4 - Wetland determination.* Based on information resulting from STEP 3, determine whether the area is a wetland. When wetland indicators of all three parameters are found, the area is a wetland. When indicators of hydrophytic vegetation and wetland hydrology are found *and* there is documented evidence that the change in hydrology occurred so recently that soils could not have developed hydric characteristics, the area is a wetland. In such cases, it is assumed that the soils are functioning as hydric soils. *CAUTION: If hydrophytic vegetation is being maintained only because of man-induced wetland hydrology that would no longer exist if the activity (e.g., irrigation) were to be terminated, the area should not be considered a wetland.*

Section G - Problem Areas

77. There are certain wetland types and/or conditions that may make application of indicators of one or more parameters difficult, at least at certain times of the year. These are not considered to be atypical situations. Instead, they are wetland types in which wetland indicators of one or more parameters may be periodically lacking due to *normal* seasonal or annual variations in environmental conditions that result from causes other than human activities or catastrophic natural events.

Types of problem areas

78. Representative examples of potential problem areas, types of variations that occur, and their effects on wetland indicators are presented in the following subparagraphs. Similar situations may sometimes occur in other wetland types. *NOTE: This section is not intended to bring nonwetland areas having wetland indicators of two, but not all three, parameters into Section 404 jurisdiction.*

a. *Wetlands on drumlins.* Slope wetlands occur in glaciated areas in which thin soils cover relatively impermeable glacial till or in which layers of glacial till have different hydraulic conditions that produce a broad zone of ground-water seepage. Such areas are seldom, if ever, flooded, but downslope groundwater movement keeps the soils saturated for a sufficient portion of the growing season to produce anaerobic and reducing soil conditions. This fosters development of hydric soil characteristics and selects for hydrophytic vegetation. Indicators of wetland hydrology may be lacking during the drier portion of the growing season.

b. *Seasonal wetlands.* In many regions (especially in western states), depressional areas occur that have wetland indicators of all three parameters during the wetter portion of the growing season, but normally lack wetland indicators of hydrology and/or vegetation during the drier portion of the growing season. Obligate hydrophytes and facultative wetland plant species ~~(Appendix C, Section 1 or 2)~~ normally are dominant during the wetter portion of the growing season, while upland species (annuals) may be dominant during the drier portion of the growing season. These areas may be inundated during the wetter portion of the growing season, but wetland hydrology indicators may be totally lacking during the drier portion of the growing season. It is important to establish that an area truly is a water body. Water in a depression normally must be sufficiently persistent to exhibit an ordinary high-water mark or the presence of wetland characteristics before it can be considered as a water body potentially subject to Clean Water Act jurisdiction. The determination that an area exhibits wetland characteristics for a sufficient portion of the growing season to qualify as a wetland under the Clean Water Act must be made on a case-by-case basis. Such determinations should consider the respective length of time that the area exhibits upland and wetland characteristics, and the manner in which the area fits into the overall ecological system as a wetland. Evidence concerning the persistence of an area's wetness can be obtained from its history, vegetation, soil, drainage characteristics, uses to which it has been subjected, and weather or hydrologic records.

c. *Prairie potholes.* Prairie potholes normally occur as shallow depressions in glaciated portions of the north-central United States. Many are landlocked, while others have a drainage outlet to streams or other potholes. Most have standing water for much of the growing season in years of normal or above normal precipitation, but are neither inundated nor have saturated soils during most of the growing season in years of below normal precipitation. During dry years, potholes often become incorporated into farming plans, and are either planted to row crops (e.g., soybeans) or are mowed as part of a haying operation. When this occurs, wetland indicators of one or more parameters may be lacking. For example, tillage would eliminate any onsite hydrologic indicator, and would make detection of soil and vegetation indicators much more difficult.

d. *Vegetated flats.* In both coastal and interior areas throughout the Nation, vegetated flats are often dominated by annual species that are categorized as OBL. Application of procedures described in Sections D and E during the growing season will clearly result in a positive wetland determination. However, these areas will appear to be unvegetated mudflats when examined during the nongrowing season, and the area would not qualify at that time as a wetland due to an apparent lack of vegetation.

Wetland determinations in problem areas

79. Procedures for making wetland determinations in problem areas are presented below. Application of these procedures is appropriate only when a decision has been made in Section D or E that wetland indicators of one or more parameters were lacking, probably due to normal seasonal or annual variations in environmental conditions. Specific procedures to be used will vary according to the nature of the area, site conditions, and parameter(s) affected by the variations in environmental conditions. A determination must be based on the best evidence available to the field inspector, including:

a. Available information (Section B).

b. Field data resulting from an onsite inspection.

c. Basic knowledge of the ecology of the particular community type(s) and environmental conditions associated with the community type.

NOTE: The procedures described below should only be applied to parameters not adequately characterized in Section D or E. Complete the following steps:

- *STEP 1 - Identify the parameter(s) to be considered.* Examine the DATA FORM 1 (Section D or E) and identify the parameter(s) that must be given additional consideration. PROCEED TO STEP 2.

- *STEP 2 - Determine the reason for further consideration.* Determine the reason why the parameter(s) identified in STEP 1 should be given further consideration. This will require a consideration and documentation of:

  a. Environmental condition(s) that have impacted the parameter(s).

  b. Impacts of the identified environmental condition(s) on the parameter(s) in question.

  Record findings in the comments section of DATA FORM 1. PROCEED TO STEP 3.

- *STEP 3 - Document available information for parameter(s) in question.* Examine the available information and consider personal ecological knowledge of the range of normal environmental conditions of the area. Local experts (e.g., university personnel) may provide additional information. Record information on DATA FORM 1. PROCEED TO STEP 4.

- *STEP 4 - Determine whether wetland indicators are normally present during a portion of the growing season.* Examine the information resulting from STEP 3 and determine whether wetland indicators are *normally* present during part of the growing season. If so, record on DATA FORM 1 the indicators normally present and return to Section D or Section E and make a wetland determination. If no information can be found that wetland indicators of all three parameters are normally present during part of the growing season, the determination must be made using procedures described in Section D or Section E.

References

Clark, J. R., and Benforado, J., eds. (1981). *Wetlands of Bottomland Hardwood Forests, Proceedings of a Workshop on Bottomland Hardwood Forest Wetlands of the Southeastern United States*, Elsevier Scientific Publishing Company, New York.

Correll, D. S., and Correll, H. B. (1972). *Aquatic and Wetland Plants of the Southwestern United States*, Publ. No. 16030 DNL 01/72, Environmental Protection Agency, Washington, DC.

Cowardin, L. M., Carter, V., Golet, F. C., and LaRoe, E. T. (1979). "Classification of Wetlands and Deepwater Habitats of the United States," FWS/OBS-79/31, U.S. Fish and Wildlife Service, Office of Biological Services, Washington, DC.

Cronquist, A., Holmgren, A. H., Holmgren, N. H., and Reveal, J. L. (1972). *Intermountain Flora - Vascular Plants of the Intermountain West, USA*, Vol. I and II, Hefner Publishing Company, New York.

Davis, R. J. (1952). *Flora of Idaho*, William C. Brown Company, Dubuque, IA.

Federal Register. (1980). "40 CFR Part 230: Section 404(b)(1) Guidelines for Specification of Disposal Sites for Dredged or Fill Material," U.S. Government Printing Office, Washington, DC, 45(249), 85,352-85,353.

__________. (1982). "Title 33: Navigation and Navigable Waters; Chapter 2. Regulatory Programs of the Corps of Engineers," U.S. Government Printing Office, Washington, DC, 47(138), 31,810.

Fernald, M. L. (1950). *Gray's Manual of Botany*, 8th ed., American Book Company, New York.

Gleason, H. A., and Cronquist, A. (1963). *Manual of Vascular Plants of Northeastern United States and Adjacent Canada*, Van Nostrand, Princeton, NJ.

Godfrey, R. K., and Wooten, J. W. (1979). *Aquatic and Wetland Plants of the Southeastern United States*, Vol. I and II, University of Georgia Press, Athens, GA.

Harrington, H. D. (1979). *Manual of the Plants of Colorado*, 2nd ed., Sage Books, Denver, CO.

Hitchcock, A. S. (1950). *Manual of Grasses of the United States*, U.S. Department of Agriculture Miscellaneous Publication No. 200, U.S. Government Printing Office, Washington, DC.

Hitchcock, C. L., and Cronquist, A. (1973). *Flora of the Pacific Northwest*, University of Washington Press, Seattle, WA.

Kearney, T. H., and Peebles, R. H. (1960). *Arizona Flora*, 2nd ed., University of California Press, Berkeley, CA.

Long, R. W., and Lakela, O. (1976). *A Flora of Tropical Florida*, Banyan Books, Miami, FL.

Munsell Color. (1975). *Munsell Soil Color Charts*, Kollmorgen Corporation, Baltimore, MD.

Munz, P. A., and Keck, D. D. (1959). *A California Flora*, University of California Press, Berkeley, CA.

Radford, A. E., Ahles, H. E., and Bell, C. R. (1968). *Manual of the Vascular Flora of the Carolinas*, The University of North Carolina Press, Chapel Hill, NC.

Small, J. K. (1933). *Manual of the Southeastern Flora*, The University of North Carolina Press, Chapel Hill, NC.

Steyermark, J. A. (1963). *Flora of Missouri*, The Iowa State University Press, Ames, IA.

Theriot, R. F. (In Review). "Flood Tolerance Indices of Plant Species of Southeastern Bottomland Forests," Technical Report, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Department of Agriculture - Soil Conservation Service. (1975). *Soil Taxonomy*, Agriculture Handbook No. 436, U.S. Government Printing Office, Washington, DC.

__________. (1983). "List of Soils with Actual or High Potential for Hydric Conditions," USDA-SCS National Bulletin No. 430-3-10, Washington, DC.

U.S. Department of Agriculture - Soil Conservation Service. (1985). "Hydric Soils of the United States," USDA-SCS National Bulletin No. 430-5-9, Washington, DC.

U.S. Department of the Interior. (1970). *National Atlas of the United States*, U.S. Geological Survey, US Government Printing Office, Washington, DC, 110-111.

Bibliography

Copeland, B. J., Hodson, R. G., and Riggs, S. R. (1984). "The Ecology of the Pamlico River, North Carolina: An Estuarine Profile," FWS/OBS-82/06, U.S. Fish and Wildlife Service, Washington, DC.

Foster, M. S., and Schiel, D. R. (1985). "The Ecology of Giant Kelp Forests in California: A Community Profile," FWS/OBS-85(7.2), U.S. Fish and Wildlife Service, Washington, DC.

Gosselink, J. G. (1984). "The Ecology of Delta Marshes of Coastal Louisiana: A Community Profile," FWS/OBS-84/09, U.S. Fish and Wildlife Service, Washington, DC.

Hobbie, J. E. (1984). "The Ecology of Tundra Ponds of the Arctic Coastal Plain: A Community Profile," FWS/OBS-83/25, U.S. Fish and Wildlife Service, Washington, DC.

Huffman, R. T., and Tucker, G. E. (1984). "Preliminary Guide to the Onsite Identification and Delineation of the Wetlands of Alaska," Technical Report Y-78-9, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Huffman, R. T., Tucker, G. E, Wooten, J. W., Limas, C. V., Feel, M. W., Forsythe, S. W., and Wilson, J. S. (1982). "Preliminary Guide to the Onsite Identification and Delineation of the Wetlands of the South Atlantic United States," Technical Report Y-78-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1982). "Preliminary Guide to the Onsite Identification and Delineation of the Wetlands of the North Atlantic United States," Technical Report Y-78-8, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Japp, W. C. (1984). "The Ecology of the South Florida Coral Reefs: A Community Profile," FWS/OBS-82/08, U.S. Fish and Wildlife Service, Washington, DC.

Gasolene, M. (1983). "The Ecology of San Francisco Bay Tidal Marshes: A Community Profile," FWS/OBS-83/23, U.S. Fish and Wildlife Service, Washington, DC.

Livingston, R. J. (1984). "The Ecology of the Apalachicola Bay System: An Estuarine Profile," FWS/OBS-82/05, U.S. Fish and Wildlife Service, Washington, DC.

Nixon, S. W. (1982). "The Ecology of New England High Salt Marshes: A Community Profile," FWS/OBS-81/55, U.S. Fish and Wildlife Service, Washington, DC.

Odum, W. E., McIvor, C. C., and Smith, T. J., III. (1982). "The Ecology of the Mangroves of South Florida: A Community Profile," FWS/OBS-81/24, U.S. Fish and Wildlife Service, Washington, DC.

Odum, W. E., Smith, T. J., III, Hoover, J. K., and McIvor, C. C. (1984). "The Ecology of Tidal Freshwater Marshes of the United States East Coast: A Community Profile," FWS/OBS-83/17, U.S. Fish and Wildlife Service, Washington, DC.

Peterson, C. H., and Peterson, N. M. (1979). "The Ecology of Intertidal Flats of North Carolina: A Community Profile," FWS/OBS-79/39, U.S. Fish and Wildlife Service, Washington, DC.

Phillips, R. C. (1984). "The Ecology of Eelgrass Meadows in the Pacific Northwest: A Community Profile," FWS/OBS-84/24, U.S. Fish and Wildlife Service, Washington, DC.

Seliskar, D. M., and Gallagher, J. L. (1983). "The Ecology of Tidal Marshes of the Pacific Northwest Coast: A Community Profile," FWS/OBS-82/32, U.S. Fish and Wildlife Service, Washington, DC.

Sharitz, R. R., and Gibbons, J. W. (1982). "The Ecology of Southeastern Shrub Bogs (Pocosins) and Carolina Bays: A Community Profile," FWS/OBS-82/04, U.S. Fish and Wildlife Service, Washington, DC.

Thayer, G. W., Kenworthy, W. J., and Fonseca, M. S. (1984). "The Ecology of Eelgrass Meadows of the Atlantic Coast: A Community Profile," FWS/OBS-84/02, U.S. Fish and Wildlife Service, Washington, DC.

U.S. Army Corps of Engineers. (1978). "Preliminary Guide to Wetlands of Peninsular Florida," Technical Report Y-78-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1978). "Preliminary Guide to Wetlands of Puerto Rico," Technical Report Y-78-3, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

U.S. Army Corps of Engineers. (1978). "Preliminary Guide to Wetlands of the West Coast States," Technical Report Y-78-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1978). "Preliminary Guide to Wetlands of the Gulf Coastal Plain," Technical Report Y-78-5, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

__________. (1982). "Preliminary Guide to the Onsite Identification and Delineation of the Wetlands of the Interior United States," Technical Report Y-78-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Witlatch, R. B. (1982). "The Ecology of New England Tidal Flats: A Community Profile," FWS/OBS-81/01, U.S. Fish and Wildlife Service, Washington, DC.

Wharton, C. H., Kitchens, W. M., and Sipe, T. W. (1982). "The Ecology of Bottomland Hardwood Swamps of the Southeast: A Community Profile," FWS/OBS-81/37, U.S. Fish and Wildlife Service, Washington, DC.

Zedler, J. B. (1984). "The Ecology of Southern California Coastal Salt Marshes: A Community Profile," FWS/OBS-81/54, U.S. Fish and Wildlife Service, Washington, DC.

Zieman, J. C. (1982). "The Ecology of the Seagrasses of South Florida: A Community Profile," FWS/OBS-82/25, U.S. Fish and Wildlife Service, Washington, DC.

Appendix A
Glossary

Active water table. A condition in which the zone of soil saturation fluctuates, resulting in periodic anaerobic soil conditions. Soils with an active water table often contain bright mottles and matrix chromas of 2 or less.

Adaptation. A modification of a species that makes it more fit for existence under the conditions of its environment. These modifications are the result of genetic selection processes.

Adventitious roots. Roots found on plant stems in positions where they normally do not occur.

Aerenchymous tissue. A type of plant tissue in which cells are unusually large and arranged in a manner that results in air spaces in the plant organ. Such tissues are often referred to as spongy and usually provide increased buoyancy.

Aerobic. A situation in which molecular oxygen is a part of the environment.

Anaerobic. A situation in which molecular oxygen is absent (or effectively so) from the environment.

Aquatic roots. Roots that develop on stems above the normal position occupied by roots in response to prolonged inundation.

Aquic moisture regime. A mostly reducing soil moisture regime nearly free of dissolved oxygen due to saturation by ground water or its capillary fringe and occurring at periods when the soil temperature at 19.7 in. is greater than 5 °C.

Arched roots. Roots produced on plant stems in a position above the normal position of roots, which serve to brace the plant during and following periods of prolonged inundation.

Areal cover. A measure of dominance that defines the degree to which above-ground portions of plants (not limited to those rooted in a sample plot) cover the ground surface. It is possible for the total areal cover in a community to exceed 100 percent because (a) most plant communities consist of two or more vegetative strata; (b) areal cover is estimated by vegetative layer; and (c) foliage within a single layer may overlap.

Atypical situation. As used herein, this term refers to areas in which one or more parameters (vegetation, soil, and/or hydrology) have been sufficiently altered by recent human activities or natural events to preclude the presence of wetland indicators of the parameter.

Backwater flooding. Situations in which the source of inundation is overbank flooding from a nearby stream.

Basal area. The cross-sectional area of a tree trunk measured in square inches, square centimeters, etc. Basal area is normally measured at 4.5 ft above the ground level and is used as a measure of dominance. The most easily used tool for measuring basal area is a tape marked in square inches. When plotless methods are used, an angle gauge or prism will provide a means for rapidly determining basal area. This term is also applicable to the cross-sectional area of a clumped herbaceous plant, measured at 1.0 in. above the soil surface.

Bench mark. A fixed, more or less permanent reference point or object, the elevation of which is known. The U.S. Geological Survey (USGS) installs brass caps in bridge abutments or otherwise permanently sets bench marks at convenient locations nationwide. The elevations on these marks are referenced to the National Geodetic Vertical Datum (NGVD), also commonly known as mean sea level (MSL). Locations of these bench marks on USGS quadrangle maps are shown as small triangles. However, the marks are sometimes destroyed by construction or vandalism. The existence of any bench mark should be field verified before planning work that relies on a particular reference point. The USGS and/or local state surveyor's office can provide information on the existence, exact location, and exact elevation of bench marks.

Biennial. An event that occurs at 2-year intervals.

Buried soil. A once-exposed soil now covered by an alluvial, loessal, or other deposit (including man-made).

Canopy layer. The uppermost layer of vegetation in a plant community. In forested areas, mature trees comprise the canopy layer, while the tallest herbaceous species constitute the canopy layer in a marsh.

Capillary fringe. A zone immediately above the water table (zero gauge pressure) in which water is drawn upward from the water table by capillary action.

Chemical reduction. Any process by which one compound or ion acts as an electron donor. In such cases, the valence state of the electron donor is decreased.

Chroma. The relative purity or saturation of a color; intensity of distinctive hue as related to grayness; one of the three variables of color.

Comprehensive wetland determination. A type of wetland determination that is based on the strongest possible evidence, requiring the collection of quantitative data.

Concretion. A local concentration of chemical compounds (e.g., calcium carbonate, iron oxide) in the form of a grain or nodule of varying size, shape, hardness, and color. Concretions of significance in hydric soils are usually iron and/or manganese oxides occurring at or near the soil surface, which develop under conditions of prolonged soil saturation.

Contour. An imaginary line of constant elevation on the ground surface. The corresponding line on a map is called a "contour line."

Criteria. Standards, rules, or tests on which a judgment or decision may be based.

Deepwater aquatic habitat. Any open water area that has a mean annual water depth >6.6 ft, lacks soil, and/or is either unvegetated or supports only floating or submersed macrophytes.

Density. The number of individuals of a species per unit area.

Detritus. Minute fragments of plant parts found on the soil surface. When fused together by algae or soil particles, this is an indicator that surface water was recently present.

Diameter at breast height (DBH). The width of a plant stem as measured at 4.5 ft above the ground surface.

Dike. A bank (usually earthen) constructed to control or confine water.

Dominance. As used herein, a descriptor of vegetation that is related to the standing crop of a species in an area, usually measured by height, areal cover, or basal area (for trees).

Dominant species. As used herein, a plant species that exerts a controlling influence on or defines the character of a community.

Drained. A condition in which ground or surface water has been reduced or eliminated from an area by artificial means.

Drift line. An accumulation of debris along a contour (parallel to the water flow) that represents the height of an inundation event.

Duration (inundation/soil saturation). The length of time during which water stands at or above the soil surface (inundation), or during which the soil is saturated. As used herein, duration refers to a period during the growing season.

Ecological tolerance. The range of environmental conditions in which a plant species can grow.

Emergent plant. A rooted herbaceous plant species that has parts extending above a water surface.

Field capacity. The percentage of water remaining in a soil after it has been saturated and after free drainage is negligible.

Fill material. Any material placed in an area to increase surface elevation.

Flooded. A condition in which the soil surface is temporarily covered with flowing water from any source, such as streams overflowing their banks, runoff from adjacent or surrounding slopes, inflow from high tides, or any combination of sources.

Flora. A list of all plant species that occur in an area.

Frequency (inundation or soil saturation). The periodicity of coverage of an area by surface water or soil saturation. It is usually expressed as the number of years (e.g., 50 years) the soil is inundated or saturated at least once each year during part of the growing season per 100 years or as a l-, 2-, 5-year, etc., inundation frequency.

Frequency (vegetation). The distribution of individuals of a species in an area. It is quantitatively expressed as

$$\frac{\text{Number of samples containing species A}}{\text{Total number of samples}} \times 100$$

More than one species may have a frequency of 100 percent within the same area.

Frequently flooded. A flooding class in which flooding is likely to occur often under normal weather conditions (more than 50-percent chance of flooding in any year or more than 50 times in 100 years).

Gleyed. A soil condition resulting from prolonged soil saturation, which is manifested by the presence of bluish or greenish colors through the soil mass or in mottles (spots or streaks) among other colors. Gleying occurs under reducing soil conditions resulting from soil saturation, by which iron is reduced predominantly to the ferrous state.

Ground water. That portion of the water below the ground surface that is under greater pressure than atmospheric pressure.

Growing season. The portion of the year when soil temperatures at 19.7 in. below the soil surface are higher than biologic zero (5 °C) (U.S. Department of Agriculture—Soil Conservation Service 1985). For ease of determination this period can be approximated by the number of frost-free days (U.S Department of the Interior 1970).

Habitat. The environment occupied by individuals of a particular species, population, or community.

Headwater flooding. A situation in which an area becomes inundated directly by surface runoff from upland areas.

Herb. A nonwoody individual of a macrophytic species. In this manual, seedlings of woody plants (including vines) that are less than 3.2 ft in height are considered to be herbs.

Herbaceous layer. Any vegetative stratum of a plant community that is composed predominantly of herbs.

Histic epipedon. An 8- to 16-in. soil layer at or near the surface that is saturated for 30 consecutive days or more during the growing season in most years and contains a minimum of 20 percent organic matter when no clay is present or a minimum of 30 percent organic matter when 60 percent or greater clay is present.

Histosols. An order in soil taxonomy composed of organic soils that have organic soil materials in more than half of the upper 80 cm or that are of any thickness if directly overlying bedrock.

Homogeneous vegetation. A situation in which the same plant species association occurs throughout an area.

Hue. A characteristic of color that denotes a color in relation to red, yellow, blue, etc; one of the three variables of color. Each color chart in the Munsell Color Book (Munsell Color 1975) consists of a specific hue.

Hydric soil. A soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture—Soil Conservation Service 1985). Hydric soils that occur in areas having positive indicators of hydrophytic vegetation and wetland hydrology are wetland soils.

Hydric soil condition. A situation in which characteristics exist that are associated with soil development under reducing conditions.

Hydrologic regime. The sum total of water that occurs in an area on average during a given period.

Hydrologic zone. An area that is inundated or has saturated soils within a specified range of frequency and duration of inundation and soil saturation.

Hydrology. The science dealing with the properties, distribution, and circulation of water.

Hydrophyte. Any macrophyte that grows in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content; plants typically found in wet habitats.

Hydrophytic vegetation. The sum total of macrophytic plant life growing in water or on a substrate that is at least periodically deficient in oxygen as a result of excessive water content. When hydrophytic vegetation comprises a community where indicators of hydric soils and wetland hydrology also occur, the area has wetland vegetation.

Hypertrophied lenticels. An exaggerated (oversized) pore on the surface of stems of woody plants through which gases are exchanged between the plant and the atmosphere. The enlarged lenticels serve as a mechanism for increasing oxygen to plant roots during periods of inundation and/or saturated soils.

Importance value. A quantitative term describing the relative influence of a plant species in a plant community, obtained by summing any combination of relative frequency, relative density, and relative dominance.

Indicator. As used in this manual, an event, entity, or condition that typically characterizes a prescribed environment or situation; indicators determine or aid in determining whether or not certain stated circumstances exist.

Indicator status. One of the categories (e.g., OBL) that describes the estimated probability of a plant species occurring in wetlands.

Intercellular air space. A cavity between cells in plant tissues, resulting from variations in cell shape and configuration. Aerenchymous tissue (a morphological adaptation found in many hydrophytes) often has large intercellular air spaces.

Inundation. A condition in which water from any source temporarily or permanently covers a land surface.

Levee. A natural or man-made feature of the landscape that restricts movement of water into or through an area.

Liana. As used in this manual, a layer of vegetation in forested plant communities that consists of woody vines. The term may also be applied to a given species.

Limit of biological activity. With reference to soils, the zone below which conditions preclude normal growth of soil organisms. This term often is used to refer to the temperature (5 °C) in a soil below which metabolic processes of soil microorganisms, plant roots, and animals are negligible.

Long duration (flooding). A flooding class in which the period of inundation for a single event ranges from 7 days to 1 month.

Macrophyte. Any plant species that can be readily observed without the aid of optical magnification. This includes all vascular plant species and mosses (e.g., *Sphagnum* spp.), as well as large algae (e.g., *Cara* spp., kelp).

Macrophytic. A term referring to a plant species that is a macrophyte.

Major portion of the root zone. The portion of the soil profile in which more than 50 percent of plant roots occur. In wetlands, this usually constitutes the upper 12 in. of the profile.

Man-induced wetland. Any area that develops wetland characteristics due to some activity (e.g., irrigation) of man.

Mapping unit. As used in this manual, some common characteristic of soil, vegetation, and/or hydrology that can be shown at the scale of mapping for the defined purpose and objectives of a survey.

Mean sea level. A datum, or "plane of zero elevation," established by averaging all stages of oceanic tides over a 19-year tidal cycle or "epoch." This plane is corrected for curvature of the earth and is the standard reference for elevations on the earth's surface. The correct term for mean sea level is the National Geodetic Vertical Datum (NGVD).

Mesophytic. Any plant species growing where soil moisture and aeration conditions lie between extremes. These species are typically found in habitats with average moisture conditions, neither very dry nor very wet.

Metabolic processes. The complex of internal chemical reactions associated with life-sustaining functions of an organism.

Method. A particular procedure or set of procedures to be followed.

Mineral soil. A soil consisting predominantly of, and having its properties determined predominantly by, mineral matter usually containing less than 20 percent organic matter.

Morphological adaptation. A feature of structure and form that aids in fitting a species to its particular environment (e.g., buttressed base, adventitious roots, aerenchymous tissue).

Mottles. Spots or blotches of different color or shades of color interspersed within the dominant color in a soil layer, usually resulting from the presence of periodic reducing soil conditions.

Muck. Highly decomposed organic material in which the original plant parts are not recognizable.

Multitrunk. A situation in which a single individual of a woody plant species has several stems.

Nonhydric soil. A soil that has developed under predominantly aerobic soil conditions. These soils normally support mesophytic or xerophytic species.

Nonwetland. Any area that has sufficiently dry conditions that indicators of hydrophytic vegetation, hydric soils, and/or wetland hydrology are lacking. As used in this manual, any area that is neither a wetland, a deepwater aquatic habitat, nor other special aquatic site.

Organic pan. A layer usually occurring at 12 to 30 in. below the soil surface in coarse-textured soils, in which organic matter and aluminum (with or without iron) accumulate at the point where the top of the water table most often occurs. Cementing of the organic matter slightly reduces permeability of this layer.

Organic soil. A soil is classified as an organic soil when it is: (1) saturated for prolonged periods (unless artificially drained) and has more than 30 percent organic matter if the mineral fraction is more than 50 percent clay, or more than 20 percent organic matter if the mineral fraction has no clay; or (2) never saturated with water for more than a few days and having more than 34 percent organic matter.

Overbank flooding. Any situation in which inundation occurs as a result of the water level of a stream rising above bank level.

Oxidation-reduction process. A complex of biochemical reactions in soil that influences the valence state of component elements and their ions. Prolonged soil saturation during the growing season elicits anaerobic conditions that shift the overall process to a reducing condition.

Oxygen pathway. The sequence of cells, intercellular spaces, tissues, and organs, through which molecular oxygen is transported in plants. Plant species having pathways for oxygen transport to the root system are often adapted for life in saturated soils.

Parameter. A characteristic component of a unit that can be defined. Vegetation, soil, and hydrology are three parameters that may be used to define wetlands.

Parent material. The unconsolidated and more or less weathered mineral or organic matter from which a soil profile develops.

Ped. A unit of soil structure (e.g., aggregate, crumb, prism, block, or granule) formed by natural processes.

Peraquic moisture regime. A soil condition in which a reducing environment always occurs due to the presence of ground water at or near the soil surface.

Periodically. Used herein to define detectable regular or irregular saturated soil conditions or inundation, resulting from ponding of ground water, precipitation, overland flow, stream flooding, or tidal influences that occur(s) with hours, days, weeks, months, or even years between events.

Permeability. A soil characteristic that enables water or air to move through the profile, measured as the number of inches per hour that water moves downward through the saturated soil. The rate at which water moves through the least permeable layer governs soil permeability.

Physiognomy. A term used to describe a plant community based on the growth habit (e.g., trees, herbs, lianas) of the dominant species.

Physiological adaptation. A feature of the basic physical and chemical activities that occurs in cells and tissues of a species, which results in it being better fitted to its environment (e.g., ability to absorb nutrients under low oxygen tensions).

Plant community. All of the plant populations occurring in a shared habitat or environment.

Plant cover. See areal cover.

Pneumatophore. Modified roots that may function as a respiratory organ in species subjected to frequent inundation or soil saturation (e.g., cypress knees).

Ponded. A condition in which water stands in a closed depression. Water may be removed only by percolation, evaporation, and/or transpiration.

Poorly drained. Soils that commonly are wet at or near the surface during a sufficient part of the year that field crops cannot be grown under natural conditions. Poorly drained conditions are caused by a saturated zone, a layer with low hydraulic conductivity, seepage, or a combination of these conditions.

Population. A group of individuals of the same species that occurs in a given area.

Positive wetland indicator. Any evidence of the presence of hydrophytic vegetation, hydric soil, and/or wetland hydrology in an area.

Prevalent vegetation. The plant community or communities that occur in an area during a given period. The prevalent vegetation is characterized by the dominant macrophytic species that comprise the plant community.

Quantitative. A precise measurement or determination expressed numerically.

Range. As used herein, the geographical area in which a plant species is known to occur.

Redox potential. A measure of the tendency of a system to donate or accept electrons, which is governed by the nature and proportions of the oxidizing and reducing substances contained in the system.

Reducing environment. An environment conducive to the removal of oxygen and chemical reduction of ions in the soils.

Relative density. A quantitative descriptor, expressed as a percent, of the relative number of individuals of a species in an area; it is calculated by

$$\frac{\text{Number of individuals of species A}}{\text{Total number of individuals of all species}} \times 100$$

Relative dominance. A quantitative descriptor, expressed as a percent, of the relative size or cover of individuals of a species in an area; it is calculated by

$$\frac{\text{Amount}^{1}\text{ of species A}}{\text{Total amount of all species}} \times 100$$

Relative frequency. A quantitative descriptor, expressed as a percent, of the relative distribution of individuals of a species in an area; it is calculated by

$$\frac{\text{Frequency of species A}}{\text{Total frequency of all species}} \times 100$$

Relief. The change in elevation of a land surface between two points; collectively, the configuration of the earth's surface, including such features as hills and valleys.

---

[1] The "amount" of a species may be based on percent areal cover, basal area, or height.

Reproductive adaptation. A feature of the reproductive mechanism of a species that results in it being better fitted to its environment (e.g., ability for seed germination under water).

Respiration. The sum total of metabolic processes associated with conversion of stored (chemical) energy into kinetic (physical) energy for use by an organism.

Rhizosphere. The zone of soil in which interactions between living plant roots and microorganisms occur.

Root zone. The portion of a soil profile in which plant roots occur.

Routine wetland determination. A type of wetland determination in which office data and/or relatively simple, rapidly applied onsite methods are employed to determine whether or not an area is a wetland. Most wetland determinations are of this type, which usually does not require collection of quantitative data.

Sample plot. An area of land used for measuring or observing existing conditions.

Sapling/shrub. A layer of vegetation composed of woody plants <3.0 in. in diameter at breast height but greater than 3.2 ft in height, exclusive of woody vines.

Saturated soil conditions. A condition in which all easily drained voids (pores) between soil particles in the root zone are temporarily or permanently filled with water to the soil surface at pressures greater than atmospheric.

Soil. Unconsolidated mineral and organic material that supports, or is capable of supporting, plants, and which has recognizable properties due to the integrated effect of climate and living matter acting upon parent material, as conditioned by relief over time.

Soil horizon. A layer of soil or soil material approximately parallel to the land surface and differing from adjacent genetically related layers in physical, chemical, and biological properties or characteristics (e.g., color, structure, texture, etc.).

Soil matrix. The portion of a given soil having the dominant color. In most cases, the matrix will be the portion of the soil having more than 50 percent of the same color.

Soil permeability. The ease with which gases, liquids, or plant roots penetrate or pass through a layer of soil.

Soil phase. A subdivision of a soil series having features (e.g., slope, surface texture, and stoniness) that affect the use and management of the soil, but which do not vary sufficiently to differentiate it as a separate series. These are usually the basic mapping units on detailed soil maps produced by the Soil Conservation Service.

Soil pore. An area within soil occupied by either air or water, resulting from the arrangement of individual soil particles or peds.

Soil profile. A vertical section of a soil through all its horizons and extending into the parent material.

Soil series. A group of soils having horizons similar in differentiating characteristics and arrangement in the soil profile, except for texture of the surface horizon.

Soil structure. The combination or arrangement of primary soil particles into secondary particles, units, or peds.

Soil surface. The upper limits of the soil profile. For mineral soils, this is the upper limit of the highest (Al) mineral horizon. For organic soils, it is the upper limit of undecomposed, dead organic matter.

Soil texture. The relative proportions of the various sizes of particles in a soil.

Somewhat poorly drained. Soils that are wet near enough to the surface or long enough that planting or harvesting operations or crop growth is markedly restricted unless artificial drainage is provided. Somewhat poorly drained soils commonly have a layer with low hydraulic conductivity, wet conditions high in the profile, additions of water through seepage, or a combination of these conditions.

Stilted roots. Aerial roots arising from stems (e.g., trunk and branches), presumably providing plant support (e.g., *Rhizophora mangle).*

Stooling. A form of asexual reproduction in which new shoots are produced at the base of senescing stems, often resulting in a multitrunk growth habit.

Stratigraphy. Features of geology dealing with the origin, composition, distribution, and succession of geologic strata (layers).

Substrate. The base or substance on which an attached species is growing.

Surface water. Water present above the substrate or soil surface.

Tidal. A situation in which the water level periodically fluctuates due to the action of lunar and solar forces upon the rotating earth.

Topography. The configuration of a surface, including its relief and the position of its natural and man-made features.

Transect. As used herein, a line on the ground along which observations are made at some interval.

Transition zone. The area in which a change from wetlands to nonwetlands occurs. The transition zone may be narrow or broad.

Transpiration. The process in plants by which water vapor is released into the gaseous environment, primarily through stomata.

Tree. A woody plant >3.0 in. in diameter at breast height, regardless of height (exclusive of woody vines).

Typical. That which normally, usually, or commonly occurs.

Typically adapted. A term that refers to a species being normally or commonly suited to a given set of environmental conditions, due to some feature of its morphology, physiology, or reproduction.

Unconsolidated parent material. Material from which a soil develops, usually formed by weathering of rock or placement in an area by natural forces (e.g., water, wind, or gravity).

Under normal circumstances. As used in the definition of wetlands, this term refers to situations in which the vegetation has not been substantially altered by man's activities.

Uniform vegetation. As used herein, a situation in which the same group of dominant species generally occurs throughout a given area.

Upland. As used herein, any area that does not qualify as a wetland because the associated hydrologic regime is not sufficiently wet to elicit development of vegetation, soils, and/or hydrologic characteristics associated with wetlands. Such areas occurring within floodplains are more appropriately termed nonwetlands.

Value (soil color). The relative lightness or intensity of color, approximately a function of the square root of the total amount of light reflected from a surface; one of the three variables of color.

Vegetation. The sum total of macrophytes that occupy a given area.

Vegetation layer. A subunit of a plant community in which all component species exhibit the same growth form (e.g., trees, saplings/shrubs, herbs).

Very long duration (flooding). A duration class in which the length of a single inundation event is greater than 1 month.

Very poorly drained. Soils that are wet to the surface most of the time. These soils are wet enough to prevent the growth of important crops (except rice) unless artificially drained.

Watermark. A line on a tree or other upright structure that represents the maximum static water level reached during an inundation event.

Water table. The upper surface of ground water or that level below which the soil is saturated with water. It is at least 6 in. thick and persists in the soil for more than a few weeks.

Wetlands. Those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas.

Wetland boundary. The point on the ground at which a shift from wetlands to nonwetlands or aquatic habitats occurs. These boundaries usually follow contours.

Wetland determination. The process or procedure by which an area is adjudged a wetland or nonwetland.

Wetland hydrology. The sum total of wetness characteristics in areas that are inundated or have saturated soils for a sufficient duration to support hydrophytic vegetation.

Wetland plant association. Any grouping of plant species that recurs wherever certain wetland conditions occur.

Wetland soil. A soil that has characteristics developed in a reducing atmosphere, which exists when periods of prolonged soil saturation result in anaerobic conditions. Hydric soils that are sufficiently wet to support hydrophytic vegetation are wetland soils.

Wetland vegetation. The sum total of macrophytic plant life that occurs in areas where the frequency and duration of inundation or soil saturation produce permanently or periodically saturated soils of sufficient duration to exert a controlling influence on the plant species present. As used herein, hydrophytic vegetation occurring in areas that also have hydric soils and wetland hydrology may be properly referred to as wetland vegetation.

Woody vine. See liana.

Xerophytic. A plant species that is typically adapted for life in conditions where a lack of water is a limiting factor for growth and/or reproduction. These species are capable of growth in extremely dry conditions as a result of morphological, physiological, and/or reproductive adaptations.

Appendix B
Blank and Example Data Forms

USER NOTES: The following field data form ("Data Form, Routine Wetland Determination, 1987 COE Wetlands Delineation Manual") dated 3/92 is the HQUSACE-approved replacement for Data Form 1 given in the 1987 Manual. (HQUSACE, 6 Mar 92)

DATA FORM
ROUTINE WETLAND DETERMINATION
(1987 COE Wetlands Delineation Manual)

Project/Site: ____________ Applicant/Owner: ____________ Investigator: ____________	Date: ________ County: ________ State: ________
Do Normal Circumstances exist on the site? Yes No Is the site significantly disturbed (Atypical Situation)? Yes No Is the area a potential Problem Area? Yes No (If needed, explain on reverse.)	Community ID: ________ Transect ID: ________ Plot ID: ________

VEGETATION

Dominant Plant Species	Stratum	Indicator	Dominant Plant Species	Stratum	Indicator
1.			9.		
2.			10.		
3.			11.		
4.			12.		
5.			13.		
6.			14.		
7.			15.		
8.			16.		

Percent of Dominant Species that are OBL, FACW or FAC
(excluding FAC-). ____________

Remarks:

HYDROLOGY

___ Recorded Data (Describe in Remarks):
 ___ Stream, Lake, or Tide Gauge
 ___ Aerial Photographs
 ___ Other
___ No Recorded Data Available

Field Observations:

Depth of Surface Water: ________(in.)

Depth to Free Water in Pit: ________(in.)

Depth to Saturated Soil: ________(in.)

Wetland Hydrology Indicators:
Primary Indicators:
 ___ Inundated
 ___ Saturated in Upper 12 Inches
 ___ Water Marks
 ___ Drift Lines
 ___ Sediment Deposits
 ___ Drainage Patterns in Wetlands
Secondary Indicators (2 or more required):
 ___ Oxidized Root Channels in Upper 12 Inches
 ___ Water-Stained Leaves
 ___ Local Soil Survey Data
 ___ FAC-Neutral Test
 ___ Other (Explain in Remarks)

Remarks:

SOILS

Map Unit Name
(Series and Phase): ____ Drainage Class: ________________
Field Observations
Taxonomy (Subgroup): ____ Confirm Mapped Type? Yes No

Profile Description:

Depth (inches)	Horizon	Matrix Color (Munsell Moist)	Mottle Colors (Munsell Moist)	Mottle Abundance/ Size/Contrast	Texture, Concretions, Structure, etc.

Hydric Soil Indicators:

___ Histosol
___ Histic Epipedon
___ Sulfidic Odor
___ Aquic Moisture Regime
___ Reducing Conditions
___ Gleyed or Low-Chroma Colors
___ Concretions
___ High Organic Content in Surface Layer in Sandy Soils
___ Organic Streaking in Sandy Soils
___ Listed on Local Hydric Soils List
___ Listed on National Hydric Soils List
___ Other (Explain in Remarks)

Remarks:

WETLAND DETERMINATION

Hydrophytic Vegetation Present? Yes No (Circle)
Wetland Hydrology Present? Yes No
Hydric Soils Present? Yes No

(Circle)
Is this Sampling Point Within a Wetland? Yes No

Remarks:

Approved by HQUSACE 3/92

DATA FORM 1

WETLAND DETERMINATION

Applicant Name:____________________ Application Number:______________ Project Name:_______________

State:__________County:_________Legal Description: Township:_____Range:_____

Date:________________ Plot No.:__________________ Section:__________________

Vegetation [list the three dominant species in each vegetation layer (5 if only 1 or 2 layers)]. Indicate species with observed morphological or known physiological adaptations with an asterisk.

Species	Indicator Status	Species	Indicator Status
Trees		Herbs	
1.		7.	
2.		8.	
3.		9.	
Saplings/shrubs		Woody vines	
4.		10.	
5.		11.	
6.		12.	

% of species that are OBL, FACW, and/or FAC:____. Other indicators:_________.

Hydrophytic vegetation: Yes ____ No ____. Basis:___________________________.

Soil

Series and phase:___________________ On hydric soils list? Yes_____; No____.

Mottled: Yes_____; No_____. Mottle color:__________; Matrix color:_________.

Gleyed: Yes____ No_____ Other indicators:_______________________________.

Hydric soils: Yes_____ No_____; Basis:____________________________________.

Hydrology

Inundated: Yes_____; No_____. Depth of standing water:_____________________.

Saturated soils: Yes_____; No_____. Depth to saturated soil:_______________.

Other indicators:____.

Wetland hydrology: Yes_____; No_____. Basis:_______________________________.

Atypical situation: Yes____; No_____.

Normal Circumstances? Yes_____ No_____.

Wetland Determination: Wetland___________________; Nonwetland_______________.

Comments:

Determined by:________________________

DATA FORM 2

VEGETATION-COMPREHENSIVE DETERMINATION

Applicant Name:__________ Application No.:__________ Project Name:__________

Location:__________ Plot #:__________ Date:__________ Determined By:__________

VEGETATION LAYER

TREES	BASAL AREA	TOTAL BASAL AREA	RANK	HERBS	MIDPOINT OF % COVER CLASS	RANK
1				1		
2				2		
3				3		
4				4		
5				5		
6				6		
7				7		
8				8		
9				9		
10				10		

SAPLINGS/SHRUBS	MIDPOINT OF HEIGHT CLASS	TOTAL HEIGHT CLASS	RANK	WOODY VINES	NUMBER OF STEMS	RANK
1				1		
2				2		
3				3		
4				4		
5				5		
6				6		
7				7		
8				8		
9				9		
10				10		

DATA FORM 3

ATYPICAL SITUATIONS

Applicant Name: ______ Application Number: ______ Project Name: ______

Location: ______ Plot Number: ______ Date: ______

A. VEGETATION:

1. Type of Alteration: ______

2. Effect on Vegetation: ______

3. Previous Vegetation: ______
(Attach documentation) ______

4. Hydrophytic Vegetation? Yes ______ No ______.

B. SOILS:

1. Type of Alteration: ______

2. Effect on Soils: ______

3. Previous Soils: ______
(Attach documentation) ______

4. Hydric Soils? Yes ______ No ______.

C. HYDROLOGY:

1. Type of Alteration: ______

2. Effect on Hydrology: ______

3. Previous Hydrology: ______
(Attach documentation) ______

4. Wetland Hydrology? Yes ______ No ______.

Characterized By: ______

DATA FORM 1

WETLAND DETERMINATION

Applicant Name: John Doe Application Number: R-85-1421 Project Name: Zena Acricultural Land

State: LA County: Choctaw Legal Description: Township: 7N Range: 2E

Date: 10/08/85 Plot No.: 1-1 Section: 32

Vegetation [list the three dominant species in each vegetation layer (5 if only 1 or 2 layers)]. Indicate species with observed morphological or known physiological adaptations with an asterisk.

Species	Indicator Status	Species	Indicator Status
Trees		Herbs	
1. *Quercus lyrata*	OBL	7. *Polygonum hydropiperoides*	OBL
2. *Carya aquatica*	OBL	8. *Boehmeria cylindrica*	FACW+
3. *Gleditsia aquatica*	OBL	9. *Brunnichia cirrhosa*	--
Saplings/shurbs		Woody vines	
4. *Forestiera acuminata*	OBL	10. *Toxicodendron radicans*	FAC
5. *Planera aquatica*	OBL	11. --	--
6. --	--	12. --	--

% of species that are OBL, FACW, and/or FAC: 100%. Other indicators: --.

Hydrophytic vegetation: Yes X No ____. Basis: 50% of dominants are OBL, FACW, and/or FAC on plant list.

Soil

Series and phase: Sharkey, frequently flooded On hydric soils list? Yes X; No ___.

Mottled: Yes X ; No ____. Mottle color: 5YR4/6 ; Matrix color: 10YR4/1 .

Gleyed: Yes ____ No X . Other indicators: ____________.

Hydric soils: Yes X No ____; Basis: On hydric soil list and matrix color .

Hydrology

Inundated: Yes ____; No X . Depth of standing water: -- .

Saturated soils: Yes X ; No ____. Depth to saturated soil: 6" .

Other indicators: Drift lines and sediment deposits present on trees .

Wetland hydrology: Yes X ; No ____. Basis: Saturated soils .

Atypical situation: Yes ____; No X .

Normal Circumstances?: Yes X No ____.

Wetland Determination: Wetland X ; Nonwetland ____________.

Comments: No rain reported from area in previous two weeks.

Determined by: Zelda Schmell (Signed)

DATA FORM 2

VEGETATION-COMPREHENSIVE DETERMINATION

Applicant Name: John Doe Application No.: R-85-1421 Project Name: Zena Agricultural Land

Location: LA (Choctaw Parish) Plot #: 1-1 Date: 10/08/85 Determined By: Zelda Schmell

VEGETATION LAYER

	TREES	BASAL AREA (in^2)	TOTAL BASAL AREA	RANK
1	*Quercus lyrata*	465	1,145	1
2	*Quercus lyrata*	680		
3	*Carya aquatica*	85	243	3
4	*Carya aquatica*	120		
5	*Carya aquatica*	38		
6	*Gleditsia aquatica*	235	253	2
7	*Gleditsia aquatica*	18		
8	*Diospyros virginiana*	46	46	
9				
10				

	HERBS	MIDPOINT OF % COVER CLASS	RANK
1	*Boehmeria cylindrica*	37.5	2
2	*Polygonum hydropiperoides*	62.5	1
3	*Brunnichia ovata*	37.5	3
4	*Gleditsia aquatica* (seedling)	2.5	
5	*Eclipta alba*	2.5	
6			
7			
8			
9			
10			

	SAPLINGS/SHRUBS	MIDPOINT OF HEIGHT CLASS	TOTAL HEIGHT CLASS	RANK
1	*Forestiera acuminata*	4.5	13.0	1
2	*Forestiera acuminata*	4.5		
3	*Forestiera acuminata*	1.5		
4	*Forestiera acuminata*	2.5		
5	*Planera aquatica*	4.5	8.0	2
6	*Planera aquatica*	3.5		
7	*Carya aquatica*	1.5	1.5	
8				
9				
10				

	WOODY VINES	NUMBER OF STEMS	RANK
1	*Toxicodendron radicans*	35	1
2	(only woody vine present)		
3			
4			
5			
6			
7			
8			
9			
10			

DATA FORM 3

ATYPICAL SITUATIONS

Applicant Name: Wetland Developers, Inc. Application Number: R-85-12 Project Name: Big Canal

Location: Joshua Co., MT Plot Number: 2 Date: 10/08/85

A. VEGETATION:

1. Type of Alteration: Vegetation totally removed or covered by placement of fill from canal (1984).
2. Effect on Vegetation: None remaining.
3. Previous Vegetation: *Carex nebrascensis* – *Juncus effusus* freshwater marsh (based on contiguous plant communities and aerial photography predating fill).
   (Attach documentation)
4. Hydrophytic Vegetation? Yes X No ____.

B. SOILS:

1. Type of Alteration: Original soil covered by 4 feet of fill material excavated from canal.
2. Effect on Soils: Original soil buried in 1984.
3. Previous Soils: Original soil examined at 10 inches below original soil surface. Soil gleyed (color notation 5Y2/0).
   (Attach documentation)
4. Hydric Soils? Yes X No ____.

C. HYDROLOGY:

1. Type of Alteration: 4 feet of fill material placed on original surface.
2. Effect on Hydrology: Area no longer is inundated.
3. Previous Hydrology: Examination of color IR photography taken on 6/5/84 showed the area to be inundated. Gaging station data from gage 2 miles upstream indicated the area has been inundated for as much as 3 months of the growing season during 8 of the past 12 years.
   (Attach documentation)
4. Wetland Hydrology? Yes X No ____.

Characterized By: Joe Zook

Appendix C
Vegetation

1. This appendix contains three sections. ~~Section 1 is a subset of the regional list of plants that occur in wetlands, but includes only those species having an indicator status of OBL, FACW, or FAC. Section 2 is a list of plants that commonly occur in wetlands of a given region. Since many geographic areas of Section 404 responsibility include portions of two or more plant list regions, users will often need more than one regional list; thus, Sections 1 and 2 will be published separately from the remainder of the manual. Users will be furnished all appropriate regional lists.~~

USER NOTES: CE-supplied plant lists are obsolete and have been superseded by the May 1988 version of the "National List of Plant Species that Occur in Wetlands" published by the U.S. Fish and Wildlife Service and available on the World Wide Web. (HQUSACE, 27 Aug 91)

2. Section 3, which is presented herein, describes morphological, physiological, and reproductive adaptations that can be observed or are known to occur in plant species that are typically adapted for life in anaerobic soil conditions.

Section 3 - Morphological, Physiological, and Reproductive Adaptations of Plant Species for Occurrence in Areas Having Anaerobic Soil Conditions

Morphological adaptations

3. Many plant species have morphological adaptations for occurrence in wetlands. These structural modifications most often provide the plant with increased buoyancy or support. In some cases (e.g., adventitious roots), the adaptation may facilitate the uptake of nutrients and/or gases (particularly oxygen). However, not all species occurring in areas having anaerobic soil condi-

tions exhibit morphological adaptations for such conditions. The following is a list of morphological adaptations that a species occurring in areas having anaerobic soil conditions may possess (a partial list of species with such adaptations is presented in Table Cl):

Table C1
Partial List of Species with Known Morphological Adaptations for Occurrence in Wetlands[1]

Species	Common Name	Adaptation
Acer negundo	Box elder	Adventitious roots
Acer rubrum	Red maple	Hypertrophied lenticels
Acer saccharinum	Silver maple	Hypertrophied lenticels; adventitious roots (juvenile plants)
Alisma spp.	Water plantain	Polymorphic leaves
Alternanthera philoxeroides	Alligatorweed	Adventitious roots; inflated, floating stems
Avicennia nitida	Black mangrove	Pneumatophores; hypertrophied lenticels
Brasenia schreberi	Watershield	Inflated, floating leaves
Caladium mariscoides	Twig rush	Inflated stems
Cyperus spp. (most species)	Flat sedge	Inflated stems and leaves
Eleocharis spp. (most species)	Spikerush	Inflated stems and leaves
Forestiera accuminata	Swamp privet	Multi-trunk, stooling
Fraxinus pennsylvanica	Green ash	Buttressed trunks; adventitious roots
Gleditsia aquatica	Water locust	Hypertrophied lenticels
Juncus spp.	Rush	Inflated stems and leaves
Limnobium spongia	Frogbit	Inflated, floating leaves
Ludwigia spp.	Waterprimrose	Adventitious roots; inflated floating stems
Menyanthes trifoliata	Buckbean	Inflated stems (rhizome)
Myrica gale	Sweetgale	Hypertrophied lenticels
Nelumbo spp.	Lotus	Floating leaves
Nuphar spp.	Cowlily	Floating leaves
Nymphaea spp.	Waterlily	Floating leaves
Nyssa aquatica	Water tupelo	Buttressed trunks; pneumatophores; adventitious roots
Nyssa ogechee	Ogechee tupelo	Buttressed trunks; multi-trunk; stooling
Nyssa sylvatica var. *biflora*	Swamp blackgum	Buttressed trunks
Platanus occidentalis	Sycamore	Adventitious roots
Populus deltoides	Cottonwood	Adventitious roots
Quercus laurifolia	Laurel oak	Shallow root system
Quercus palustris	Pin oak	Adventitious roots
Rhizophora mangle	Red mangrove	Pneumatophores
Sagittaria spp.	Arrowhead	Polymorphic leaves
Salix spp.	Willow	Hypertrophied lenticels; adventitious roots; oxygen pathway to roots
Scirpus spp.	Bulrush	Inflated stems and leaves
Spartina alterniflora	Smooth cordgrass	Oxygen pathway to roots
Taxodium distichum	Bald cypress	Buttressed trunks; pneumatophores

[1] Many other species exhibit one or more morphological adaptations for occurrence in wetlands. However, not all individuals of a species will exhibit these adaptations under field conditions, and individuals occurring in uplands characteristically may not exhibit them.

a. *Buttressed tree trunks.* Tree species (e.g., *Taxodium distichum)* may develop enlarged trunks (Figure Cl) in response to frequent inundation. This adaptation is a strong indicator of hydrophytic vegetation in non-tropical forested areas.

b. *Pneumatophores.* These modified roots may serve as respiratory organs in species subjected to frequent inundation or soil saturation. Cypress knees (Figure C2) are a classic example, but other species (e.g., *Nyssa aquatica, Rhizophora mangle)* may also develop pneumatophores.

Figure C1. Buttressed tree truck (bald cypress)

Figure C2. Pneumatophores (bald cypress)

c. *Adventitious roots.* Sometimes referred to as "water roots," adventitious roots occur on plant stems in positions where roots normally are not found. Small fibrous roots protruding from the base of trees (e.g., *Salix nigra)* or roots on stems of herbaceous plants and tree seedlings in positions immediately above the soil surface (e.g., *Ludwigia* spp.) occur in response to inundation or soil saturation (Figure C3). These usually develop during periods of sufficiently prolonged soil saturation to destroy most of the root system. *CAUTION: Not all adventitious roots develop as a result of inundation or soil saturation. For example, aerial roots on woody vines are not normally produced as a response to inundation or soil saturation.*

Figure C3. Adventitious roots

d. *Shallow root systems.* When soils are inundated or saturated for long periods during the growing season, anaerobic conditions develop in the zone of root growth. Most species with deep root systems cannot survive in such conditions. Most species capable of growth during periods when soils are oxygenated only near the surface have shallow root systems. In forested wetlands, windthrown trees (Figure C4) are often indicative of shallow root systems.

e. *Inflated leaves, stems, or roots.* Many hydrophytic species, particularly herbs (e.g., *Limnobium spongia*, *Ludwigia* spp.) have or develop spongy (aerenchymous) tissues in leaves, stems, and/or roots that provide buoyancy or support and serve as a reservoir or passageway for oxygen needed for metabolic processes. An example of inflated leaves is shown in Figure C5.

f. *Polymorphic leaves.* Some herbaceous species produce different types of leaves, depending on the water level at the time of leaf formation. For example, *Alisma* spp. produce strap-shaped leaves when totally submerged, but produce broader, floating leaves when plants are emergent. *CAUTION: Many upland species also produce polymorphic leaves.*

g. *Floating leaves.* Some species (e.g., *Nymphaea* spp.) produce leaves that are uniquely adapted for floating on a water surface (Figure C6). These leaves have stomata primarily on the upper surface and a thick waxy cuticle that restricts water penetration. The presence of species with floating leaves is strongly indicative of hydrophytic vegetation.

h. *Floating stems.* A number of species (e.g., *Alternanthera philoxeroides*) produce matted stems that have large internal air spaces when occurring in inun-

Figure C4. Wind-thrown tree with shallow root system

Figure C5. Inflated leaves

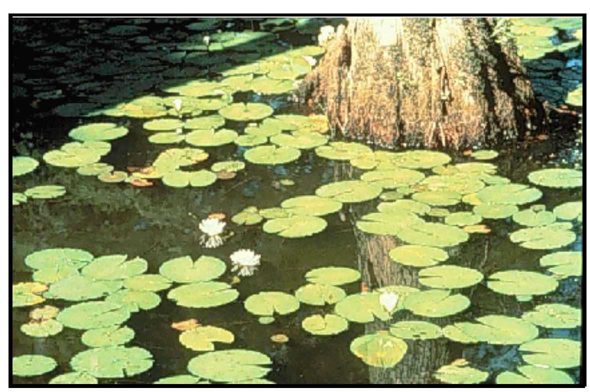


Figure C6. Floating leaves

dated areas. Such species root in shallow water and grow across the water surface into deeper areas. Species with floating stems often produce adventitious roots at leaf nodes.

i. *Hypertrophied lenticels.* Some plant species (e.g., *Gleditsia aquatica*) produce enlarged lenticels on the stem in response to prolonged inundation or soil saturation. These are thought to increase oxygen uptake through the stem during such periods.

Figure C7. Multitrunk plant

k. *Multitrunks or stooling.* Some woody hydrophytes characteristically produce several trunks of different ages (Figure C7) or produce new stems arising from the base of a senescing individual (e.g., *Forestiera acuminata, Nyssa ogechee)* in response to inundation.

l. *Oxygen pathway to roots.* Some species (e.g., *Spartina alterniflora*) have a specialized cellular arrangement that facilitates diffusion of gaseous oxygen from leaves and stems to the root system.

Physiological adaptations

4. Most, if not all, hydrophytic species are thought to possess physiological adaptations for occurrence in areas that have prolonged periods of anaerobic soil conditions. However, relatively few species have actually been proven to possess such adaptations, primarily due to the limited research that has been conducted. Nevertheless, several types of physiological adaptations known to occur in hydrophytic species are discussed below, and a list of species having one or more of these adaptations is presented in Table C2. *NOTE: Since it is impossible to detect these adaptations in the field, use of this indicator will be limited to observing the species in the field and checking the list in Table C2 to determine whether the species is known to have a physiological adaptation for occurrence in areas having anaerobic soil conditions.*

Table C2
Species Exhibiting Physiological Adaptations for Occurrence in Wetlands

Species	Physiological Adaptation
Alnus incana	Increased levels of nitrate reductase; malate accumulation
Alnus rubra	Increased levels of nitrate reductase
Baccharis viminea	Ability for root growth in low oxygen tensions
Betula pubescens	Oxidizes the rhizosphere; malate accumulation
Carex arenaria	Malate accumulation
Carex flacca	Absence of ADH activity
Carex lasiocarpa	Malate accumulation
Deschampsia cespitosa	Absence of ADH activity
Filipendula ulmaria	Absence of ADH activity
Fraxinus pennsylvanica	Oxidizes the rhizosphere
Glyceria maxima	Malate accumulation; absence of ADH activity
Juncus effusus	Ability for root growth in low oxygen tensions; absence of ADH activity
Larix laricina	Slight increases in metabolic rates; increased levels of nitrate reductase
Lobelia dortmanna	Oxidizes the rhizosphere
Lythrum salicaria	Absence of ADH activity
Molinia caerulea	Oxidizes the rhizosphere
Myrica gale	Oxidizes the rhizosphere
Nuphar lutea	Organic acid production
Nyssa aquatica	Oxidizes the rhizosphere
Nyssa sylvatica var. *biflora*	Oxidizes the rhizosphere; malate accumulation
Phalaris arundinacea	Absence of ADH activity; ability for root growth in low oxygen tensions
Phragmites australis	Malate accumulation
Pinus contorta	Slight increases in metabolic rates; increased levels of nitrate reductase
Polygonum amphibium	Absence of ADH activity
Potentilla anserina	Absence of ADH activity; ability for root growth in low oxygen tensions
Ranunculus flammula	Malate accumulation; absence of ADH activity
Salix cinerea	Malate accumulation
Salix fragilis	Oxidizes the rhizosphere
Salix lasiolepis	Ability for root growth in low oxygen tensions
Scirpus maritimus	Ability for root growth in low oxygen tensions
Senecio vulgaris	Slight increases in metabolic rates
Spartina alterniflora	Oxidizes the rhizosphere
Trifolia subterraneum	Low ADH activity
Typha angustifolia	Ability for root growth in low oxygen tensions

a. *Accumulation of malate*. Malate, a nontoxic metabolite, accumulates in roots of many hydrophytic species (e.g., *Glyceria maxima*, *Nyssa sylvatica* var. *biflora*). Nonwetland species concentrate ethanol, a toxic by-product of anaerobic respiration, when growing in anaerobic soil conditions. Under such conditions, many hydrophytic species produce high concentrations of malate and unchanged concentrations of ethanol, thereby avoiding accumulation of toxic materials. Thus, species having the ability to concentrate malate instead of ethanol in the root system under anaerobic soil conditions are adapted for life in such conditions, while species that concentrate ethanol are poorly adapted for life in anaerobic soil conditions.

b. *Increased levels of nitrate reductase.* Nitrate reductase is an enzyme involved in conversion of nitrate nitrogen to nitrite nitrogen, an intermediate step in ammonium production. Ammonium ions can accept electrons as a replacement for gaseous oxygen in some species, thereby allowing continued functioning of metabolic processes under low soil oxygen conditions. Species that produce high levels of nitrate reductase (e.g., *Larix laricina*) are adapted for life in anaerobic soil conditions.

c. *Slight increases in metabolic rates.* Anaerobic soil conditions effect short-term increases in metabolic rates in most species. However, the rate of metabolism often increases only slightly in wetland species, while metabolic rates increase significantly in nonwetland species. Species exhibiting only slight increases in metabolic rates (e.g., *Larix laricina, Senecio vulgaris)* are adapted for life in anaerobic soil conditions.

d. *Rhizosphere oxidation.* Some hydrophytic species (e.g., *Nyssa sylvatica*, *Myrica gale*) are capable of transferring gaseous oxygen from the root system into soil pores immediately surrounding the roots. This adaptation prevents root deterioration and maintains the rates of water and nutrient absorption under anaerobic soil conditions.

e. *Ability for root growth in low oxygen tensions.* Some species (e.g., *Typha angustifolia*, *Juncus effusus*) have the ability to maintain root growth under soil oxygen concentrations as low as 0.5 percent. Although prolonged (>l year) exposure to soil oxygen concentrations lower than 0.5 percent generally results in the death of most individuals, this adaptation enables some species to survive extended periods of anaerobic soil conditions.

f. *Absence of alcohol dehydrogenase (ADH) activity.* ADH is an enzyme associated with increased ethanol production. When the enzyme is not functioning, ethanol production does not increase significantly. Some hydrophytic species (e.g., *Potentilla anserina, Polygonum amphibium*) show only slight increases in ADH activity under anaerobic soil conditions. Therefore, ethanol production occurs at a slower rate in species that have low concentrations of ADH.

Reproductive adaptations

5. Some plant species have reproductive features that enable them to become established and grow in saturated soil conditions. The following have been identified in the technical literature as reproductive adaptations that occur in hydrophytic species:

a. *Prolonged seed viability.* Some plant species produce seeds that may remain viable for 20 years or more. Exposure of these seeds to atmospheric oxygen usually triggers germination. Thus, species (e.g., *Taxodium distichum)* that grow in very wet areas may produce seeds that germinate only during infrequent periods when the soil is dewatered. *NOTE: Many upland species also have prolonged seed viability, but the trigger mechanism for germination is not exposure to atmospheric oxygen.*

b. *Seed germination under low oxygen concentrations.* Seeds of some hydrophytic species germinate when submerged. This enables germination during periods of early-spring inundation, which may provide resulting seedlings a competitive advantage over species whose seeds germinate only when exposed to atmospheric oxygen.

c. *Flood-tolerant seedlings.* Seedlings of some hydrophytic species (e.g., *Fraxinus pennsylvanica)* can survive moderate periods of total or partial inundation. Seedlings of these species have a competitive advantage over seedlings of flood-intolerant species.

Appendix D
Hydric Soils

1. This appendix consists of two sections. Section 1 describes the basic procedure for digging a soil pit and examining for hydric soil indicators. ~~Section 2 is a list of hydric soils of the United States.~~

Section I - Procedures for Digging a Soil Pit and Examining for Hydric Soil Indicators

Digging a soil pit

2. Apply the following procedure: Circumscribe a 1-ft-diam area, preferably with a tile spade (sharpshooter). Extend the blade vertically downward, cut all roots to the depth of the blade, and lift the soil from the hole. This should provide approximately 16 inches of the soil profile for examination. *NOTE: Observations are usually made immediately below the A-horizon or 10 in. (whichever is shallower).* In many cases, a soil auger or probe can be used instead of a spade. If so, remove successive cores until 16 inches of the soil profile have been removed. Place successive cores in the same sequence as removed from the hole. *NOTE: An auger or probe cannot be effectively used when the soil profile is loose, rocky, or contains a large volume of water (e.g., peraquic moisture regime).*

Examining the soil

3. Examine the soil for hydric soils indicators (paragraphs 44 and/or 45 of main text (for sandy soils)). *NOTE: It may not be necessary to conduct a classical characterization (e.g., texture, structure, etc.) of the soil*. Consider the hydric soil indicators in the following sequence *(NOTE: The soil examination can be terminated when a positive hydric soil indicator is found):*

Nonsandy soils.

a. Determine whether an organic soil is present (see paragraph 44 of the main text). If so, the soil is hydric.

b. Determine whether the soil has a histic epipedon (see paragraph 44 of the main text). Record the thickness of the histic epipedon on Data Form 1.

c. Determine whether sulfidic materials are present by smelling the soil. The presence of a "rotten egg" odor is indicative of hydrogen sulfide, which forms only under extreme reducing conditions associated with prolonged inundation/soil saturation.

d. Determine whether the soil has an aquic or peraquic moisture regime (see paragraph 44 of the main text). If so, the soil is hydric.

e. Conduct a ferrous iron test. A colorimetric field test kit has been developed for this purpose. A reducing soil environment is present when the soil extract turns pink upon addition of α,α'-dipyridyl.

f. Determine the color(s) of the matrix and any mottles that may be present. Soil color is characterized by three features: hue, value, and chroma. Hue refers to the soil color in relation to red, yellow, blue, etc. Value refers to the lightness of the hue. Chroma refers to the strength of the color (or departure from a neutral of the same lightness). Soil colors are determined by use of a Munsell Color Book (Munsell Color 1975).[1] Each Munsell Color Book has color charts of different hues, ranging from 10R to 5Y. Each page of hue has color chips that show values and chromas. Values are shown in columns down the page from as low as 0 to as much as 8, and chromas are shown in rows across the page from as low as 0 to as much as 8. In writing Munsell color notations, the sequence is always hue, value, and chroma (e.g., 10YR 5/2). To determine soil color, place a small portion of soil[2] in the openings behind the color page and match the soil color to the appropriate color chip. *NOTE: Match the soil to the nearest color chip.* Record on DATA FORM 1 the hue, value, and chroma of the best matching color chip. *CAUTION: Never place soil on the face or front of the color page because this might smear the color chips.* Mineral hydric soils usually have one of the following color features immediately below the A-horizon or 10 inches (whichever is shallower):

(1) Gleyed soil.

---

[1] See references at the end of the main text.
[2] The soil must be moistened if dry at the time of examination.

Determine whether the soil is gleyed. If the matrix color best fits a color chip found on the gley page of the Munsell soil color charts, the soil is gleyed. This indicates prolonged soil saturation, and the soil is highly reduced.

(2) Nongleyed soil.

(a) Matrix chroma of 2 or less in mottled soils.[1]

(b) Matrix chroma of 1 or less in unmottled soils.[1]

(c) Gray mottles within 10 in. of the soil surface in dark (black) mineral soils (e.g., Mollisols) that do not have characteristics of (a) or (b) above.

Soils having the above color characteristics are normally saturated for significant duration during the growing season. However, hydric soils with significant coloration due to the nature of the parent material (e.g., red soils of the Red River Valley) may not exhibit chromas within the range indicated above. In such cases, this indicator cannot be used.

g. Determine whether the mapped soil series or phase is on the national list of hydric soils (Section 2). *CAUTION: It will often be necessary to compare the profile description of the soil with that of the soil series or phase indicated on the soil map to verify that the soil was correctly mapped. This is especially true when the soil survey indicates the presence of inclusions or when the soil is mapped as an association of two or more soil series.*

h. Look for iron and manganese concretions. Look for small (>0.08-in.) aggregates within 3 in. of the soil surface. These are usually black or dark brown and reflect prolonged saturation near the soil surface.

Sandy soils.

Look for one of the following indicators in sandy soils:

a. A layer of organic material above the mineral surface or high organic matter content in the surface horizon (see paragraph 45*a* of the main text). This is evidenced by a darker color of the surface layer due to organic matter interspersed among or adhering to the sand particles. This is not observed in upland soils due to associated aerobic conditions.

b. Streaking of subsurface horizons (see paragraph 45*b* of the main text). Look for dark vertical streaks in subsurface horizons. These streaks

[1] The soil must be moistened if dry at the time of examination.

represent organic matter being moved downward in the profile. When soil is rubbed between the fingers, the organic matter will leave a dark stain on the fingers.

c. Organic pans (see paragraph 45*c* of the main text). This is evidenced by a thin layer of hardened soil at a depth of 12 to 30 inches below the mineral surface.

Section 2 - Hydric Soils of the United States

4. The list of hydric soils of the United States ~~(Table D1)~~ was developed by the National Technical Committee for Hydric Soils (NTCHS), a panel consisting of representatives of the Soil Conservation Service (SCS), Fish and Wildlife Service, Environmental Protection Agency, Corps of Engineers, Auburn University, University of Maryland, and Louisiana State University. Keith Young of SCS was committee chairman.

5. The NTCHS developed the following definition of hydric soils:

~~A hydric soil is a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation (U.S. Department of Agriculture (USDA) Soil Conservation Service 1985, as amended by the NTCHS in December 1986).~~

> USER NOTES: The hydric soil definition, criteria, and hydric soil list (Table D1) published in the 1987 Corps Manual are obsolete. Current hydric soil definition, criteria, and lists are available over the World Wide Web from the U.S.D.A. Natural Resources Conservation Service (NRCS). (HQUSACE, 27 Aug 91, 6 Mar 92)

Criteria for hydric soils

6. Based on the above definition, the NTCHS developed the following criteria for hydric soils, and all soils appearing on the list will meet at least one criterion:

a. ~~All Histosols[1] except Folists;~~

b. ~~Soils in Aquic suborders, Aquic subgroups, Albolls suborder, Salorthids great group, or Pell great groups of Vertisols that are:~~

[1] Soil taxa conform to USDA-SCS (1975).

(1) ~~Somewhat poorly drained and have water table less than 0.5 ft from the surface for a significant period (usually a week or more) during the growing season, or~~

(2) ~~Poorly drained or very poorly drained and have either:~~

(a) ~~A water table at less than 1.0 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is equal to or greater than 6.0 in/hr in all layers within 20 inches; or~~

(b) ~~A water table at less than 1.5 ft from the surface for a significant period (usually a week or more) during the growing season if permeability is less than 6.0 in/hr in any layer within 20 inches; or~~

c. ~~Soils that are ponded for long duration or very long duration during part of the growing season; or~~

d. ~~Soils that are frequently flooded for long duration or very long duration during the growing season.~~

7. ~~The hydric soils list was formulated by applying the above criteria to soil properties documented in USDA-SCS (1975) and the SCS Soil Interpretation Records (SOI-5).~~

Use of the list

8. ~~The list of hydric soils of the United States (Table D1) is arranged alphabetically by soil series. Unless otherwise specified, all phases of a listed soil series are hydric. In some cases, only those phases of a soil series that are ponded, frequently flooded, or otherwise designated as wet are hydric. Such phases are denoted in Table D1 by the following symbols in parentheses after the series name:~~

~~F - flooded~~

~~FF - frequently flooded~~

~~P - ponded~~

~~W - wet~~

~~D - depressional~~

9. ~~Drained phases of some soil series retain their hydric properties even after drainage. Such phases are identified in Table D1 by the symbol "DR" in parentheses following the soil series name. In such cases, both the drained and un-~~

~~drained phases of the soil series are hydric.~~ *CAUTION: Be sure that the profile description of the mapping unit conforms to that of the sampled soil. Also, designation of a soil series or phase as hydric does not necessarily mean that the area is a wetland. An area having a hydric soil is a wetland only if positive indicators of hydrophytic vegetation and wetland hydrology are also present.*

REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1987	Final report

4. TITLE AND SUBTITLE
Corps of Engineers Wetlands Delineation Manual

5. FUNDING NUMBERS

6. AUTHOR(S)
Environmental Laboratory

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Technical Report Y-87-1

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Corps of Engineers
Washington, DC 20314-1000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This document presents approaches and methods for identifying and delineating wetlands for purposes of Section 404 of the Clean Water Act. It is designed to assist users in making wetland determinations using a multiparameter approach. Except where noted in the manual, this approach requires positive evidence of hydrophytic vegetation, hydric soils, and wetland hydrology for a determination that an area is a wetland. The multiparameter approach provides a logical, easily defensible, and technical basis for wetland determinations. Technical guidelines are presented for wetlands, deepwater aquatic habitats, and nonwetlands (uplands).

Hydrophytic vegetation, hydric soils, and wetland hydrology are also characterized, and wetland indicators of each parameter are listed.

Methods for applying the multiparameter approach are described. Separate sections are devoted to preliminary data gathering and analysis, method selection, routine determinations, comprehensive determinations, atypical situations, and problem areas. Three levels of routine determinations are described, thereby affording significant flexibility in method selection.

(Continued)

14. SUBJECT TERMS

Delineation	Methods	Vegetation
Hydrology	Plant communities	Wetlands
Manual	Soil	

15. NUMBER OF PAGES
169

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. (Concluded).

Four appendices provide supporting information. Appendix A is a glossary of technical terms used in the manual. Appendix B contains data forms for use with the various methods. Appendix C, developed by a Federal interagency panel, contains a list of all plant species known to occur in wetlands of the region. Each species has been assigned an indicator status that describes its estimated probability of occurring in wetlands of the region. Morphological, physiological, and reproductive adaptations that enable a plant species to occur in wetlands are also described, along with a listing of some species having such adaptations. Appendix D describes the procedure for examining the soil for indicators of hydric soil conditions, and includes a national list of hydric soils developed by the National Technical Committee for Hydric Soils.

Moist-Soil Management Guidelines for the U.S. Fish and Wildlife Service Southeast Region

Moist-Soil Management Guidelines

for the

U.S. Fish and Wildlife Service

Southeast Region

Prepared by:

Robert W. Strader and Pat H. Stinson

Migratory Bird Field Office
Division of Migratory Birds
Southeast Region
U.S. Fish and Wildlife Service
Jackson, MS

July 2005

These guidelines have been prepared to provide the moist-soil manager with some basic information that can be used to manage and evaluate moist-soil management units for wintering waterfowl foraging habitat. The contents are intended to improve moist-soil management on national wildlife refuges in the Southeast Region. The contents are not intended to be mandatory or to restrict the actions of any agency, organization, or individual. Literature citations and scientific names are purposefully kept to a minimum in the text. A listing of many common and scientific names of moist-soil plants is included in APPENDIX 1. References to seed sources are provided for information purposes only and do not represent an endorsement.

A note of appreciation is extended to the following individuals who reviewed and provided comments to improve this handbook: Frank Bowers, Mike Chouinard, Richard Crossett, Tom Edwards, Whit Lewis, David Linden, Don Orr, and John Stanton of the U.S. Fish and Wildlife Service; Ken Reinecke of the U.S. Geological Survey; Scott Durham of the Louisiana Department of Wildlife and Fisheries; Rick Kaminski and Jennifer Kross of Mississippi State University; Ed Penny of Ducks Unlimited; and Jimmy Grant of Wildlife Services.

TABLE OF CONTENTS

LIST OF TABLES AND FIGURE

LIST OF APPENDICES

Introduction

Moist-soil impoundments provide plant and animal foods that are a critical part of the diet of wintering and migrating waterfowl and have become a significant part of management efforts on many refuges and some private lands projects. Preferred moist-soil plants provide seeds and other plant parts (e.g., leaves, roots, and tubers) that generally have low deterioration rates after flooding and provide substantial energy and essential nutrients less available to wintering waterfowl in common agricultural grains (i.e., corn, milo, and soybeans). Moist-soil impoundments also support diverse populations of invertebrates, an important protein source for waterfowl. The plants and invertebrates available in moist-soil impoundments provide food resources necessary for wintering and migrating waterfowl to complete critical aspects of the annual cycle such as molt and reproduction.

The purpose of these guidelines is to provide the moist-soil manager on national wildlife refuges in the Southeast Region with some basic information that can be used to manage and evaluate moist-soil management units for wintering waterfowl foraging habitat. The basis for much of the information presented is from the *Waterfowl Management Handbook* [Cross, D.H. (Compiler). 1988. Waterfowl Management Handbook. Fish and Wildlife Leaflet 13. United States Department of the Interior, Fish and Wildlife Service. Washington, D.C.] and supplemented with the observations of the authors and personal experience of wetland managers working mostly in Louisiana and Mississippi. The guidelines are presented in nine sections, representing some of the most critical aspects of moist-soil management and evaluation: 1.) management objectives; 2.) moist-soil plant management; 3.) a list of plants by their relative foraging value to waterfowl; 4.) nuisance plant control; 5.) procedures for quantifying the foraging value of moist-soil units to migrating and wintering waterfowl; 6.) supplemental planting; 7.) flood schedule; 8.) integrating management for other wetland-dependent birds; and 9.) keeping records and reporting.

More detailed information on moist-soil plant management and foraging values for migrating and wintering waterfowl is presented in the *Waterfowl Management Handbook*, available on-line or as a CD available from the Publications Unit, U.S. Fish and Wildlife Service, Department of the Interior, 1849 C Street NW, MS 130 Webb Building, Washington, D.C. 202440 (FAX 703/358-2283). Several of the most pertinent articles in the *Waterfowl Management Handbook* are included in a publication titled *Wetland Management for Waterfowl Handbook* edited and compiled by Kevin Nelms in 2001 (most refuges and Migratory Bird biologists should have a copy of this handbook).

Management Objective

For moist-soil impoundments, the average foraging value varies tremendously depending on factors affecting food availability, production, and quality. Samples collected from a few selected refuge impoundments in the Lower Mississippi Valley

(LMV) from 2001 through 2004 using the sampling technique provided in APPENDIX 2 indicated moist-soil seed production ranged from 50 to almost 1,000 pounds per acre. A realistic goal should be to achieve at least 50% cover of "good" or "fair" plants as listed in APPENDIX 1 and/or produce a minimum of 400 pounds of readily available moist-soil seeds per acre in each impoundment, realizing some impoundments will be undergoing necessary or planned management treatments that will reduce waterfowl food production that year.

This moist-soil objective of 400 pounds per acre is at least partially derived from the Lower Mississippi Valley Joint Venture (LMVJV). In calculating the acreage needed to meet waterfowl foraging habitat objectives in the LMV, that Joint Venture established wintering waterfowl foraging habitat capabilities by habitat type. These capabilities are derived from the daily energy requirements of mallards (ducks) and represent the number of ducks that could obtain daily food requirements (duck use-days) from each acre of major foraging habitats, including various agricultural grains (harvested and unharvested), moist-soil habitat, and bottomland hardwoods (Table 1). In calculating the duck use-day value for moist-soil habitat, the LMVJV assumed an average of about 400 pounds per acre of native seeds were available to waterfowl.

Table 1. LMVJV waterfowl foraging capabilities by habitat type [expressed as duck use-days (DUD) per acre].[a]

Habitat type	DUD/acre
Moist-soil	1,386
Harvested crop	
Rice[b]	131
Soybean	121
Milo	849
Corn	970
Unharvested crop	
Rice	29,364
Soybean	3,246
Milo	16,269
Corn	25,669
Millet	3,292
Bottomland hardwood	
30% red oak	62
60% red oak	191
90% red oak	320

[a] From the LMVJV Evaluation Plan, page 15.

[b] From Stafford, J.D., R.M. Kaminski, K.J. Reinecke, and S.W. Manley. 2005. Waste grain for waterfowl in the Mississippi Alluvial Valley. Journal of Wildlife Management 69:in press.

Moist-Soil Plant Management

Moist-soil management is often referred to as more of an art than a science. However, through adaptive management and evaluation, moist-soil management is being science directed and, as such, positive results can be repeated. There is no easy formula for success across the southeast beyond the need to develop a **plan**; frequently **monitor** plant and wildlife responses; and **keep detailed records** of natural conditions, management actions, and plant and wildlife responses. The most important factors that determine plant responses to moist-soil manipulations are:

1.) amount of sunlight reaching the ground/plant;
2.) soil temperature;
3.) soil moisture;
4.) soil chemistry (pH, nutrients, etc.);
5.) seed bank; and
6.) successional stage of the plant community.

Sunlight. Moist-soil management involves managing early successional, herbaceous vegetation that typically requires full sunlight to maximize growth and seed production. Thus, moist-soil management should be focused in impoundments with little or no woody vegetation.

Soil temperature. Soil temperature, as it relates to the timing of the drawdown, has a great effect on the species of plants that germinate. Often the timing of the drawdown is presented in moist-soil management literature as early, mid-season, and late. These are relative terms that vary depending on location. In the *Waterfowl Management Handbook*, Chapter 13.4.6., "Strategies for Water Level Manipulations in Moist-soil Systems," Dr. Leigh Fredrickson describes early drawdowns as those that occur during the first 45 days of the growing season, late drawdowns as those that occur during the last 90 days of the growing season, leaving mid-season drawdowns as a variable length depending on the location and length of time between average first and last frosts. A description of soil temperature, moisture conditions, and expected plant response is provided in generic terms in Table 2 and are generally applicable regardless of your location.

Soil moisture. Maintaining high soil moisture (or true moist-soil conditions) throughout the growing season is key to producing large quantities of desired waterfowl food (e.g., smartweed, millet, sedge, sprangletop, etc.) on a consistent basis. A slow drawdown is an effective way to conserve soil moisture early in the growing season. In most cases, frequent, complete to partial re-flooding or flushing the impoundment throughout the growing season is desirable, followed by fall and winter shallow flooding to ensure food availability.

Table 2. A general description of soil temperature, moisture conditions, and expected plant response.

Drawdown date	Soil temperature	Rainfall	Evaporation	Expected plant response
early (first 45 days after average last frost)	cool to moderate	high	low	smartweed, chufa, spikerush, millet *(E. crusgalli)*
mid-season	moderate to warm	moderate	moderate to high	red rooted sedge, panic grass, millet *(E. colonum and walteri),* coffeebean, cocklebur
late (last 90 days before average first frost)	warm	moderate to low	high	sprangletop, crabgrass, beggarticks
shallow flood through-out growing season				duck potato, spikerush

The importance of complete water control or the ability to flood and drain impoundments as needed cannot be overstated when managing moist-soil. This is not to say that moist-soil impoundments cannot be successfully managed without complete water control, but management options are certainly increased with the ability to flood and drain when necessary, especially if each impoundment can be flooded and drained independent of all other impoundments. Stoplog water control structures that permit water level manipulations as small as 2 inches provide a level of fine tuning that facilitates control of problem vegetation or enhancement of desirable vegetation. If 6-inch and 4-inch boards are used to hold water behind stoplog structures, 2-inch boards need to be available to facilitate water level management during drawdowns.

Without the ability to re-flood or irrigate an impoundment during the growing season as needed, it has been our experience that a better plant response is achieved by keeping water control structures closed to hold winter water and additional rainfall, allowing water to slowly evaporate through the growing season. The practice of opening structures to dewater the impoundment during the spring and leaving it dry all summer generally results in poor moist-soil seed production.

Another option for impoundments with partial water control is to conduct an early drawdown and then replace boards to catch additional rainfall that may or may not occur at a rate fast enough to compensate for evaporation and transpiration later in the summer. If adequate rainfall is received, this option can result in a plant community important to waterfowl (e.g., barnyard grass and smartweed). However, if inadequate rainfall results in moist-soil seed production well below desired levels, other options (e.g., disk, plant a crop, etc.) should be considered. Remember that, as a general rule, desirable moist-soil plants can tolerate more flooding than nuisance plants such as coffeebean and cocklebur, two plant species that can dominate a site to the point of virtually eliminating more preferred species within an entire impoundment.

<u>Soil chemistry</u>. Salinity and pH have significant influences on plant response to management actions but do not receive much attention in the literature. Both are factors that must be considered where applicable. Soil tests should be conducted to assess pH and other nutrient levels and provide recommendations for lime and fertilization to address soil deficiencies. Particularly in coastal impoundments, water with moderate levels of salinity can be used as a management tool by timing the opening of structures to irrigate or flood an impoundment to control salt-intolerant plants.

<u>Seed bank</u>. In most cases, seeds of preferred moist-soil plants remain abundant in the soil, even following years of intensive agricultural activity. Where there is concern about the lack of available seed, supplemental planting (see below) could be considered until an adequate seed bank develops.

<u>Successional stage</u>. Generally, the most prolific seed producers and, therefore, the most desirable plants for waterfowl are annuals that dominate early successional seral stage. Without disturbance, plant succession proceeds within a few years to perennial plants that are generally less desirable for waterfowl food production. <u>It is necessary to set back plant succession by disking, burning, or year-round flooding every 2 to 4 years to stimulate the growth of annuals</u>. If the manager does not have the ability to re-flood following disking, the ground is usually dry, creating conditions that favor a flush of undesirable plants (e.g., coffeebean and cocklebur). In an effort to keep from having a year of low food production, it may be necessary to rotate a grain crop (e.g., rice, corn, milo, millet, etc.) by force account or cooperative farming. Another alternative would be to disk, re-flood, and dedicate that impoundment to shorebird foraging habitat during fall migration. Shorebird foraging habitat can be created by maintaining the re-flood for at least 2-3 weeks to allow invertebrate populations to respond before initiating a slow drawdown from mid-July through October (at this time of the year evaporation may cause a drawdown faster than desired, requiring some supplemental pumping to keep from losing water/moisture too fast). Deep disking (24-36 inches) is a tool that has been used to set back succession and improve soil fertility. Whenever disking is used, it is preferred to follow with a cultipacker or other implement to finish with a smooth surface. Large clumps will result in uneven soil moisture as the tops of clumps dry much faster and create conditions more conducive to less desirable species, such as coffeebean and cocklebur.

Traditionally, soil disturbance occurs in the spring followed by a grain crop or other management action(s) (e.g., re-flooding) with the objective of good waterfowl food production that same year. Some units, or at least in wet springs, remain too wet to till until early summer and can be planted to a relatively quick maturing crop such as millet. In extreme cases, tillage is completed so late that foraging habitat is essentially foregone in that year to improve production of preferred moist-soil plants or crops the following year(s).

To maintain a dominance of annual plants, managers should set up a 2 to 4-year rotational schedule for disturbing moist-soil impoundments based on site specific objectives, capabilities, control of nuisance plants, and knowledge of the area. Simple examples include:

Year 1	early season drawdown followed by disking and either 1) planting a grain crop, 2) frequent flushing of water for moist-soil plant production, or 3) shallow re-flood and hold until late summer drawdown for shorebirds;
Year 2	slow drawdown in early/mid season keeping soil moist for as long in the growing season as possible; and
Year 3	either early season drawdown or maintain shallow water throughout growing season, if monitoring indicates a less than desirable plant response, then conduct a late summer drawdown for fall migrating shorebirds, then disk (an alternative would be to have a late summer drawdown for fall migrating shorebirds, then disk).

or

Year 1	maintain 12-inch depth until July 15, then allow water to drop with evaporation and hold a shallow flood until winter or release any remaining water on September 15 to disk if needed (encourages delta duck potato);
Year 2	early drawdown by March 1 then close structure to catch rainfall or pump to flush impoundment, monitor for coffeebean and overtop to control if necessary, flood October – December (encourages wild millet);
Year 3	maintain 36-inch depth through the growing season and winter until the following July (encourages recycling of plant debris by invertebrates and provides diving duck habitat);
Year 4	maintain 36-inch depth until July1, then stagger drawdown for shorebirds, pump as necessary to maintain mudflats, re-flood November 1 (provides fall shorebird habitat).

The 4-year rotation is a simplified version of the one used at the Cox Ponds moist-soil complex on Yazoo NWR. These scenarios may be modified to find rotation(s)/practices that best meet specific management objectives. Consistently acceptable moist-soil seed production requires intensive management by managers who are perceptive, flexible, and able to adjust quickly to various situations. To achieve best results, it is critical that plans be developed, plant and animal responses monitored, and records maintained and reviewed.

Moist-Soil Plants

Hundreds of plant species would be found in moist-soil units across the southeast if complete plant inventories were conducted. Some of these plants provide good food value to waterfowl and some are of little or no value to waterfowl. A listing of some plants and relative food values for waterfowl is attached (APPENDIX 1: A Waterfowl Food Value Guide for Common Moist-Soil Plants in the Southeast). The plants on that list are given relative food values of good, fair, or none (little or no known value) as an arbitrary classification based on several plant guides and professional judgment.

Fortunately, impoundments on most refuges will be dominated by 25 or fewer species depending upon the successional stage of the plant community. Knowledge of those plants and their ecology is critical to successful moist-soil management. In meeting moist-soil objectives, the manager must be sensitive to plant species tolerance to dry or wet soil conditions, whether it can tolerate flooding, if it is an annual or perennial, its usefulness to waterfowl, etc. Species composition of a plant community is a product of past and current site conditions. The moist-soil manager must create the conditions necessary to produce and maintain the most valuable plants to waterfowl and other waterbirds.

Typically, preferred moist-soil plants are valued for the above-ground seed production. <u>Plants such as duck potato and chufa provide valuable underground tubers that present a viable alternative</u>. Promotion of these plant species can provide additional diversity to waterfowl/wetland habitats that should not be overlooked in developing and monitoring a moist-soil management program. David Linden reports that duck potato can be promoted in selected impoundments by maintaining a shallow-flooded (12 inches) condition through the growing season where tubers exist or tubers have been planted to colonize an impoundment. Once established, duck potato production typically increases for several years or until other plant species begin to dominate the site. Chufa tubers can reportedly be promoted by drying, shallow (2 inches) disking, and flushing an impoundment. Chufa tubers are commercially available and can be planted to colonize an impoundment (additional information is available in “Chufa Biology and Management,” Chapter 13.4.18. in the *Waterfowl Management Handbook*).

Undesirable Plant Control

In “Preliminary Considerations for Manipulating Vegetation” (*Waterfowl Management Handbook*, Section 13.4.9., page 2), Drs. Leigh Fredrickson and Fritz Reid stated that,

> “‘Undesirable’ plants are not simply ‘a group of plants whose seeds rarely occur in waterfowl gizzard samples.’ Rather, plants that quickly shift diverse floral systems toward monocultures, are difficult to reduce in abundance, have minimal values for wetland wildlife, or out compete plants with greater value should be considered less desirable.”

Coffeebean (a.k.a., *Sesbania*), cocklebur, and alligatorweed are three of the most prevalent undesirable species in actively managed moist-soil units in the southeast that can dominate a site to the point of virtually eliminating preferred species within an entire impoundment. Once these species germinate, they can be difficult to control.

Coffeebean, a legume, is a particularly common problem following disking, which scarifies seed otherwise lying dormant in the seed bank. Refuge Biologist David Linden (Yazoo NWR) has had good success controlling coffeebean by flooding over the top of young plants. It may take 10 days or more of flooding above the top of the coffeebeans before the apical meristem softens and the plants are killed depending on temperature. If coffeebean plants are not flooded early enough and grow ("stretch") to keep the top of the plant above the water surface, the water can be raised to kill the lateral meristems for some distance up the stem. After the impoundment is drained, the coffeebean can be mowed below the height of the surviving meristems to effectively eliminate the undesirable plants and encourage the growth of preferred plant species.

Cocklebur is a common product of late spring or early summer drawdowns (higher soil temperatures). It is a serious problem at St. Catherine Creek NWR where late spring/early summer floods from the Mississippi River do not recede from much of the refuge until June or July in some years. According to David Linden, cocklebur can be controlled using the flooding method described above for coffeebean. Eliminating cocklebur generally requires shorter flood duration than coffeebean and, even if the plant is not overtopped, growth can be arrested by flooding and allowing more moisture-tolerant plants to gain competitive advantage and mature.

Dr. Rick Kaminski reports that he will reverse steps in this control technique by first mowing and then flooding over the clipped stubble to kill coffeebean and other undesirable vegetation. Under either scenario, it is important to inspect the flooded undesirable plants and drain the water soon after they are killed. If the water is held too long after the undesirable plants are killed, the manager runs the risk of killing desirable plants in the impoundment, which then requires disking and flushing to stimulate germination of more seeds for a moist-soil crop or managing the area as a mudflat for shorebirds.

Alligatorweed is a common undesirable plant in some areas. Information collected by Migratory Bird Biologist Don Orr (retired), indicates that, in the more southerly portions of the region, alligator flea beetles are an effective control mechanism. (A source for beetles is Charlie Ashton, U.S. Army Corps of Engineers, Jacksonville, FL, phone: 904.232.2219.) Where alternate methods are needed, the best control method is to spray with glyphosate (other herbicides such as 2,4-D may also be effective) at the recommended rate. Two applications may be needed the first year and spot application to control residual plants thereafter. After spraying, the area can be disked and planted to a crop to achieve some food production. As an alternative, biologists at Cameron Prairie NWR in southwest Louisiana have had some success in controlling alligatorweed by drying infested fields and disking or, if conditions require, water buffaloing (a.k.a., roller chopping) shallow-flooded fields, then draining. Note that, in southwest Louisiana, the water table remains high and fields rarely dry to the extent they do in non-coastal areas of the southeast.

"Tools" available to set back the plant community successional stage or to control problem vegetation include: maintaining moist soil conditions with irrigation throughout the summer, flooding/re-flooding, disking, water buffaloing, mowing, continuous flood, and spraying approved herbicides (APPENDIX 3). Disking can be highly effective tool for setting back plant succession and controlling woody plants (e.g., black willow and common buttonbush) but can stimulate coffeebean as well as be the vector for the spread of other undesirable plants. Mowing is an effective management tool, particularly for controlling dicots (e.g., coffeebean and cocklebur) and promoting monocots (e.g., millets and sedges) in fields dominated by early successional species. Herbicides are often the easiest and most effective method to control undesirable plant response. The manager should select the appropriate "tool" based on the objective, local effectiveness, and available resources.

Sampling Techniques

Plant species composition in moist-soil units should be monitored throughout the growing season. Cursory samples should be conducted at least weekly early in the growing season to detect undesirable plant response that can be addressed in favor of more desirable species. Later in the growing season, it is important to conduct quantitative samples of vegetation to determine if management objectives (e.g., 400 pounds of seed per acre) are being met, monitor plant response (spring, summer, and fall) to management actions, identify plant species composition, monitor vegetation trends, complete habitat evaluations for the current year, and develop habitat plans for the following year, etc. It is critical that management actions and plant response be recorded and archived in a format that others can understand so the successes can be replicated and failures avoided, data can be analyzed to establish long-term trends, and good, efficient management can be maintained following personnel changes.

A sampling strategy must be developed to gather the data needed within the available time. The following plant sampling recommendations are made for the purposes stated above. If more detailed information is needed, additional time will be required to collect the data. In some cases, other sampling methods may more efficiently/effectively meet stated objectives.
Seed estimator. One useful tool that can be used to quantify seed production is discussed in the *Waterfowl Management Handbook*, Chapter 13.4.5., entitled "A Technique for Estimating Seed Production of Common Moist-Soil Plants" (APPENDIX 2). That technique involves the collection of data from plants that occur in a 25 cm x 25 cm sample frame and use of regression analyses to calculate pounds per acre of seed produced by individual species and cumulatively across species for

the moist-soil unit. The software and other information needed to use the seed production estimator can be downloaded from the web address (or search for "seed estimation software"): *http://www.fort.usgs.gov/products/software/seedyld/seedyld.asp.* This is a fairly simple program and data can be collected fairly quickly once the biologist gets familiar with the data needs. Drawbacks of this method is that regression formulas are only available for 11 plant species that are among the most common in moist-soil units and only for plants that produce seeds. Several users of this software have gotten unreasonably high seed estimates for red-rooted sedge (*Cyperus erythrorhizos*), bringing to question the reliability of the software for this species. Herbaceous plant parts, roots, and tubers are not considered in this methodology. A sample data sheet is attached to this guide (APPENDIX 4).

Plant densities. Visual estimates of the percent cover of the 5 or 6 most common species at each sample site in management units usually provide an adequate index of herbaceous plant composition for most moist-soil management needs. This information is most easily collected by estimating percent cover on a 0 to 100 percent scale within relatively small plots (e.g., 1-meter square or circular plots). Remember that dense herbaceous plant cover can be layered such that percent cover estimates could frequently exceed 100 percent. An alternative would be to estimate plant cover, by species, into classes, such as 0-5%, 6-25%, 26-50%, 51-75%, and >76%. Samples can be totaled and averaged by species. The line-intercept method (measured length of the line that each plant shades or touches) for determining plant cover of a unit can be used but data collection typically requires much more time.

Sampling schemes. It is preferred that two vegetation samples be collected each year. A sample should be taken one-third to nearly half way into the growing season to capture any early germinating species (e.g., spikerush) that could be gone and missed by a later, once-a-season vegetation sample. Another advantage of an early sample would be to allow time to plan and implement major management actions, such as herbicide treatments or disking and planting millet, to address developing problems and meet desired moist-soil production objectives.

A more comprehensive sampling and perhaps more critical sample effort should be done at least once, about two-thirds to three-fourths into the growing season. It is recommended that the sampling be conducted as described in "A Technique for Estimating Seed Production of Common Moist-Soil Plants" (APPENDIX 2) for estimating seed production and/or percent cover. It is recommended that, as a general rule, one sample be taken for every 2 acres in a moist-soil unit. Collecting 20 or 30 samples from across the entire moist-soil unit should account for variation and be adequate for most moist-soil work. Sample variability can be greatly reduced by conducting samples within homogeneous plant communities such that, if a moist-soil unit contains several distinguishable plant communities or zones, sampling should be conducted within each zone and analyzed independently. If time does not allow for sampling at this level of detail, the number of samples in each zone should be representative of its cover extent within the unit. For example, if a 10-acre moist-soil unit has two recognizable plant zones one dominated by millet (4 acres) and a second dominated by cocklebur (6 acres), a sample design should be established to get 2 samples from the millet zone and 3 from the cocklebur zone. Properly done, a random-systematic sample design, where the first sample is randomly placed and subsequent samples are equally spaced across a sample area, should accomplish the sampling needs. If the unit is digitized in ArcView or updated program, random or random-systematic points can be easily generated. Care should be taken to not follow and sample along treatments such as disked paths. If this is a potential problem, sample points can be randomly generated in the office using ArcView and located in the field using a GPS. Further assistance can be obtained from Migratory Bird Field Offices.

Vegetation sampling is important but can get time consuming. The number of samples is almost always a compromise between sample validity (representing what is actually there) and time and money constraints. Those conducting the field work usually have a good feel if the results accurately represent what is in the moist-soil unit. If time prevents sampling as described above, it is always better to collect and archive data at 5 to 10 properly spaced plots than not to collect data at all.

Management implications. Sample results should be used to determine if moist-soil objectives are being met and to help determine which, if any, management actions are necessary. It is recommended that seed production be at least 400 pounds per acre and/or “good” and “fair” plants (APPENDIX 1) comprise at least 50 percent of the cover estimate for the unit. If these objectives are not being met, then some alternative management action needs to be implemented. For example, suppose seed production (or percent cover of good plants) has been declining in a unit from 900 pounds of seed per acre 2 years ago to only 350 pounds per acre this year. Or, the percent cover of “good” and “fair” plants has similarly dropped from 85 percent to 40 percent with an increasing amount of perennials dominating the site, it is likely that the timing of drawdown and some mechanical disturbance (e.g., disking) needs to be scheduled for the following growing season. If the unit is really poor (seed production had fallen to 75 pounds per acre and only 20 percent cover of “good” or “fair” plants), consideration should be given to immediate mechanical disturbance followed by planting a grain crop or re-flooding and late summer drawdown for shorebirds. Either action would increase management options and productivity the following year.

Supplemental Planting

Rice, milo, corn, and millet are high-energy foods and the top choices as grain crops for ducks. It is important to select varieties and planting methods that will encourage quick germination and successful competition with the native plants. Most grain crops will produce much more acceptable results if nitrogen is added. Extension agents and agricultural experiment stations are good sources of information for varieties of grains and fertilization rates that will produce the best results in your area.

Rice is susceptible to depredation, sprouting, and rots following wet, warm fall conditions but is particularly resistant to decomposition once flooded in winter. Cypress and Lamont are two rice varieties that germinate quickly. Soaking rice seed prior to planting will encourage rapid germination, and keeping the soil shallowly flooded (0.1 to 8 inches of water) or at least very moist will facilitate growth and survival. Failure to maintain these moisture conditions after germination and 4-6 inches of growth will result in poor rice production. With some flooding, the addition of about 60 pounds of nitrogen fertilizer per acre and minimal broadleaf weed control, refuge grown rice on Morgan Brake NWR produced an average of about 1,500 pounds of seed per acre in addition to a good crop of moist-soil plants including sprangletop, millet, spikerush, and toothcup. Food production far exceeded the 400-pound per acre target for moist-soil plants.

Milo and corn are more suited to dry fields and can generally be kept above the water surface after fall/winter flooding. Depredation can be a problem and seeds degrade rapidly once the kernels are flooded. Short varieties of milo (~2 ft in height) are recommended so water levels can be managed to facilitate waterfowl gleaning grain from standing milo stalks. Large dabbling ducks, such as mallard and northern pintail, can readily obtain seeds from standing milo plants. Midges can be a major problem with milo and should be controlled if possible. Corn with an understory of barnyard grass and various other grasses can provide quality waterfowl foraging habitat. This is a fairly common crop planted or left for waterfowl in Tennessee and Missouri and is gaining popularity on private lands in the Mississippi Delta.

Soybeans are generally considered a poor choice of waterfowl foods because they degrade rapidly after flooding and, like some other legumes, contain digestive inhibitors that reduce the availability of protein and other nutrients. Waterfowl will eat soybeans and derive about the same energy from beans as red oaks [R.M. Kaminski, J.B. Davis, H.W. Essig, P.D. Gerard, and R.J. Reinecke. 2003. True metabolizable energy for wood ducks from acorns compared to other waterfowl foods. Journal of Wildlife Management 67(3):542-550].

Millet is another commonly planted grain because it only takes about 60 days to mature, is adapted to perform well in conditions common in moist-soil units, and is highly desired by waterfowl. The short growing season make it a preferred crop following a mid-summer treatment (e.g., disking or drawdown) when it is unlikely that desirable moist-soil plants will dominate a site and mature. Browntop millet is recommended on slightly drier sites; Japanese millet is preferred on more moist sites. Barnyard grass is a wild millet present in most fields or impoundments and is commercially available (Azlin Seed, Leland, MS, 662.686.4507). This wild millet prefers moist to shallowly flooded conditions similar to rice or moist-soil plants discussed above. Improved varieties of barnyard grass are reportedly being developed.

If millets mature too early, they frequently shatter, germinate following early fall rains, and are virtually unavailable to wintering waterfowl. David Linden reports that on Yazoo NWR in central Mississippi a slow, mid-August drawdown will produce a wild millet crop with little competition from nuisance plants due to the shortened growing season. Once flooded, seeds of at least some species of millets deteriorate rapidly. The Natural Resources Conservation Service has reportedly developed Chiwapa millet. It is similar to Japanese millet but has a 120-day maturation period. Hence, it can be planted in mid-summer, and it will mature and not resprout as much as Japanese millet. A commercial source is Specialty Seed, Inc. (662.836.5740).

Flood Schedule

Migrating and wintering waterfowl are frequently found in the Southeast Region from August until May; however, September through early April is when key concentrations are most likely to occur. It is our responsibility to provide waterfowl habitat throughout that period and to match the amount of water and foraging habitat with the needs of waterfowl as dictated by migration chronology, local population levels, and physiological needs. It should also be kept in mind that the <u>preferred water depth for foraging ranges from ½ to 12 inches</u>. Food resources covered by more than 18 inches of water are out of the reach of dabbling ducks. These factors should be used to modify local flood schedules depending on the location of the moist-soil units.

In central Mississippi and much of the LMV, blue-winged teal begin arriving in August followed by several other early migrants. It is not until November or December when large numbers of ducks begin to accumulate, reaching peak numbers from mid-December through mid- to late January. Numbers remain high until early to mid-February when duck numbers steadily decrease until mid-March leaving relatively low numbers of late migrants. Blue-winged teal might linger until May.

Under this central Mississippi scenario (Table 3 and Figure 1), managers should flood about 5-10% of the impoundments by mid-August and hold until early November, increasing to 15-25% of the impoundments that should be flooded by late November. By mid-December, 50-75% of the impoundments should be flooded as waterfowl begin to accumulate in the area. Additional areas should continue to be flooded until mid- to late January when 100% of the area should be flooded. By mid-January, a slow drawdown should begin in those impoundments flooded earliest and/or scheduled for early drawdown to concentrate invertebrates for ducks that are beginning to increase lipid and protein reserves. The drawdown should continue such that only 80% of the impoundments are flooded by the end of January and only 20% are flooded in mid-March.

Typically, there is enough natural flood water available on and off of refuges for waterfowl after the hunting season and through the spring to meet those late migration needs so the emphasis from this point forward should be on managing water levels in moist-soil impoundments for seed production the following year. No more than 10% of the impoundments should be purposefully flooded for waterfowl after April 15 unless it is a management strategy (e.g., mid- to late season drawdown) to either improve seed production for the following year or integrate habitat conditions for other wetland-dependent birds (e.g., shorebirds, wading birds, and secretive marsh birds). It is imperative that managers be familiar with the topography in impoundments so that optimal water depths can be factored into the recommendations expressed in Table 3 as percent of area flooded. (Note: As stated previously, impoundments that cannot readily be re-flooded or irrigated may have a better plant response by keeping water-control structures closed in spring and summer to allow water to slowly evaporate through the growing season.)

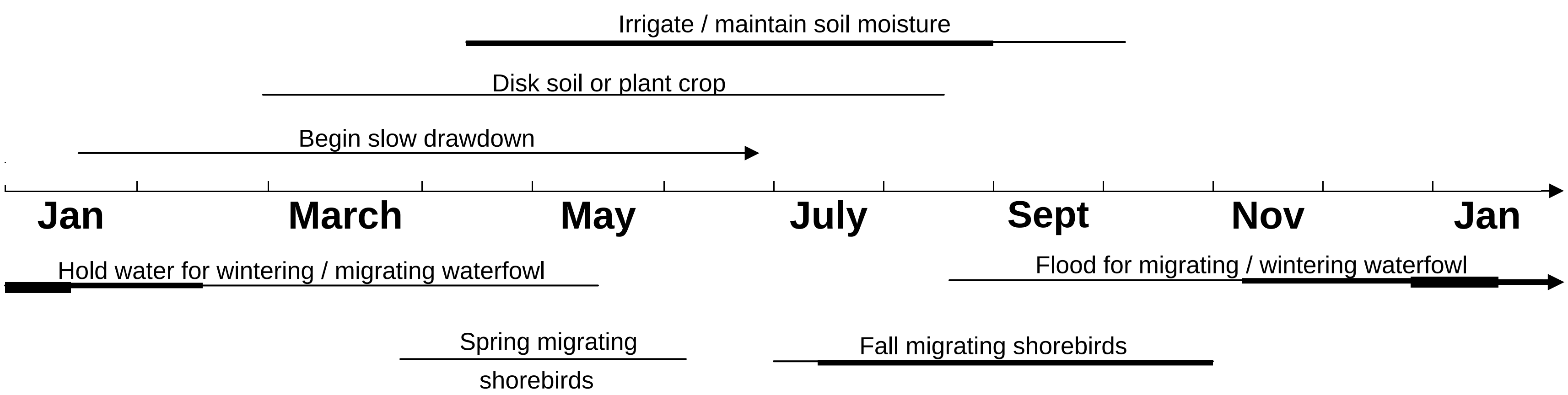
Table 3. Suggested flood schedule to provide migrating and wintering waterfowl foraging habitat at the latitude of central Mississippi. The timing of water management may change depending on latitude, objectives, and target bird species.

Date	Area flooded (%) and comments
Mid-August until early November	5-10%; maintain flood
Early November - late November	15-25%; increase flood to support arriving ducks
Late November - mid-December	50-75%; increase flood to support arriving ducks
Mid-December - late January	80-100%; slow drawdown on some impoundments after January 15
Early February – mid-March	20-80%*; decrease flood to concentrate invertebrates
After mid-March	Water management should focus on food production for the following year and spring and fall shorebird migration.

* After early to mid-February, it may be more important to adjust flood schedules in preparation for moist-soil production in subsequent years. This management decision should be based on the availability of alternate, post hunting season habitat in the general vicinity and location relative to migration chronology. Refuges farther north in the flyway may want to delay late season management actions (e.g., drawdowns) until March or April.

15

Figure 1. Conceptual timeline for moist-soil management actions for the latitude of central Mississippi. The timing of water management changes depending on latitude, objectives, and target species.



Integrating Management for other Wetland-Dependent Birds

Sites with wetland complexes comprised of a number of impoundments having independent water management capabilities provide the manager the luxury of implementing strategies that accommodate a variety of vegetation, water regimes, and waterbird guilds in the same year. Often slight variations in management actions can provide significant benefits to other wetland-dependent birds. Shorebirds migrate through the Southeast Region in the spring from March through May and in the fall from July through October. During migration they are seeking mudflat to shallowly flooded (<4" deep) areas varying in size from small pools for foraging to larger sites providing a minimum of 40-100 acres of suitable habitat for foraging and roosting. Vegetation must be absent or very sparse. Matching drawdowns on moist-soil impoundments to coincide with migration can provide habitat for impressive numbers of shorebirds. Shorebird habitat is generally considered to be much more limiting during fall migration and, therefore, higher priority than spring habitat in the LMV.

Moist-soil management can produce abundant crops of crawfish and other invertebrates, herps, and can trap small fish following flood events. Slow drawdowns are typically best for moist-soil management and tend to concentrate food for wading birds for an extended period of time. Standing water under wading bird rookeries is critical to limiting predation and enhancing nest success. Draining impoundments while wading birds are actively nesting is strongly discouraged, regardless of other management needs.

Secretive marsh birds (e.g., rails, gallinules, etc.) seek permanently flooded marsh habitats that are typically dominated by tall emergent vegetation (e.g., rushes and cattail). These plant communities generally represent the next seral stage succeeding desired moist-soil habitat conditions (annual plants). Where space or management opportunities/limitations allow, consideration should be given to managing some units for tall emergent vegetation, which also provides preferred habitat for numerous species of amphibians and reptiles, and wood duck broods. Rails require areas within marsh habitats that naturally dry during the summer for brood foraging. The drying marsh often produces desirable moist-soil plants.

Records/Reporting

It is important that records for each impoundment be kept through the year and include management objective, management actions, natural events/conditions (e.g., rainfall), water level, plant responses, plant composition (% cover) and seed production (weight), and wildlife responses. At the end of the season a **brief** narrative should be written summarizing these variables, responses, and recommended management actions. Include alternatives that might improve management of each unit in the future. If possible, a photographic record should also be maintained. All of this information can be mainta ined in a digital format and included in annual habitat management plans. This could be the most valuable source of information a new manager/biologist will have to continue management of moist-soil units as personnel changes occur.

The LMVJV is in the process of developing a database link on their web site (LMVJV.org) for estimating seed production and calculating percent cover by wetland unit. The user will be able to also use that database for archiving management actions.

Conclusions

Moist-soil impoundments are a critical part of waterfowl management on refuges and have an established goal to produce at least 400 pounds of available seed per acre. Because moist-soil management is different in every location, it is not possible to produce a step-by-step listing of what the manager/biologist should do to maximize production on each moist-soil unit. However, it is critical that a plan be developed, plant and animal responses monitored, and records kept in a form usable by whoever is managing the unit, current staff as well as those that might be assuming those duties in the future. Intensive water management, regular soil disturbance, monitoring moist-soil plant responses and associated waterfowl use, controlling nuisance plants, and archiving of data are the keys to successful, consistent moist-soil seed production and waterfowl use of the impoundments. With a scientific approach and adaptive management, moist soil objectives can be consistently met or exceeded. In addition, knowledge and awareness of the habitat needs of other species often allows the moist-soil manager an opportunity to exercise management options that benefit other species groups while minimally affecting moist-soil seed production.

APPENDIX 1: A Waterfowl Food Value Guide for Common Moist-Soil Plants in the Southeast

A Waterfowl Food Value Guide for Common Moist-Soil Plants in the Southeast

Scientific Name	Common Name	Food Value
Acer spp.	maple[1]	Good (wood ducks)
Agrostis spp.	bent grasses	Fair
Alisma subcordatum	water plantain	Fair
Alopecurus carolinianus	foxtail	Fair
Alternanthera philoxeroides	alligatorweed	None
Amaranthus spp.	pigweed	Fair
Ambrosia artemisiifolia	common ragweed	Fair
Ammania latifolia	ammania	Fair
Ammannia coccinea	toothcup	Fair
Amorpha fruticosa	indigo bush	None
Andropogon virginicus	broomsedge	None
Apocynum cannabinum	indian hemp	
Arundiraria gigantea	cane, switch	None
Asclepiadacea currassavica	milkweed, scarlet	None
Asclepias spp.	milkweed	None
Aster spp.	aster, fall	None
Aster spp.	aster	None
Baccharis halimifolia	baccharis	None
Bacopa spp.	water hyssop, bacopa	Good
Bidens cernua	beggar ticks	Good
Bidens laevis	bur marigold	Good
Bidens spp.	beggar ticks	Good
Brasenia shreberii	watershield	Fair
Brunnichia cirrhosa	redvine	None
Calamagrostis cinnoides	reed grass	Good
Campsis radicans	trumpet creeper	None
Cardiospermum halicacabum	balloon-vine	None
Carex spp.	sedge	Good
Centella asiatica	centella	Fair
Cephalanthus occidentalis	buttonbush[1,3]	Fair
Ceratophyllum demersum	coontail	Fair
Chara spp.	muskgrass	Good
Chenopodium album	goosefoot	Good
Clethora alnifolia	sweet pepperbush	Fair
Cyperus erythrorhizos	flatsedge, redroot	Good
Cyperus esculentus	sedge, yellow nut	Good
Cyperus iria	rice flatsedge	Good
Cyperus spp.	flatsedge[3]	Good

Scientific Name	Common Name	Food Value
Decodon verticillatus	water loosestrife	None
Digitaria spp.	crabgrass	Good
Diodia virginiana	buttonweed	Fair
Distichlis spicata	saltgrass	Fair
Echinochloa colonum	jungle rice	Good
Echinochloa crusgalli	barnyardgrass	Good
Echinochloa spp.	millet	Good
Echinochloa walteri	millet, walter's	Good
Echinodorus cordifolius	burhead	None
Eclipta alba	eclipta	None
Elatine spp.	waterwort	Fair
Eleocharis obtusa	spikerush, blunt	Good
Eleocharis palustris	spikerush,common	Fair
Eleocharis parvula	spikerush, dwarf	Good
Eleocharis quadrangulata	foursquare	Good
Eleocharis spp.	spikerush	Good
Eleocharis tenuis	spikerush, slender	Fair
Elodea spp.	waterweed	Fair
Eragrostis spp.	love grass	Good
Erianthus giganteus	beardgrass, wooly	None
Erianthus giganteus	grass, plume	None
Erigeron belliadastrum	fleabane daisy	
Erigeron spp.	horseweed	None
Eupatorium capillifolium	dog fennel	None
Eupatorium serotinum	boneset	None
Fimbristylis spadicea	fimbristylis	Fair
Fraxinus spp.	ash[1]	Fair
Fuirena squarrosa	umbrella-grass	Fair
Gerardia spp.	gerardia	None
Helenium spp.	sneezeweed	None
Heteranthera limosa	mudplantain	None
Hibiscus moscheutos	marsh mallow	None
Hibiscus spp.	rose mallow	None
Hydrochloa spp.	watergrass	Fair
Hydrocotyle umbellata	pennywort, marsh	Fair
Hydrolea ovata	hydrolea	None
Hypericum spp.	st. johns wort	None
Ipomoea purpurea	morning glory	None
Ipomoea spp.	morning glory	None
Iva annua	sumpweed	None
Iva frutescens	marsh elder	None
Juncus effusus	rush, soft	None

Scientific Name	Common Name	Food Value
Juncus repens	rush, creeping	Fair
Juncus roemerianus	needlerush, black	None
Juncus spp.	rushes	Fair
Lachnanthes caroliniana	redroot	Good
Leersia oryzoides	rice cutgrass	Good
Lemna spp.	duckweed	Good
Leptochloa filiformis	sprangletop	Good
Leptochloa spp.	sprangletop	Good
Lippia lanceolata	frog fruit	None
Ludwigia spp.	seedbox	Fair
Ludwigia spp.	water primrose[2]	Fair
Lysimachia terrestris	loosestrife, swamp	None
Lythrum salicaria	loosestrife, purple[2]	PEST
Melilotus alba	white sweet clover	None
Mikania scandens	hempweed, climbing	None
Myriophyllum spp.	milfoil, water	Fair
Najas guadalupensis	naiad, southern	Good
Najas spp.	naiads	Good
Nelumbo lutea	american lotus	None
Nitella spp.	nitella	Fair
Nuphar luteum	yellow cow-lily	Fair
Nymphaea mexicana	banana water lily	Good
Nymphaea odorata (or tuberosa)	white waterlily	Fair
Obolaria virginica	pennywort	Fair
Oryza sativa	red rice	Good
Panicum dichotomiflorum	fall panicum	Good
Panicum spp.	grasses, panic	Fair to Good
Paspalum disticum	knotgrass	Fair
Paspalum spp.	paspalum	Fair
Paspalum urvillei	vasey grass	None
Peltandra virginica	arrow arum	Fair
Phalaris arundinacea	reed canary grass	
Phragmites communis	common reed	PEST
Plantago lanceolata	english plantain	None
Pluchea camphorata	camphorweed	None
Pluchea pupurascens	fleabane, saltmarsh	None
Polygonum coccineum	water smartweed	Fair
Polygonum hydropiperoides	water pepper	Fair
Polygonum hydropiper	water pepper	Fair
Polygonum lapathifolium	ladysthumb smartweed	Good
Polygonum pensylvanicum	penns. smartweed	Good
Polygonum spp.	smartweed	Fair/Good

Scientific Name	**Common Name**	**Food Value**
Polypogon monspeliensis	rabbits-foot grass	Fair
Pontederia cordata	pickerelweed	Fair
Populus spp.	cottonwood	None
Potamogeton pectinatus	pondweed, sago	Good
Potamogeton perfoliatus	redhead grass	Good
Potamogeton spp.	pondweed	Good
Proserpinaca palustris	mermaidweed	Fair
Quercus spp.	oak[1]	None
Ranunculus spp.	buttercup	Fair
Rhynchospora spp.	rush, beaked	Fair
Rotala ramosior	rotala	Fair
Rubus spp.	blackberry	None
Rumex spp.	dock, swamp	Fair
Ruppia maritima	widgeon grass	Good
Sabatia stellaris	marsh pink	None
Sacciolepis striata	gibbons panicgrass	Good
Sagittaria graminea	grassy arrowhead	Good
Sagittaria lancifolia	bulltongue	Fair
Sagittaria latifolia	arrowhead, duck potato	Fair/Good
Sagittaria longiloba	narrow leaf arrowhead	None
Sagittaria montevidensis	giant arrowhead	Good
Sagittaria platyphylla	delta duck potato	Good
Sagittaria spp.	arrowhead	Fair
Salicornia spp.	glasswort	Fair
Salix spp.	willow[1]	None
Saururus cernuus	lizard's tail	None
Scirpus americanus	bulrush, american (olneyi-three	Good
Scirpus confervoides	bulrush, algal	Fair
Scirpus cyperinus	woolgrass	None
Scirpus pungens	sword-grass	Fair
Scirpus robustus	bulrush, saltmarsh	Good
Scirpus spp.	bulrush	Fair
Scirpus spp.	bulrush, slender	None
Scirpus validus	bulrush, softstem[4]	Fair
Sesbania exaltata	sesbania[2]	Fair
Sesbania macrocarpa	sesbania[2]	None
Sesbania spp.	sesbania	None
Setaria spp.	foxtail	Good
Sida spinosa	prickly mallow (ironweed)	None
Solanum spp.	nightshade	None
Solidago spp.	goldenrod	None
Sonchus spp.	sowthistle	

Scientific Name	Common Name	Food Value
Sorghum halepense	johnson grass	
Sorghum vulgare	milo	Good
Sparganium spp.	burreed	Fair
Spartina cynosuroides	big cordgrass	None
Spartina patens	grass, cord (saltmeadow hay)	Fair
Sphenoclea zeylanica	goose weed	None
Spirodella spp.	duckweed, great	Good
Sporobolus spp.	dropseed	Fair
Triglochin striata	arrowgrass	Good
Tripsacum dactyloides	grass, gamma	None
Typha angustifolia	narrow-leaf cattail	None
Typha spp.	cattail	None
Utricularia spp.	bladderwort[5]	Fair
Vallisneria americana	wild celery	Good
Wolffia spp.	water meal	Good
Woodwardia aredata	fern, netted chain	None
Xanthium spp.	cocklebur[2]	None
Xanthium strumarium	cocklebur[2]	None
Xyris spp.	yellow-eyed grass	Fair
Zizania aquatica	southern giant rice	Fair
Zizania aquatica	wild rice, northern	Good
Zizaniopsis miliacea	wild rice, southern, giant cut-	Good

1. Woody plants typically undesirable in moist-soil units.
2. Can be undesirable.
3. When in abundant stands.
4. Tubers only.
5. With invertebrates present.

This guide was originally prepared by the Biologists' Group of the Roanoke-Tar-Neuse-Cape Fear Ecosystem of the U.S. Fish and Wildlife Service in September 2000. It was developed to assist them in standardizing waterfowl food values rankings for freshwater marsh/swamp vegetation. The original area the guide covered is northeastern North Carolina and southeastern Virginia. Several of the National Wildlife Refuges in this area complete annual vegetation transects in moist-soil impoundments and summarize these data to monitor vegetation response to various management actions. The ranking classifications were chosen arbitrarily as None, Fair, and Good. In an attempt to broaden the scope of the RTNCF Ecosystem efforts to the entire southeast, particularly the MAV, the Jackson Migratory Bird Field Office, with comments from biologists from the MAV, added numerous species and rankings to their list. Various published plants guides were consulted and professional judgment was used to assign the rankings. **This guide is considered a**

working guide and as new information becomes available, will be updated and redistributed. Please send comments and additions to Bob Strader, Migratory Bird Field Office, Jackson, MS 39213, 601-965-4903 x12 or e-mail: bob_strader@fws.gov.

REFERENCES CONSULTED

Beal, Ernest O., Feb.1977, A Manual of Marsh and Aquatic Plants of North Carolina with Habitat Data. North Carolina Agricultural Research Service, Raleigh, NC, Tech. Bulletin No. 247. 298pp.

Hotchkiss, N. 1972. Common marsh, underwater and floating-leaved plants of the United States and Canada. Dover Publications, New York, 124pp.

Martin, A. C. and F. M. Uhler. 1939. Food of game ducks in the United States and Canada. U.S. Dept. of Agriculture, Tech. Bulletin No. 634, 157pp.

Moist Soil Management Advisor, Windows Version 1.11. U.S. Geological Survey and Gaylord Memorial Lab.

Radford, A. E., H.E. Ahles, and C. R. Bell. 1968. Manual of the Vascular Flora of the Carolinas. The University of North Carolina Press, Chapel Hill. 1183pp.

Stutzenbaker, Charles D. 1999. Aquatic and Wetland Plants of the Western Gulf Coast. Texas Parks and Wildlife Press. 465pp.

U.S. ARMY CORPS OF ENGINEERS. Feb.1, 1977. Wetlands Plants of the Eastern United States - NADP 200-1-1, () - North Atlantic Division, 90 Church St., N.Y.

APPENDIX 2: A Technique for Estimating Seed Production of Common Moist-Soil Plants

13.4.5. A Technique for Estimating Seed Production of Common Moist-soil Plants

Murray Laubhan
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri—Columbia
Puxico, MO 63960

Seeds of native herbaceous vegetation adapted to germination in hydric soils (i.e., moist-soil plants) provide waterfowl with nutritional resources including essential amino acids, vitamins, and minerals that occur only in small amounts or are absent in other foods. These elements are essential for waterfowl to successfully complete aspects of the annual cycle such as molt and reproduction. Moist-soil vegetation also has the advantages of consistent production of foods across years with varying water availability, low management costs, high tolerance to diverse environmental conditions, and low deterioration rates of seeds after flooding.

The amount of seed produced differs among plant species and varies annually depending on environmental conditions and management practices. Further, many moist-soil impoundments contain diverse vegetation, and seed production by a particular plant species usually is not uniform across an entire unit. Consequently, estimating total seed production within an impoundment is extremely difficult.

The chemical composition of seeds also varies among plant species. For example, beggartick seeds contain high amounts of protein but only an intermediate amount of minerals. In contrast, barnyardgrass is a good source of minerals but is low in protein. Because of these differences, it is necessary to know the amount of seed produced by each plant species if the nutritional resources provided in an impoundment are to be estimated.

The following technique for estimating seed production takes into account the variation resulting from different environmental conditions and management practices as well as differences in the amount of seed produced by various plant species. The technique was developed to provide resource managers with the ability to make quick and reliable estimates of seed production. Although on-site information must be collected, the amount of field time required is small (i.e., about 1 min per sample); sampling normally is accomplished on an area within a few days. Estimates of seed production derived with this technique are used, in combination with other available information, to determine the potential number of waterfowl use-days available and to evaluate the effects of various management strategies on a particular site.

Technique for Estimating Seed Production

To estimate seed production reliably, the method must account for variation in the average amount of seed produced by different moist-soil species. For example, the amount of seed produced by a single barnyardgrass plant outweighs the seed produced by an average panic grass plant. Such differences prevent the use of a generic method to determine seed production because many species normally occur in a sampling unit.

My technique consists of a series of regression equations designed specifically for single plant species or groups of two plant species closely related with regard to seed head structure and plant height (Table 1). Each equation was developed from data collected on wetland areas in the Upper Mississippi alluvial and Rio Grande valleys. The regression equations should be applicable throughout the range of each species because the physical growth form of each species (i.e., seed head geometry) remains constant. As a result, differences in seed production occur because of changes in plant density, seed head size, and plant height, but not because of the general shape of the seed head. This argument is supported by the fact that the weight of seed samples collected in the Rio Grande and Upper Mississippi valleys could be estimated with the same equation.

Estimating seed production requires collecting the appropriate information for each plant species and applying the correct equations. The equations provide estimates in units of grams per 0.0625 m^2; however, estimates can readily be converted to pounds per acre by using a conversion factor of 142.74 (i.e., grams per 0.0625-$m^2 \times 142.74$ = pounds per acre). Computer software developed for this technique also converts grams per square meter to pounds per acre.

Collection of Field Data

Measurements Required

Plant species
Seed heads (number)
Average seed head height (cm)
Average seed head diameter (cm)
Average plant height (m)

Equipment Required

Meter stick
Square sampling frame (Fig. 1)
Clipboard with paper and pencil (or field computer)

Method of Sampling

1. Place sampling frame in position. Include only those plants that are rooted within the sampling frame.

Table 1. *Regression equations for estimating seed production of eleven common moist-soil plants.*

Measurement[a] group	Plant species	Regression equation[bc] (weight in grams per 0.0625 m^2)	Coefficient of determination (R^2)
Grass			
	Barnyardgrass[d]	$(HT \times 3.67855) + (0.000696 \times VOL)$[e]	0.89
	Crabgrass	$(0.02798 \times HEADS)$	0.88
	Foxtail[f]	$(0.03289 \times VOL)$[g]	0.93
	Fall panicum	$(0.36369 \times HT) + (0.01107 \times HEADS)$	0.93
	Rice cutgrass	$(0.2814 \times HEADS)$	0.92
	Sprangletop	$(1.4432 \times HT) + (0.00027 \times VOL)$[e]	0.92
Sedge			
	Annual sedge	$(2.00187 \times HT) + (0.01456 \times HEADS)$	0.79
	Chufa	$(0.00208 \times VOL)$[h]	0.86
	Redroot flatsedge	$(3.08247 \times HEADS) + (2.38866 \times HD) - (3.40976 \times HL)$	0.89
Smartweed			
	Ladysthumb/water smartweed	$(0.10673 \times HEADS)$	0.96
	Water pepper	$(0.484328 \times HT) + (0.0033 \times VOL)$[g]	0.96

[a] Refer to Fig. 3 for directions on measuring seed heads.
[b] HT = plant height (m); HEADS = number of seed heads in sample frame; HL = height of representative seed head (cm); HD = diameter of representative seed head (cm); VOL = volume (cm^3).
[c] Conversion factor to pounds per acre is: grams per 0.0625 $m^2 \times 142.74$.
[d] *Echinochloa crusgalli* and *E. muricata*.
[e] VOL (based on geometry of cone) calculated as: $(HEADS) \times (\pi r^2 h/3)$; $\pi = 3.1416$, r = HD/2, h = HL.
[f] *Setaria* spp.
[g] VOL (based on geometry of cylinder) calculated as: $(HEADS) \times (\pi r^2 h)$; $\pi = 3.1416$, r = HD/2, h = HL.
[h] VOL (based on geometry of half sphere) calculated as: $(HEADS) \times (1.33\pi r^3/2)$; $\pi = 3.1416$, r = HD/2.

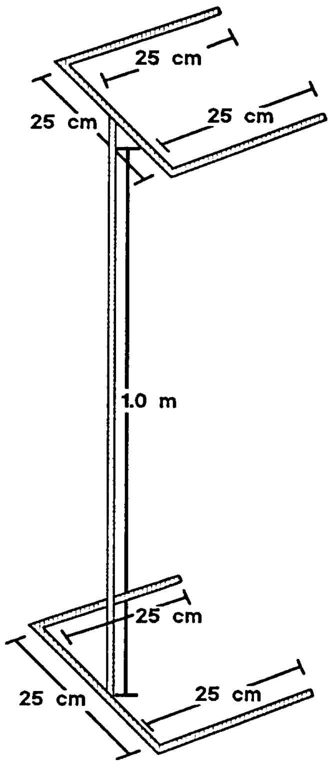


Fig. 1. Sampling frame design.

2. Record plant species present within sample frame on data form (Fig. 2).
3. For each plant species, record the number of seed heads within the sample frame. All seed heads occurring within an imaginary column formed by the sample frame should be counted.
4. For each plant species, select a single representative plant and measure
   a. the straightened height of the entire plant (from the ground to the top of the tallest plant structure) in meters,
   b. the number of seed heads within the sample frame,
   c. the height of the seed head in centimeters (measure along the rachis [i.e., main stem of flower] from the lowest rachilla [i.e., secondary stem of flower] to the top of the straightened seed head [Fig. 3].), and
   d. the diameter (a horizontal plane) of the seed head in centimeters (measure along the lowest seed-producing rachilla [Fig 3].).

Although average values calculated by measuring every plant within the sample frame would be more accurate, the time required to collect a sample would increase greatly. In contrast, obtaining measurements from a single representative plant allows a larger number of samples to be collected per unit time. This method also permits sampling across a greater portion of the unit, which provides results that are more representative of seed production in an entire unit.

Suggested Sampling Schemes

There are two basic approaches to estimating seed production within an impoundment. Both methods should supply similar results in most instances. The choice of method will depend largely on physical attributes of the impoundment and management strategies that determine the diversity and distribution of vegetation.

First approach: Sample across entire unit. The most direct procedure of estimating seed production is to collect samples across an entire unit using the centric systematic area sample design (Fig. 4). This method is recommended when vegetation types are distributed randomly across the entire impoundment (e.g., rice cutgrass and smartweed occur together across the entire

Plot Number	Plant species	Height (m)	Seed heads (no.)	Seed head height (cm)	Seed head diameter (cm)
1					
2					
3					
4					
5					
6					

Fig. 2. Sample data form for collecting information necessary to estimate seed production.

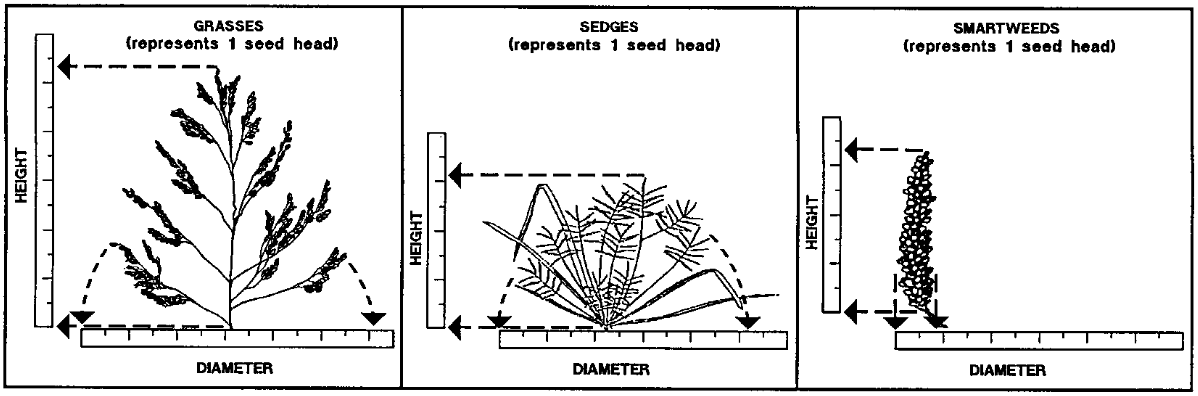


Fig. 3. Method of measuring dimensions of three seed head types.

impoundment; Fig. 5a). Divide an entire unit into blocks of equal dimension and establish a 0.0625-m^2 sample frame at the center of each block. In the field, this is accomplished by walking down the center of a row of such blocks and sampling at the measured interval. The precise number of samples necessary to provide a reliable estimate depends on the uniformity of each plant species within the impoundment and the desired accuracy of the estimate. The dimensions of the blocks are adjustable, but collect a minimum of one sample for every 2 acres of habitat. For example, a block size of 2 acres (i.e., 295 feet per side) results in 25 samples collected in a 50-acre moist-soil unit.

At each sampling station, measure and record each plant species of interest and the associated variables (i.e., plant height, number of seed heads, seed head height, and seed head diameter)

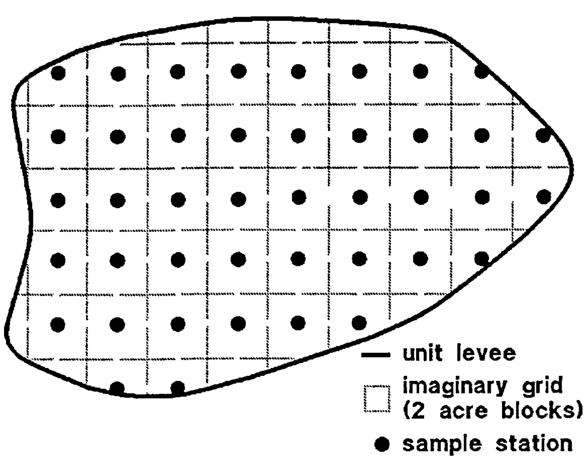


Fig. 4. Centric area sample method (unit = 84 acres)

necessary for estimating seed production of that species. If the same plant species occurs at two distinct heights (e.g., 0.4 m and 1.2 m), determine a seed estimate for plants at each height. If a plant species for which an estimate is desired does not occur within the sample frame, the plant species should still be recorded and variables assigned a value of zero. For example, if barnyardgrass seed production is to be estimated and the sample frame is randomly placed in an area where no barnyardgrass occurs, record a zero for plant height, number of seed heads, seed head height, and seed head diameter. This represents a valid sample and must be included in calculating the average seed production of barnyardgrass in the unit.

Collect samples across the entire unit to ensure that a reliable estimate is calculated. Exercise care to sample only those areas that are capable of producing moist-soil vegetation. Borrow areas or areas of high elevation that do not produce moist-soil vegetation should not be sampled.

Estimate the weight of seed produced by each plant species in a sample with the appropriate regression equation (Table 1), or with the software developed for this purpose. Determine the average seed produced by each species in an impoundment by calculating the mean seed weight of all samples collected (if the species is absent from a sample, a zero is recorded and used in the computation of the mean) and multiplying the mean seed weight (grams per 0.0625m^2) by the total area of the unit. Determine total seed production by summing the average seed produced by each plant species sampled. Following collection of at least five samples, the accuracy of the estimate also can be

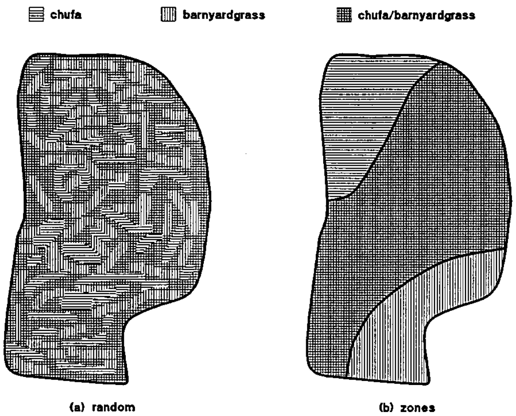


Fig. 5. Two general types of vegetation distribution.

determined. If higher accuracy is desired, collect additional samples by reducing the block size the appropriate amount or by randomly collecting additional samples.

Second approach: Sample within vegetation zones of a unit. This method is recommended for use in impoundments when species or groups of plants occur in distinct and nonoverlapping zones within a unit (e.g., smartweeds only occur at low elevations and barnyardgrass only occurs at higher elevations within the same unit; Fig. 5b). The same general methodology previously outlined for sampling an entire unit applies to this sampling scheme, except that

1. the centric area sampling method is applied separately to each vegetation zone within an impoundment,
2. seed production of an individual plant species over the entire unit is determined by multiplying the average seed production (based only on the samples collected within that zone) by the acreage of the zone sampled,
3. total seed production within a zone is calculated by summing the seed production estimates of each plant species occurring within that zone, and
4. total seed production across the entire impoundment is calculated by summing the seed production estimates of all zones composing the unit. If this sampling scheme is used, a cover map delineating vegetation zones is useful for calculating the acreage of zones sampled.

When to Collect Field Data

Samples must be collected when vegetation has matured and seed heads are fully formed because the regression equation for each plant species is based on seed head dimensions and plant height. Timing of sampling varies across latitudes because of differences in growing season length and maturation times of plant species. Information can be collected before the after-ripening of seeds (i.e., seed heads completely formed but seeds not mature) because seed head dimensions will not change appreciably. Information also can be collected following seed drop because seed head dimensions can be determined based on the geometry of the remaining flower parts (i.e., rachis and rachilla). This allows a greater time span for collecting information. If timed correctly, estimates for most moist-soil plants can be determined during the same sampling period.

Under certain conditions, two crops of moist-soil seeds can be produced within the same unit in a single year. Often, the second crop will be composed of plant species different from those composing the first crop. If this occurs, estimating total seed production requires sampling both first- and second-crop vegetation, even if the species composition of the second seed crop is similar to the first crop. Estimates based on the first crop cannot be applied to the second crop because seed head dimensions will be different.

Determining Required Sample Size

The number of samples necessary to estimate seed production will depend on the level of accuracy desired. Although as few as three samples will provide a mean value of seed production and an estimate of the variability within the unit, this type of estimate normally is unreliable. The most important factors influencing accuracy include the degree of uniformity in plant distribution and the species of plant sampled.

Plant distribution affects accuracy if the density of a plant species varies widely within the area sampled. Potential factors influencing changes in plant density include differential hydrology, use of spot mechanical treatments, and changes in soil type. Often, these factors can be controlled by selecting the appropriate sampling scheme. In addition, seed production by perennials that propagate by tubers tends to be more variable and, therefore, a larger number of samples may be required.

Following collection of at least five samples in a unit, the standard deviation (SD) can be calculated with the equation SD = $(s^2)^{1/2}$. The sample variance (s^2) is estimated with the formula $s^2 = (\sum_{i=1}^{n} x_i - \bar{x})^2 / n-1$, where x_i = seed estimate of sample i, $\bar{x}$ = average seed weight of all samples, and n = number of samples collected. The standard deviation indicates the degree of variation in seed weight and is, therefore, a measure of precision (see example)—the larger the SD, the lower the precision of the estimate.

The number of samples necessary to achieve a specified level of precision (95% confidence interval) can be calculated with the formula $n = 4s^2/L^2$, where s^2 = sample variance and L = allowable error (± pounds per acre). The sample variance (s^2) can be estimated from previous experience or calculated based on preliminary sampling. Because seed production varies among plant species and units, sample variance should be determined independently for individual plant species and units. Numerous environmental factors influence seed production on a particular site. Therefore, sample variance should be calculated annually for each site. A subjective decision must be made concerning how large an error (L) can be tolerated. This decision should be based on how the seed production estimate is to be used. For example, an L of ± 100 pounds per acre would be acceptable for determining the number of waterfowl use-days available. In other cases, a larger error might be acceptable. As the allowable error increases, the number of samples required decreases.

Estimating Seed Production

Although the technique is simple to use, several important factors must be considered to obtain accurate estimates of seed weight. The following example illustrates the process of making these decisions. In addition, the process of computing estimates using the regression equations demonstrates the correct manner of using field data to arrive at valid estimates.

1. *Unit considerations*—unit size is 10 acres. Vegetation consists of barnyardgrass distributed uniformly across the entire unit.
2. *Sampling strategy*—use a centric area sampling method with a maximum recommended block size of 2 acres to establish the location of five sample areas uniformly across the unit.
3. *Data collection*—at each plot, select a representative barnyardgrass plant within the sample frame and record the necessary information (Table 2).
4. *Estimate seed production*—for each sample, use the appropriate equation to determine the estimated seed weight. In this example, only the barnyardgrass equation is required (Table 3).
5. *Maximum allowable error*—in this example, an L of ± 100 pounds per acre is used for barnyardgrass. The standard deviation is then calculated to determine the precision of the estimate. If the standard deviation is less than the allowable error, no additional samples must be collected. However, if the standard deviation is greater than the allowable error, the estimated number of additional samples that must be collected is calculated.

- Allowable error = L = ± 100 pounds per acre
- Number of samples collected = n = 5
- Weight of individual samples (pounds per acre) = x_i = 982; 1,119; 871; 1,124; 1,237
- Average weight of samples (pounds per acre) = $\bar{x}$

  = 982 + 1,119 + 871 + 1,124 + 1,237 / 5
  = 5,333 / 5
  = 1,066.6 or 1,067
- Variance = $s^2 = \Sigma(x_i - \bar{x})^2/n-1$

  $= (982 - 1{,}067)^2 + (1{,}119 - 1{,}067)^2 + (871 - 1{,}067)^2$
  $+ (1{,}124 - 1{,}067)^2 + (1{,}237 - 1{,}067)^2 / 5 - 1$
  $= (-85)^2 + (52)^2 + (-196)^2 + (57)^2 + (170)^2 / 4$
  = 7,225 + 2,704 + 38,416 + 3,249 + 28,900 / 4
  = 80,494 / 4
  = 20,123.5 or 20,124 pounds per acre
- Standard deviation = $s = (s^2)^{1/2}$

  $= 20{,}124^{1/2}$
  = 141.8 or 142 pounds per acre

Based on these computations, an estimated average weight of 1,067 ± 142 pounds per acre (i.e., 925–1,209 pounds per acre) of barnyardgrass seed was produced. However, the standard deviation (142 pounds per acre) is greater than the allowable error (100 pounds per acre), indicating that additional samples must be collected to obtain an average seed weight value that is within the acceptable limits of error.

Table 2. *Sample data sheet for estimating seed production.*

Plot	Plant species	Height (m)	Seed heads (number)	Seed head height (cm)	Seed head diameter (cm)
			Initial samples		
1	Barnyardgrass	1.1	12	16	9
2	Barnyardgrass	1.1	13	16	10
3	Barnyardgrass	1.1	11	16	8
4	Barnyardgrass	1.1	14	15	10
5	Barnyardgrass	1.2	9	18	12
			Additional samples		
6	Barnyardgrass	1.1	12	16	10
7	Barnyardgrass	0.9	15	17	9
8	Barnyardgrass	0.9	14	17	10

Table 3. *Estimating seed weight of individual samples.*

Plant species	Regression equation[a]	Plot	Estimated weight (grams per 0.0625-m^2)	Estimated weight (pounds per acre)
		Initial samples		
Barnyardgrass	(HT × 3.67855) + (0.000696 × VOL)	1	6.88[b]	982 [c]
		2	7.84	1,119
		3	6.10	871
		4	7.88	1,124
		5	8.67	1,237
		Additional samples		
		6	7.55	1,077
		7	7.08	1,010
		8	7.65	1,092

[a] HT = plant height (m); HEADS = number of seed heads in sample frame; HL = height of representative seed head (cm); HD = diameter of representative seed head (cm); VOL = volume (based on geometry of cone) calculated as: (HEADS) × (πr^2h/3); π = 3.1416, r = HD/2, h = HL.
[b] Weight (grams per 0.0625-m^2) = (HT × 3.67855) + (0.000696 × VOL) = (1.1 × 3.67855) + (0.000696 × 4081.6) = 4.0464 + 2.8408 = 6.88 VOL = (HEADS) × (πr^2h/3); π = 3.1416, r = 9/2 = 4.5, r^2 = 20.3, h = 16 = (12) × (3.1416 × 20.3 × 16/3) = (12) × (340.131) = 4081.6
[c] Conversion from grams per 0.0625-m^2 to pounds per acre: 6.88 × 142.74 = 982.

Total number of samples required = $4s^2/L^2$
= (4 × 20,124) / (100)^2
= 80,496 / 10,000
= 8
Additional samples required = total samples required – samples collected
= 8 – 5
= 3

Based on these calculations, three additional samples must be collected.

6. *Additional samples*—collect additional samples at random locations (Tables 3 and 4). Following collection of data, the average seed weight and standard deviation of samples must be recalculated using the equations in Step 5. If the accompanying software is used, these calculations are performed automatically. In this example, the revised estimate of average seed weight ($\bar{x}$) is 1,064 pounds per acre, and the standard deviation (s) is 110 pounds per acre.
7. *Estimating total seed production*—after collecting a sufficient number of samples of each species to obtain an average seed estimate with a standard deviation less than the maximum allowable error, estimate total seed production. An estimate of seed produced by each species is determined by computing the average seed weight of that species in all samples collected and multiplying this value by the area sampled. Total seed production is estimated by summing seed produced by each species. In this example only barnyardgrass was sampled. Therefore, total seed produced is equivalent to barnyardgrass seed produced.

Barnyardgrass seed produced = average seed weight × area sampled
= 1,064 (± 110) pounds per acre × 10 acres
= 10,640 ± 1,100 pounds in unit.

Computer Software

Computer software is available for performing the mathematical computations necessary to estimate seed weight. The program is written in Turbo Pascal and can be operated on computers with a minimum of 256K memory. The program computes the estimated seed weight of individual plant species collected at each sample location and displays this information following entry of each sample. In addition, a summary screen displays estimates of average and total seed produced in an impoundment as well as the standard deviation of the estimate. This information is automatically stored in a file that can be printed or saved on a disk. A copy of the program is available upon request. Instructions pertaining to the use of the program are obtained by accessing the README file on the program diskette.

Suggested Reading

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148, Washington, D.C. 29 pp.

Reinecke, K. J., R. M. Kaminski, D. J. Moorehead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi alluvial valley. Pages 203–247 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Appendix. Common and Scientific Names of Plants Named in Text.

Annual sedge	*Cyperus iria*
Barnyardgrass	*Echinochloa crusgalli*
Barnyardgrass	*Echinochloa muricata*
Beggarticks	*Bidens* spp.
Chufa	*Cyperus esculentus*
Crabgrass	*Digitaria* spp.
Fall panicum	*Panicum dichotomiflorum*
Foxtail	*Setaria* spp.
Ladysthumb smartweed	*Polygonum lapathifolium*
Redroot flatsedge	*Cyperus erythrorhizos*
Rice cutgrass	*Leersia oryzoides*
Sprangletop	*Leptochloa filiformis*
Water pepper	*Polygonum hydropiper*
Water smartweed	*Polygonum coccineum*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

APPENDIX 3: Herbicides and Application Uses on Moist-Soil Units in the Southeast

Some herbicides and application uses on moist-soil units in the Southeast Region.

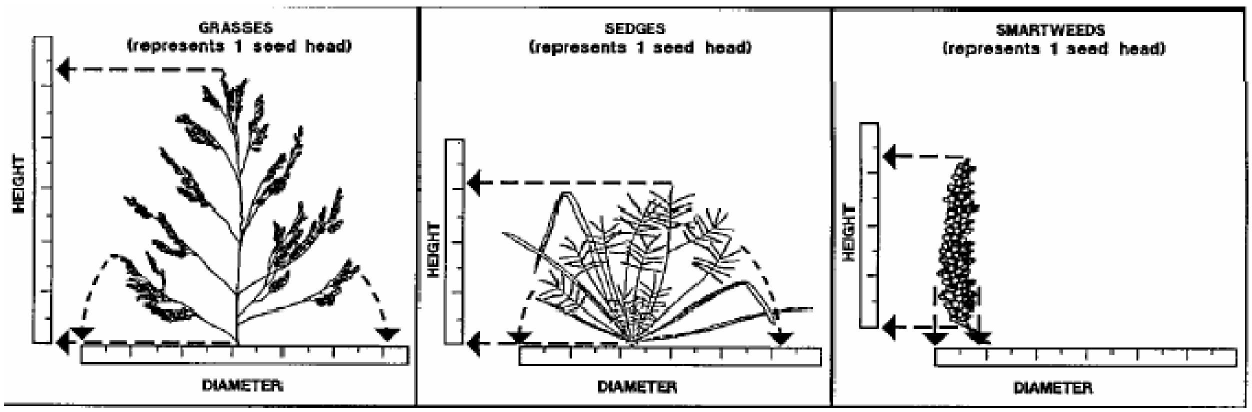
Trade name	Common name	Aquatic label	Application uses
Round-up, several others	glysophosate	No	Highly effective, broad spectrum herbicide.
Rodeo, several others	glysophosate	Yes	Highly effective, broad spectrum herbicide approved for aquatic applications.
Various	2,4-D	Yes	Highly effective, inexpensive broadleaf herbicide (includes sedges) used to release grasses. Effective on hard to control weeds like alligatorweed. Extreme caution is recommended for use in cotton growing areas, check for applicable restrictions
Aim	Carfentrazone	Yes	Broadleaf herbicide used in rice culture when weeds are small. Can be used a lowest recommended rates to treat coffeebean. Will also eliminate desirable broadleaves such as pigweed.
Blazer, others	Acifluorfen	No	Broadleaf herbicide, particularly effective on coffeebean.
Basagran	Bentazon	No	Broadleaf herbicide, particularly effective on cocklebur.
Banvil, others	Dicamba	No	Broadleaf herbicide for controlling small broadleaf weeds, including morning glory, smartweed, redvine (a.k.a., ladies-eardrop), etc.
Habitat	Imazapyr	Yes	Highly effective broad spectrum herbicide, including emergent, floating, or spreading aquatics (maidencane), and woody vegetation (willows and Chinese tallow). Not approved for use on crops or irrigation water.

Notes: 1.) Except AIM, all of the above-listed herbicides are on the refuge manager's approval list.
2.) Refuge managers must require all applicators to abide by all label guidelines and/or restrictions
3.) In selecting an herbicide, applicators must be familiar with the potential desired and undesired affects.
4.) Much of the information presented here and a good source for additional information is the LSU Extension Service's Weed Control Guide for 2005 (www.lsuagcenter.com/Subjects/guides/weedguide/01weeds.htm). Another good source of information can be found at the Greenbook web site (www.greenbook.net).

APPENDIX 4: Seed Production Estimator "Cheat" Sheet and Sample Data Form

Seed Production Cheat Sheet

1. Place sampling frame in position.
2. Record species present that are also on the list below.
3. For each species, record the number of seed heads in the frame.
4. For each species, select **ONE** representative plant and measure:
    a. Straightened height of the entire plant (from ground to tip) in meters
    b. Height of seed head in cm.
    c. Diameter of seed head in cm.



Seed estimates can only be performed on the following species:

Barnyardgrass[a] . . . . *Echinochloa crusgalli*
Barnyardgrass[a] . . . . *Echinochloa muricata*
Crabgrass . . . . *Digitaria* spp.
Foxtail . . . .*Setaria* spp.
Fall panicum . . . . *Panicum dichotomiflorum*
Rice cutgrass . . . .*Leersia oryzoides*
Sprangletop . . . .*Leptochloa filiformis*
Annual sedge . . . .*Cyperus iria*
Chufa . . . . *Cyperus esculentus*
Redroot flatsedge . . . . *Cyperus erythrorhizos*
Ladysthumb smartweed[b] . . . . *Polygonum lapathifolium*
Water pepper[b] . . . .*Polygonum hydropiper*
Water smartweed . . . . *Polygonum coccineum*

[a] Considered as one for the estimate.
[b] Considered as one for the estimate. We also lumped Pennsylvania smartweed, *P. pennsylvanicum* with these.

Moist-Soil Plants (m^2)/Seed Production (1/4 m^2) Data Sheet

Refuge:____________ Impoundment:_______________ Observer(s):_____________ Date:_________

Plot # (UTM)	Species (Top 5 for % cover)	# Seed Heads	Plant Height (m) (% Cover)	Head Diam (cm)	Head Height (cm)

Wildlife Habitat Management Institute

Wetland Mammals

March 2001 *Fish and Wildlife Habitat Management Leaflet* *Number 21*

National Oceanic and Atmospheric Administration

Wetlands provide a diversity of productive habitats for mammals, birds and other wildlife.

Wetland Basics

Wetlands are those lands between aquatic and terrestrial environments. The U.S. Fish and Wildlife Service (Cowardin et al. 1979) described five major systems of wetlands and deepwater habitats: marine, estuarine, lacustrine (lakes), riverine (rivers and streams), and palustrine (marshes, swamps, and bogs). Marine and estuarine systems include coastal habitats, while the other three systems include most inland freshwater wetlands. At least 50% of the original wetland area in the continental United States has been lost to drainage, land-use development, and other human activities since colonial settlement.

Water is the most influential component of wetland ecosystems, controlling soil characteristics and associated plant and animal life. Wetland substrates are inundated or saturated near the surface long enough during the growing season to influence the vegetation community. Plants that are adapted to tolerate wet environments (generally referred to as hydrophytes) are more likely to inhabit wetland systems than plants that favor upland sites. Hydric soils develop in wetlands, largely due to the anaerobic conditions created by saturation at or near the surface during the growing season. Therefore, wetland hydrology, hydrophytic vegetation, and hydric soils are the three basic characteristics of wetland habitats.

Wetlands provide a variety of biological and socio-economic functions, and are among the most productive ecosystems in the world. They provide diverse wildlife habitats and support complex food chains. At least 150 bird species and 200 fish species are wetland-dependent. About 900 terrestrial animal species use wetland habitats of the United States periodically throughout their lives for breeding, foraging, or other activities. The Prairie Pothole Region in the northern plains contains 10 percent of U.S. wetland area, but supports 50 percent of U.S. mallard, northern pintail, and green-winged teal production. The Great Basin area of the intermountain west also provides important wetland habitat for migrating birds.

Many species of mammals depend on wetland habitats for survival. Some mammals are herbivores, while others are omnivores or carnivores that rely on varying

Wetland Functions and Values

Hydrological
- ❖ Help control floodwater and lower flood and erosion potential.
- ❖ Contribute to aquifer and groundwater recharge.

Geochemical
- ❖ Filter pollutants and heavy metals from precipitation and point source and non-point source pollution (agricultural runoff, industrial discharge, etc.).

Biological
- ❖ Provide habitat for fish and wildlife.

Socio-economic
- ❖ Support timber production.
- ❖ Support shellfish production and aquaculture.
- ❖ Provide water sources for agriculture.
- ❖ Provide fuel source (peat) in some countries.
- ❖ Provide recreational opportunities such as hunting, trapping, canoeing, and bird watching.
- ❖ Provide educational opportunities.
- ❖ Aesthetic values.

combinations of aquatic invertebrates, amphibians, fish, and other prey. Many wetland mammals consume large numbers of insects, cultivate the soil, or modify habitat used by waterfowl and other wildlife.

This leaflet is designed as an introduction to wetland mammal identification and management, and is intended to assist landowners in their efforts to effectively manage wetland mammal habitats. The success of any management strategy depends on targeting the specific needs of the desired species and analyzing designated habitat areas to ensure all required habitat elements are present. Not all habitat management recommendations are suitable for all wetlands. Most successful plans use a combination of management methods that improve wetland biodiversity. Individual plans should take into account local climate, flora, and fauna. Landowners should be familiar with state and federally listed plant and animal species (see U.S. Fish and Wildlife Service Endangered Species Homepage, http://engangered.fws.gov) and are encouraged to consult natural resource professionals to achieve management objectives and identify future goals.

Wetland Mammals

Wetlands throughout North America are used by a wide variety of mammals. However, some species are more closely associated with wetland habitats than others. This leaflet focuses on species considered wetland mammals by Neiring (1992) and Burt and

Table 1. Species of wetland mammals in North America.

Order	Family name	Species name
Insectivora	Soricidae	Arctic shrew, masked shrew, Pacific shrew, Pacific water shrew, smoky shrew, water shrew
	Talpidae	Star-nosed mole
Rodentia	Zapodidae	Meadow jumping mouse
	Muridae*	Cotton mouse, golden mouse, marsh rice rat, meadow vole, southern red-backed vole, water vole, muskrat, round-tailed muskrat, southern bog lemming
	Capromyidae	Nutria
	Castoridae	Beaver
Lagomorpha	Leporidae	Marsh rabbit, swamp rabbit
Carnivora	Mustelidae	Mink, river otter

**Incorporates and replaces Cricetidae*

USDA Natural Resources Conservation Service

Tidal marshes provide numerous functions, including food chain support of coastal fisheries and habitat functions for mammals, birds, and other wildife.

Grossenheider (1980).

Wetland mammals inhabit a variety of wetland habitats, and have diverse food and cover requirements. Below are general descriptions of wetland mammals, tracks, ranges, and habitat associations.

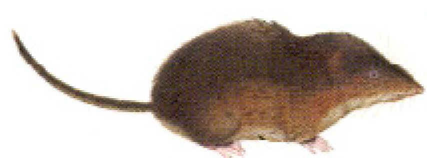
Shrews

Shrews are small, mouse-size insectivores with long, pointed noses and small eyes. They are found throughout most of North America and are active year-round. Shrews require an enormous amount of food to fuel their fast metabolisms. They feed on insects, slugs, and other invertebrates, and small vertebrates such as salamanders, frogs, and other mammals. Predators such as snakes, hawks, owls, weasels, and foxes often rely heavily on shrews as a major diet component. Prolific breeders, most shrews can produce up to three litters a year, each litter containing two to ten young. Six species of North American shrews are closely associated with wetlands: the Arctic shrew, smoky shrew, water shrew, Pacific water shrew, Pacific shrew, and masked shrew.

Moles

Moles dig shallow and deep tunnel systems below the ground surface. The low ridge of pushed-up soil on the ground surface is a sign that moles are below foraging for food. The more permanent, deeper tunnels are

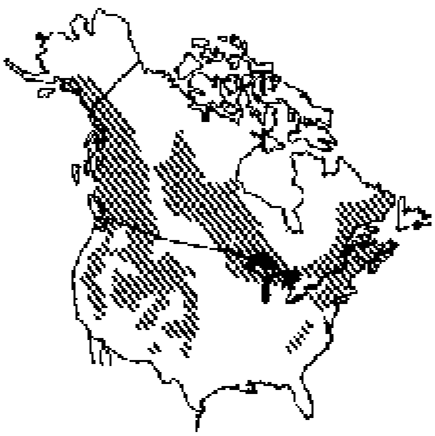
Arctic shrew (*Sorex arcticus*)
Total length: 10.1-12.6 cm (4-5 in.)
Range: Most of Canada and Alaska south to North Dakota, northeast South Dakota, Minnesota, Wisconsin, and Michigan's Upper Peninsula.
Habitat: Swamps, bogs, marshes, and grass-sedge meadows.



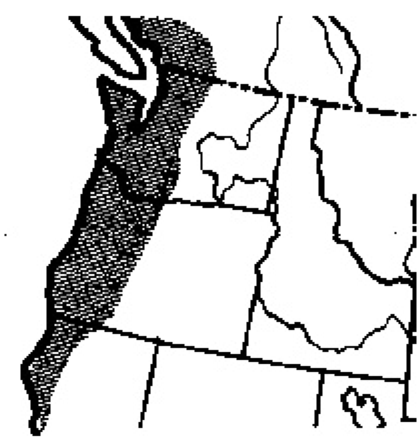
Arctic shrew from Burt and Grossenheider (1980).

Smoky shrew (*Sorex fumeus*)
Total length: 11-12.7 cm (4 1/4-5 in.)
Range: Northeastern U.S. south through mountains to eastern Tennessee, north Georgia, and northern South Carolina; north to Ontario, Quebec, New Brunswick, and Nova Scotia.
Habitat: Various types of moist wooded areas, swamps, and along streams.
Comments: Uses tunnels made by red-backed voles, bog lemmings, northern short-tailed shrews, and star-nosed moles.

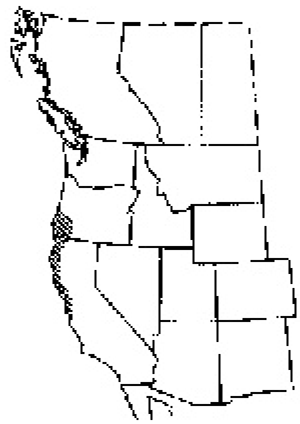
Water shrew (*Sorex palustris*)
Total length: 14.4-15.8 cm (5 5/8-6 1/4 in.)
Range: Most of Canada south through northeastern California, Utah, and isolated populations in the White Mountains of Arizona; central states to northeastern South Dakota, northern Minnesota, Wisconsin, and Michigan; New England south through the Appalachians to North Carolina.
Habitat: Among boulders along mountain streams or in sphagnum moss around lakes.
Comments: Semi-aquatic with large, broad hindfeet, slightly webbed between third and fourth toes; all toes have stiff hairs on the sides to increase swimming efficiency; fur traps air bubbles underwater for buoyancy.



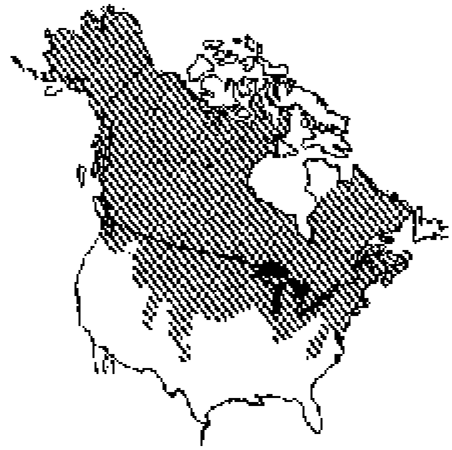
Pacific water shrew (*Sorex bendirii*)
Total length: 14.7-17.4 cm (5 7/8-6 7/8 in.)
Range: Coastal northern California north to southeastern British Columbia.
Habitat: Marshes, along streams, occasionally moist forests.
Comments: Largest *Sorex* species; fringed hairs on toes give it buoyancy to run on top of the water's surface for several seconds; also dives.

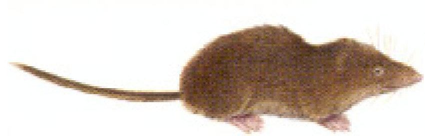


Pacific shrew (*Sorex pacificus*)
Total length: 12.9-16 cm (5 1/8-6 1/4 in.)
Range: Pacific Coast from southern Oregon to northern California.
Habitat: Spruce and redwood forests; stands of alder-skunk cabbage along the edges of streams.
Comments: Nocturnal.



Masked shrew (*Sorex cinereus)*
Total length: 7.5-11 cm (3-4 1/4 in.)
Range: Most of northern North America south to Washington, Idaho, south-central Utah, north-central New Mexico, Nebraska, Iowa, Indiana, Extreme northern Kentucky, Maryland and south through the Applachians.
Habitat: Marshes, moist fields, bogs, moist or dry woods.
Comments: Primarily nocturnal, rarely seen.





Masked shrew from Burt and Grossenheider (1980).

used for resting, raising young, and food storage. Moles have broad, spade-like forefeet that are used for moving soil. The eyes are tiny and external ears are nonexistent. Moles eat a variety of insects and other invertebrates, and are typically important prey for raptors, snakes, owls, weasels, foxes, and other carnivores. Most moles live in well-drained upland areas. However, one species, the star-nosed mole, is adapted to living in the muddy soils of wetlands. The fleshy appendages on its nose enable it to recognize prey items by touch.

Dr. Ken Catania, Vanderbilt University

The fleshy, tentacle-like projections around the nose of the star-nosed mole are used for tactile detection of prey.

Mice, rats, lemmings, and voles

Mice, rats, lemmings, and voles are small to medium-size rodents. Most live on or under the ground, and some are semi-aquatic. Lemmings and voles have short tails and small ears and eyes in contrast with the longer, thinner tails and larger ears and eyes of mice and rats. These rodents are active year-round and are primarily nocturnal. They feed on a variety of foods from subterranean fungus, seeds, fruits and green vegetation, to terrestrial and aquatic invertebrates, to small bird eggs and young. Mice, rats, lemmings, and voles are important prey for many predators including owls, hawks, raccoons, foxes, mink, weasels, skunks, and others. The number of litters and the number of young per litter vary among species. Several species of mice, voles, and the southern bog lemming are considered wetland species in North America.

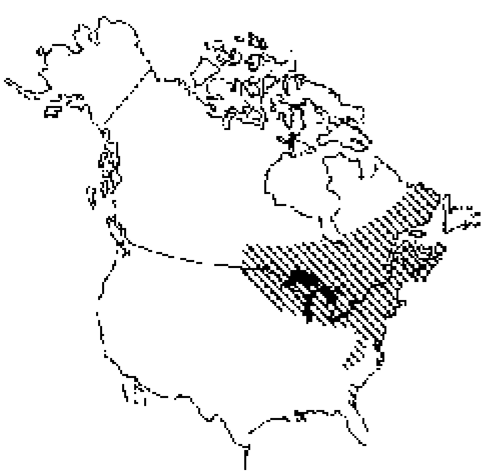
Star-nosed mole (*Condylura cristata*)

Total length: 15.2-21.1 cm (5 7/8-8 1/4 in.)

Range: Most of the northeastern U.S.; southeastern Labrador south through most of Minnesota, northeastern Indiana, northern Ohio, south through the Appalachians and along coastal Virginia; isloated populations along Georgia coast.

Habitat: Swamps, wet woods or fields, sometimes moist lawns.

Comments: The only semi-aquatic mole; 22 tentacle-like, fleshy projections around tip of nose that act as tactile organs to probe/search out prey; waterproof fur, uses spade-like feet as paddles, tail as rudder; hunts stream bottoms for aquatic invertebrates, crustaceans, mollusks, even small fish; forages in tunnels for terrestrial invertebrates.

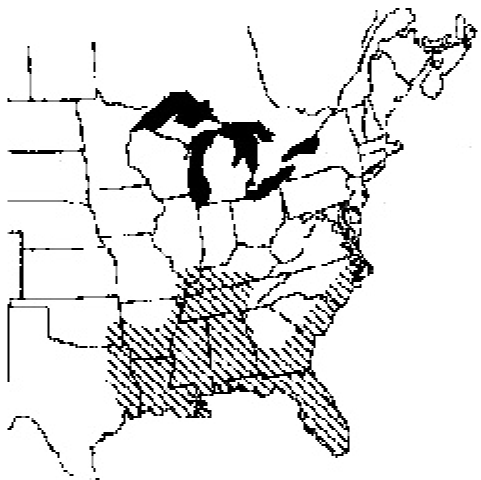


CVIOG/GeorgiaInfo

The cotton mouse is a strong swimmer that inhabits moist woodlands, swamps, and other wetland areas.

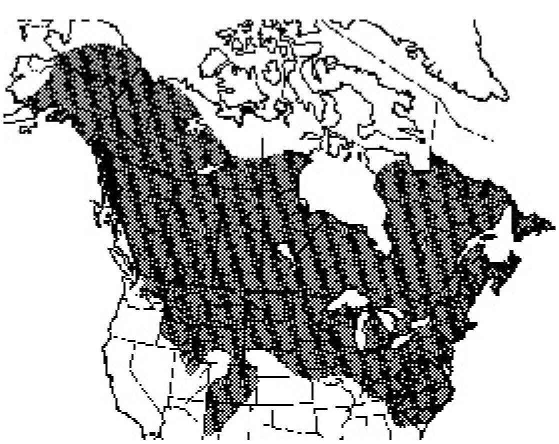
Cotton mouse (*Peromyscus gossypinus*)

Total length: 15.2-20.5 cm (6-8 1/8 in.)
Range: Southeastern U.S. from eastern Texas and southeastern Oklahoma east to southeastern Virginia, eastern North Carolina, eastern South Carolina, Georgia, and Florida.
Habitat: Swamps, moist woodlands, beaches, rocky areas and brushlands.
Comments: Strong swimmers and regularly climb trees; nocturnal.



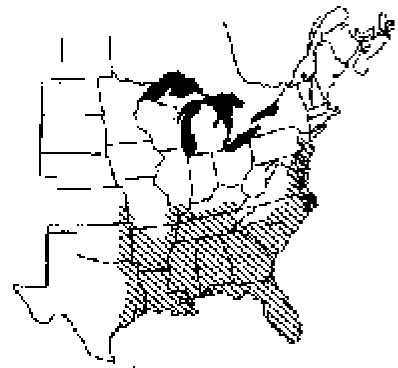
Meadow vole (*Microtus pennsylvanicus*)

Total length: 14-19.5 cm (5 1/2-7 3/4 in.)
Range: Canada and Alaska (except northern most portions) south and east to northern Washington, Idaho, Utah, New Mexico, Wyoming, Nebraska, northern Missouri, northern Illinois, Kentucky, northeastern Georgia, and South Carolina.
Habitat: Marshes, swamps, woodland glades, mountaintops, fields.
Comments: Active day or night; good swimmer, nests above or below ground.



Marsh rice rat (*Oryzomys palustris*)

Total length: 18.7-30.5 cm (7 3/8-12 in.)
Range: Mostly the southeastern U.S.; eastern Texas north to southeastern Kansas, southeastern Missouri, southern Illinois, southern Kentucky, eastern North Carolina, and north to southeastern Pennsylvania and southern New Jersey.
Habitat: Mostly marshes.
Comments: Semi-aquatic and swims underwater; water repellant fur; small internal cheek pouches; subterranean fungus *Endogone* is an important diet component.

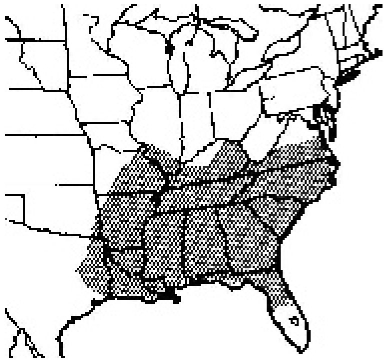


Mansell 1998. CVIOG/GeorgiaInfo

Meadow jumping mouse (*Zapus hudsonius*)

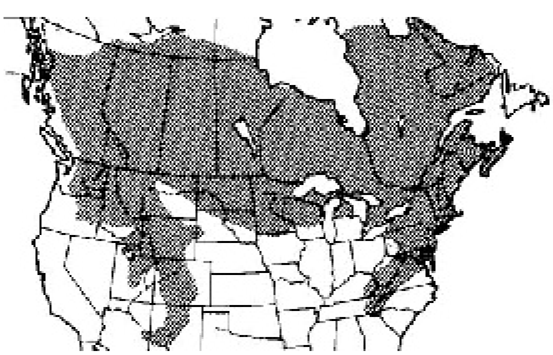
Total length: 18.7-25.5 cm (7 1/4-10 in.)
Range: Southern Alaska and most southern portions of Canadian provinces; northeastern U.S. west to eastern Wyoming and south to northeastern Oklahoma and northeastern Georgia.
Habitat: Moist fields, marshes, brushy fields, woodlands with thick vegetation.
Comments: Belongs to the family of jumping mice, Zapodidae; primarily nocturnal; Hibernates in winter nest two to three feet below ground surface, October or November; emerges from hibernation in April or May; can take jumps three to four feet long on large hindfeet; feeds mostly on invertebrates in spring, seeds and green plants, and the subterranean fungus *Endogone* in summer and fall.

Golden mouse (*Ochrotomys nuttali*)
Total length: 15-19 cm (5 7/8-7 1/2in.)
Range: Eastern Texas and Oklahoma, southern Missouri and southern Illinois to the East Coast; southern Virginia south to central Florida.
Habitat: Swamps, greenbrier thickets, rocky hemlock slopes.
Comments: Arboreal mouse, uses long tail for balance; bright golden-cinnamon color with white belly.



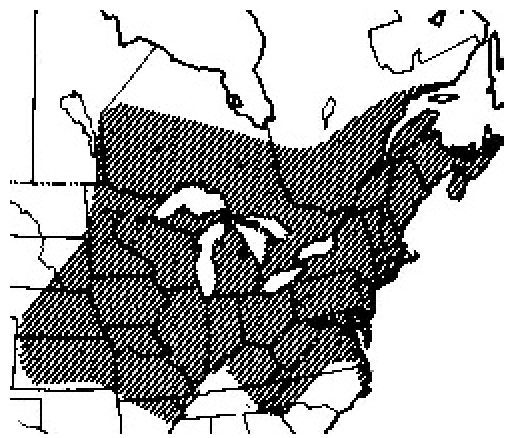
Mansell 1998. CVIOG/GeorgiaInfo

Southern red-backed vole (*Clethrionomys gapperi*)
Total length: 12-15.8 cm (4 3/4-6 1/4 in.)
Range: Southern portion of most Canadian provinces south into Oregon; Rocky Mountain system to Arizona and New Mexico; North and South Dakota, Minnesota, Wisconsin, northern Michigan; Allegheny Mountain system to North Carolina, New England south to Maryland.
Habitat: Cool, damp forests; swamps and bogs.
Comments: Active day and night; usually uses natural runways along fallen logs, tree roots, along rocks or tunnels of other animals; climbs trees.



Water vole (*Arvicola richardsoni*)
Total length: 19.8-26.1 cm (7 3/4-10 1/4 in.)
Range: Southeastern and southwestern British Columbia and southwestern Alberta south through central and eastern Washington; central and eastern Oregon, northern Idaho, north-central Utah and western Wyoming.
Habitat: Upland creek- and streambanks and marshes; often above timberline.
Comments: Large, semi-aquatic vole; burrows along streambanks and lives in colonies.

Southern bog lemming (*Synaptomys cooperi*)
Total length: 11.8-15.4 cm (4 5/8-6 1/8 in.)
Range: Southeastern Manitoba east to Newfoundland and south to Kansas, northeastern Arkanses, western North Carolina, and northeastern Virginia.
Habitat: Low, damp bogs and meadows with heavy vegetation.
Comments: Active day or night; uses underground runways of other small animals; also burrows about six inches underground to create own system of tunnels.



Muskrats

Muskrats are active year round, and feed on emergent wetland plants including the roots and shoots of cattails, arrowheads, duck potato, bur reed, bulrushes, pondweed, or other aquatic vegetation. Corn, clover, alfalfa, carrots, apples, insects, and aquatic invertebrates are also eaten. Muskrats do not cache food for the winter. Instead, they dig up roots and tubers from under the ice in cold regions, creating visible “push-ups” —mounds of ice that are visible on the surface of the ice. During warmer months, feeding stations are usually within 200 yards of the cone-

Muskrat (*Ondatra zibethicus*)
Total length: 40.9-62 cm (16 1/8-24 3/8 in.)]

Range: Most of U.S. and Canada; except for extreme southern U.S. and arctic regions of Canada.
Habitat: Marshes, edges of ponds, lakes, rivers, and streams; brackish or saltwater waterways; dislike strong currents.
Comments: Aquatic rodents; hindfeet partially webbed and vertically flattened, long scaly tail used for swimming; build conical houses of marsh vegetation two to three feet above the surface of the water; houses usually have one nesting chamber with one or more underwater entrance; several muskrats may live in one house during cold months; also burrows into banks of streams and ponds; valuable fur bearer.

Mansell 1998. CVIOG/GeorgiaInfo

shaped house/den, which is built of vegetation above the water's surface. Some dig burrows and nest chambers in streambanks with entrances below the water level. Runs created through wetland vegetation may be visible on the bottom of shallow marshes, streams, or other frequently used areas. Muskrat predators include mink, red foxes, raccoons, bobcats, snapping turtles, large snakes and fish, and some raptors.

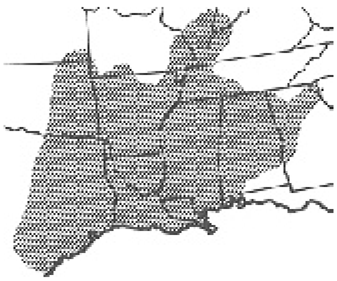
Muskrats have a valvular mouth that allows them to feed underwater. The dense pelage of nearly waterproof underfur overtopped with longer, coarse guard hairs provides insulation. Muskrats have glands under the skin near the anus that produce a musky odor, especially during the breeding season. These aquatic rodents can have two or three litters per year, averaging six young per litter. Females with young can be aggressive and territorial.

Rabbits

Swamp rabbits and marsh rabbits are similar to their upland cottontail cousins, but are associated with bottomland hardwood wetlands and coastal marshes of the Southeast. Feeding on a variety of wetland and upland plants, these species are popular game animals in many areas. They are also an important food source for many carnivores associated with bottomland hardwood and coastal wetlands including alligators, snakes, raptors, bobcats, and foxes. Being strong swimmers, both species readily take to water to escape from predators.

Marsh rabbit (*Sylvilagus palustris*)
Total length: 35-45 cm (14 1/8-18 in.)
Range: Southeastern Virginia southwest to Florida.
Habitat: Wet bottomlands, swamps, hummocks, lake borders, coastal waterways.
Comments: Primarily nocturnal; takes to water when threatened, good swimmer.

Swamp rabbit (*Sylvilagus aquaticus*)
Total length: 53-54 cm (20 7/8-21 1/4 in.)
Range: Eastern Texas and eastern Oklahoma east to southern Illinois and northern Georgia.
Habitat: Swamps, marshes, wet bottomlands, canebreaks.
Comments: Also called cane-cutter rabbit; can do damage to agricultural crops near swamps; good swimmer and swims as regular mode of locomotion; runs circles in front of hunting dogs; rarely burrows.



Mansell 1998. CVIOG/GeorgiaInfo

Nutria

Nutria are semi-aquatic, primarily herbivorous South American rodents that were introduced in North America in 1899 by California fur producers. Eventually, nutria escaped or were introduced in 22 states across the U.S. Nutria are smaller than beavers, but larger than muskrats. Under optimal habitat conditions, female nutria born during the summer can reach sexual maturity at four months of age. They are prolific breeders and may have two or three litters per year, each litter averaging four to five young. Nutria are considered habitat generalists because they are common where they are established and inhabit a variety of habitats, including coastal and inland freshwater and brackish marshes, bottomland hardwood forests, lagoons, swamps, drainage canals, freshwater impoundments, and banks of lakes, rivers,

Mike Haramis, USGS Patuxent Wildlife Research Center

The foraging and tunneling activity of nutria can severely degrade sensitive coastal marshes.

and streams. Nutria feed mostly at night, but are also active during daylight hours. Besides humans, alligators, and raptors, there are few natural predators to control nutria numbers.

The foraging and burrowing activities of nutria can destroy wetland vegetation, degrade native wetland ecosystems, and damage human economic interests.

Nutria (*Myocastor coypus*)
Total length: 67-140 cm (26 3/8-55 1/8 in.)
Range: Introduced in the Southeast from South America; also in Maryland, southern New Jersey, scattered in the Great Plains, northern Oregon, and Washington.
Habitat: Marshes, swamps, ponds, and lakes.
Comments: Also known as Coypu, incisors dark-orange and protrude beyond lips; Primarily nocturnal, feeds on available aquatic vegetation, eats at feeding station (log, vegetation, other raised object); typically builds nest of vegetation on surface of water; rarely burrows into banks to nest.

Mike Haramis, USGS Patuxent Wildlife Research Center

Nutria with kits.

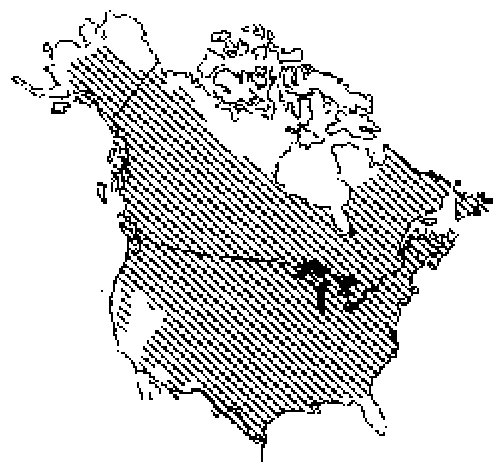
They consume the basal portions of plants, including roots, rhizomes, and tubers. During the winter months, nutria may feeds on the bark of willows, bald cypress, or other bottomland hardwood species. Nutria also eat agricultural crops adjacent to aquatic habitats such as sugarcane, rice, grain sorghum, and ornamental plantings. Native muskrats consume only the stems of aquatic plants, but nutria typically excavate the entire plant leaving little chance for regrowth. The cut stems may be used to build feeding stations. Their foraging activities destroy the root mat that is so important to soil stabilization in aquatic ecosystems. Without the root mat, erosion increases and vegetated marsh is converted into open water degrading the marsh habitat required by many wildlife species, and wetland vegetation regrowth is inadequate or nonexistent. These open areas, void of vegetation caused by foraging activities, are called "eatouts" and can result in permanent marsh loss. Burrowing activities can damage dikes, levees, and other water control structures. Nutria can also outcompete and displace native muskrat populations.

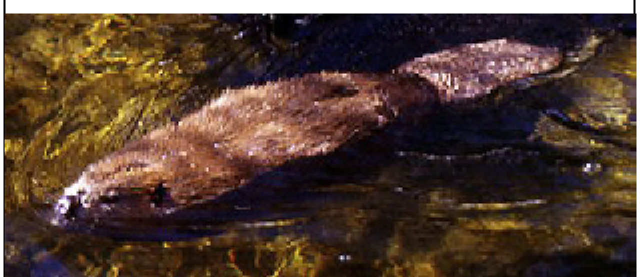
Beaver

Beavers are the largest living rodents in North America. Beavers are active year-round, mostly at night. The most obvious characteristic is the flat, paddle-like tail that is used for temperature regulation, fat storage, and for communication (during alarm situations). The scaly tail is also used as a rudder while swimming and for balance when cutting trees. The ears, nose, and mouth are valvular for underwater activities. A nictitating membrane covers the eyes for clear, underwater vision. Specialized toes on the hindfeet comb the fur and distribute water-repellent oil from two abdominal oil glands. Large castor (anal scent) glands produce castoreum, a yellowish-brown oil that is deposited on mud scent mounds to mark territory. Scent mounds are generally close to the water's edge and have a pungent smell. Family groups typically contain paired adults, three or four kits, and yearlings residing in one lodge or burrow. At the age of two years, young beavers are driven out of the family lodge and territory. Females can breed at 1 1/2 years of age.

Beaver (*Castor canadensis*)

Total length: 90-117 cm (35 1/2-46 in.)
Range: Most of Canada and the U.S. except for most of Florida and Nevada, and southern California.
Habitat: Rivers, streams, marshes, lakes, and ponds.
Comments: Beavers inhabiting faster moving rivers and streams burrow into the banks to create chambers with underwater entrances; others build stick-and-mud dams across streams and large conical lodges of sticks and mud at the water's edge (one or more underwater entrances); wood chips on floor absorb moisture, vent near top of lodge provides fresh air.





Mansell 1998. CVIOG/GeorgiaInfo

C. Rewa

Beaver manipulate wetland vegetation and hydrology by cutting trees for building dams on streams.

Beaver dams can enhance habitat for some wildlife by increasing water depth and aqautic invertebrate production.

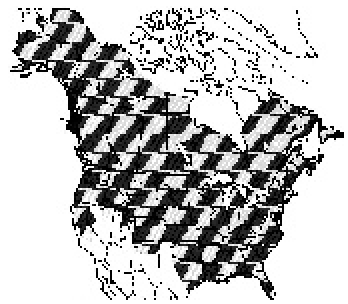
Beavers inhabit wooded lakes, streams, and rivers throughout much of North America. Beavers prefer the bark and green twigs of aspen, poplar, birch, maple, sweetgum, blackgum, black cherry, tulip poplar, and willow trees. Leaves and roots of woody plants are consumed along with grasses, sedges, and rushes during the summer. They use woody materials to build stick-and-mud dams, lodges, and underwater winter food caches.

The waterproof underfur is covered by long, dark brown guard hairs. Prime beaver pelts were the backbone of the fur trade in colonial times. Overharvesting almost caused the beaver's extinction. Repatriation of beavers to their former range, establishment of bag limits, and falling fur prices helped re-establish beaver populations in much of their former range.

Mink

The mink is a semi-aquatic member of the weasel family (Mustelidae). Mink were the first American furbearers to be raised in captivity for their pelts. Elongated bodies and waterproof fur allow the mink to swim easily and feed on crayfish, frogs, and fish. Mink also prey on small mammals, birds, and eggs. When the mink is threatened or disturbed, it releases musk from scent glands located in the anal region. The musk, along with droppings, is also used to mark territory on waterways. Mink are typically solitary and are primarily nocturnal.

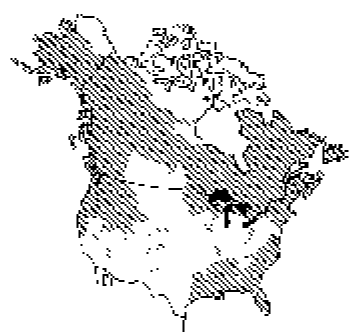
Mink (*Mustela vison*)
Total length: 49.1-72 cm (19 1/4-28 1/4 inches)
Range: Most of United States and Canada except Arizona, southern California, southern Utah, southern New Mexico, and western Texas.
Habitat: Along rivers, streams, lakes, ponds, and marshes.
Comments: Primarily nocturnal; males larger than females; both sexes can be hostile to intruders; one of the most valuable fur animals; rich dark brown, usually with a white chin patch; eyes are yellowish-green; male pelts usually worth more than female pelts because they are larger.



River otter

River otters are sociable, semi-aquatic members of the weasel family. Webbed feet and clawed toes, along

River otter (*Lutra canadensis*)
Total length: 88.9-131.3 cm (35-51 5/8 inches)
Range: Alaska, most of Canada south to northern California and northern Utah; Newfoundland south to Florida; extirpated from most of Midwest.
Habitat: Rivers, ponds, lakes, streams in wooded areas, but has been known to travel far from water.
Comments: Males larger than females; active during the day if isolated from human disturbance.



CVIOG/GeorgiaInfo

with a streamlined body and thick, tapered tail, help river otters move swiftly underwater. Fish, crayfish, frogs, salamanders, snails, turtles, snakes, small birds, and some vegetation make up the river otter's diet. Otters are chiefly nocturnal, but can be seen during the day playing with each other or their food. Slides are smooth grass-, mud- or snow-covered slopes at the water's edge up to 25 feet long that river otters use repeatedly. Otters typically have 1-5 kits that stay with the parents for as long as one year. Dense, oily underfur limits the market value of river otter pelts.

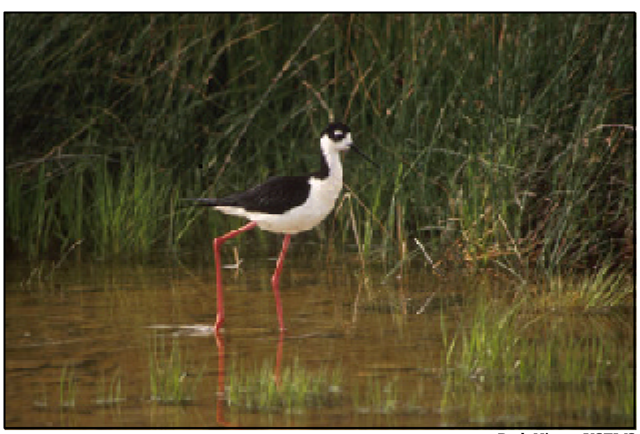
Other mammals

Other mammals such as raccoons, black bears, white-tailed deer, and moose use wetlands extensively, but also rely on a variety of upland habitats. Raccoons are associated with forests, wooded swamps, streams, and lakes. Black bears may wade into lakes and streams to catch an occasional fish (black bears eat mostly vegetable matter). White-tailed deer are generally considered an upland species, but find food and cover in wetland habitats. Moose feed on submerged wetland vegetation, and use water as an escape from biting insects. Moose are typically found in spruce forests and aspen and willow thickets close to water.

Raccoon, black bear, white-tailed deer, and moose are some upland mammals that are also associated with wetland habitats.

Habitat Management for Wetland Mammals

Habitat management practices applied to a particular wetland depends on the goals of the landowner or manager. Management efforts can be directed toward a specific wildlife species, or aimed at increasing the overall biodiversity of wetlands and associated upland habitats. Successful efforts usually increase seed sources, invertebrate populations (an important food source for waterfowl and other birds, small mammals, fish, and amphibians) and other wetland mammal foods. Management efforts should also address the cover needs of targeted species.



Ruth Nissan, USFWS

Shorebirds like the black-necked stilt, wading birds, and waterfowl can benefit from vegetation management and water level manipulation conducted to improve wetland mammal habitat.

Wetland mammal habitat management typically involves manipulating the hydrologic condition (defined as the rate and timing of inflow and outflow, source, duration, frequency, and depth of flooding, ponding, or saturation), hydrophytic plant communities, and/or other habitat components. Many factors affect management practices including:

- topography, shape, and size of the wetland;
- water quality, depth, and natural/controlled fluctuating water level;
- soil characteristics (especially if plantings are a consideration);
- local climate;
- existing and desired vegetation species, composition, and structure;
- existing wildlife species and populations; and

- condition and management of associated upland habitats.

Managers should consider how proposed management actions would affect the following topics before taking action:

- impact on existing wetland functions;
- change in plant growth rate or composition due to changes in volume of available water;
- effects on downstream flows, associated wetlands, and other water-related resources;
- effects on water temperature as related to plant growth or fish and wildlife populations;
- effects of management on non-target fish and wildlife species, and threatened and endangered species;
- effects of livestock grazing on run-off, infiltration, and wetland vegetation; and
- value of adjacent wetlands or bodies of water that contribute to the wetland system complexity and diversity, decrease habitat fragmentation, and maximize use of the site by wetland associated wildlife.

Physical habitat management practices such as disking, mowing, and prescribed burning should be avoided during the nesting and brooding season (March to August). Landowners and managers should consult wetland and wildlife professionals to decide on the most appropriate course of action to meet habitat management objectives.

Water level management

Providing a variety of water depths can maximize food and cover for wetland mammals and other wildlife. Natural water cycles depend on how close the water table is to the surface, natural inflow/outflow sources such as streams and rivers, and seasonal water fluctuations. Irregular, gently rolling topography helps create varying water depths that suit plant species with different levels of water tolerance, and habitat needs for invertebrates, waterfowl and other birds, amphibians, fish, reptiles, and wetland mammals.

In natural wetland systems, water levels may fluctuate seasonally, providing a variety of hydrologic conditions throughout the year. Tidal wetlands typically have regular, daily fluctuations, with greater fluctuations associated with storms and monthly spring tides. When possible, wetland hydrology management practices should support or mimic these natural cycles.

G. Kramer

Drop-log inlets and other water control structures can be installed to enable managers to manipulate water levels on restored and created wetlands.

Water control structures are commonly used to create and restore wetlands by artificially manipulating water levels. In addition, a variety of water depths can be established by creating surface contours and microtopographic relief with construction equipment during the wetland creation or restoration process. The best time to manipulate surface contours is before hy-

C. Rewa

Surface contours can be excavated during the wetland restoration process to increase the diversity of water depths and associated wetland vegetation.

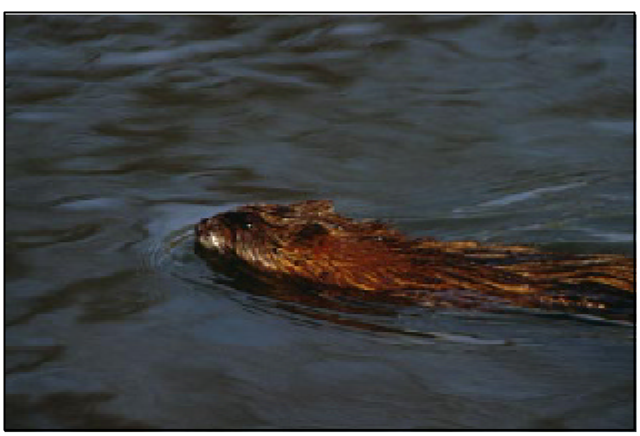
drology is returned to wetlands being restored or when water levels are artificially drawn down.

Disturbing the hydrology of naturally functioning wetland systems is not usually recommended. Landowners and managers should consult federal, state, and local wetland regulatory authorities before manipulating wetland hydrology.

Vegetation management

When used in combination with other methods of vegetation management, water level manipulation can significantly influence vegetation composition and associated wildlife. High water levels, resulting from natural flood cycles or managed flooding, can be used to control undesirable vegetation or help reduce high wetland herbivore populations. Lowering water levels can stimulate germination of emergent wetland plants. Reflooding abandoned beaver ponds can also rejuvenate some wetland vegetation and increase biodiversity.

Disking is a mechanical method used to control or break up dense stands of undesirable vegetation on managed wetlands. Some managed wetlands can be drained, disked, and then reflooded. Disking benefits wetland vegetation because it aerates the soil and exposes drained soils to sunlight, which stimulates germination of moist soil plant seeds and invertebrate production. The entire process is generally conducted on annual, 3-year, or 5-year intervals, depending on management goals. Other management practices may accompany disking to achieve a specific management objective, such as prescribed burning or mowing to control invading woody species.



Jim and Karen Hollingsworth, USFWS

Muskrats can reduce dense stands of emergent wetland vegetation. High muskrat populations can also cause eatouts, leaving wetland habitats temporarily void of emergent vegetation.

In some situations, prescribed burning can be used to reduce emergent vegetation and revert plant communities back to earlier successional stages. New growth stimulated by fire attracts a variety of wildlife. When used in combination with disking or mowing, prescribed burning can be an effective habitat management tool. Benefits of prescribed burning on herbaceous wetlands may include:

- ❖ reducing dense or impenetrable stands of undesirable vegetation;
- ❖ exposing seed for wildlife use;
- ❖ improving soil conditions for seeds and stimulating germination;
- ❖ stimulating vegetation growth used as wildlife food and cover;
- ❖ opening up dense stands of vegetation for waterfowl movement; and
- ❖ helping control woody vegetation and invasive species.

Prescribed burning should be conducted under proper weather conditions and under the supervision of licensed personnel. Water control structures help regulate water flow before and after burning. Burning should be avoided during the nesting season (March to August) and during times of drought.

Plantings can increase the amount of desirable vegetation in newly created or restored wetlands, and in wetlands dominated by undesirable vegetation. However, planting vegetation can be expensive and time-consuming. Undesirable plant species may need to be removed before planting desirable species to help ensure success.

Other vegetation management methods include mowing, prescribed grazing, and managing wildlife species that have the ability to alter habitat, such as beavers and muskrats. Muskrats can open up dense stands of cattails. Openings created by muskrat foraging can make emergent wetlands more attractive to waterfowl,

The following is a list of possible management actions to enhance habitat value for wetland mammals. NRCS Conservation Practices and various programs that may provide financial or technical assistance to carry out specific managment practices are listed where applicable.

Habitat component	Management options for increasing habitat quality or availability	Conservation practices and assistance programs*
Food	Restore natural wetland hydrology and vegetation in previously converted or degraded wetlands.	657 WRP, PFW
	Protect coastal and freshwater wetlands, marshes, lakes, and ponds from siltation and non-point source pollution by establishing conservation buffers, controlling livestock access, and providing bank stabilization through vegetation plantings.	393, 643, 657 WRP, WHIP, EQIP, PFW, CRP
	Reduce herbicide use on wetlands and adjacent uplands where application results in reduction of invertebrates (terrestrial or aquatic).	
Cover	Protect existing wetlands and restore natural wetland hydrology and vegetation to previously converted or degraded wetlands.	657 WRP, PFW
	Allow vegetation to grow in grassland meadows and prairies and conduct appropriate grassland management practices such as prescribed burning, managed grazing, and rotational mowing.	327, 338, 528A, 644, 645 WHIP, EQIP, PFW
	Manage water levels to provide a variety of water depths and associated wetland vegetation structure.	
	Increase surface contour diversity by excavating small swales, islands, and level channels prior to re-establishing hydrology in restored wetlands or during the draw-down phase of managed wetlands.	657 WRP, PFW
	Establish conservation cover on adjacent croplands and other disturbed areas and initiate rotational grazing on surrounding grazing lands.	327, 528A, 647 CRP, EQIP
Habitat interspersion	Combine above prescriptions to increase interspersion of habitat components and amount of suitable habitat.	

* See table on page 18 for a description of assistance programs.

especially where the ratio of vegetation to open water is maintained at around 50:50 with good interspersion throughout.

In general, grazing should be restricted in riparian areas through fencing or other means. Maintaining or expanding riparian buffer zones along streams and other waterways, or around lakes, ponds, and other bodies of water increases the amount and availability of wildlife habitat.

Glyphosphate-based herbicides formulated for use on wetland vegetation (e.g., Rodeo®—reference to products does not imply endorsement) have been used to

NRCS Conservation Practices that may be useful in undertaking the above management actions.

Conservation Practice	Code
Conservation Cover	327
Prescribed Burning	338
Riparian Forest Buffer	391
Filter Strip	393
Prescribed Grazing	528A
Restoration & Management of Declining Habitats	643
Wetland Wildlife Habitat Management	644
Upland Wildlife Management	645
Early Successional Habitat Development	647
Wetland Restoration	657

Effects of Beaver Activity

Benefits of beaver ponds:

- Enhance habitat for a variety of wildlife such as cavity-nesting waterfowl and other nesting birds (trees killed by flooding support nests of herons, egrets, ospreys, and other birds), aquatic invertebrates, reptiles, amphibians, and other wetland mammals.
- Improve warm water fish habitat by increasing water depth and water temperature thereby increasing aquatic invertebrate food production. Note: Habitat for cold water fish (e.g., trout) downstream of beaver ponds may be compromised by increasing water temperatures and restricting upstream movements.
- Provide suitable nesting, brood-rearing, foraging, and migration habitat for waterfowl, shorebirds, wading birds, and other birds.
- Reduce water velocity and eroding potential of streams.
- Reduce peak and frequency of flooding.
- Provide fertile substrate for new herbaceous growth when area is abandoned by beavers or pond is permanently drained.

In general, beaver activities establish, maintain, and enhance affected wetland habitats. However, there are cases when beaver activity results in inundation of roads or economically valuable areas. Beavers typically try to plug up what they perceive as "leaks" in water control structures, culverts, and drain pipes. These structures plugged by beavers can result in flooding and damage to roadways, agricultural fields, dwellings, timber, and other property. Southeastern states have experienced extensive timber damage caused by tree-cutting and flooding by beavers, especially in bottomland hardwood stands. Use of beaver pond levelers (see box on next page) and other measures can minimize economic losses associated with beaver activity.

CVIOG/GeorgiaInfo

The eastern newt and other amphibians can benefit from vegetation management and water level manipulation directed at wetland mammal management.

control *Phragmites* and other invasive plants. However, herbicides are not generally recommended to control wetland vegetation because most are not species-specific. More importantly, herbicides can have negative effects on some aquatic life and ecosystems, and the toxic effects of many herbicides remain unknown.

Environmental Effects of Wetland Mammal Activity

Wetland mammals can affect wetland habitats in a variety of ways. Herbivores such as beavers, nutria, and muskrats can significantly alter vegetation structure and composition, while omnivores and carnivores can affect small mammal and invertebrate populations. Ground-dwelling mammals, like the star-nosed mole and various vole species, can aerate soil but can also

CVIOG/GeorgiaInfo

While not considered a wetland mammal, white-tailed deer frequently use shrub swamps, forested wetlands, and other wetland habitats. In northern areas, dense stands of conifer trees in and around wetland areas provide thermal cover for deer during winter.

limit root and plant growth as a result of their foraging activities. Mink can affect upland nesting waterfowl, eggs, and young.

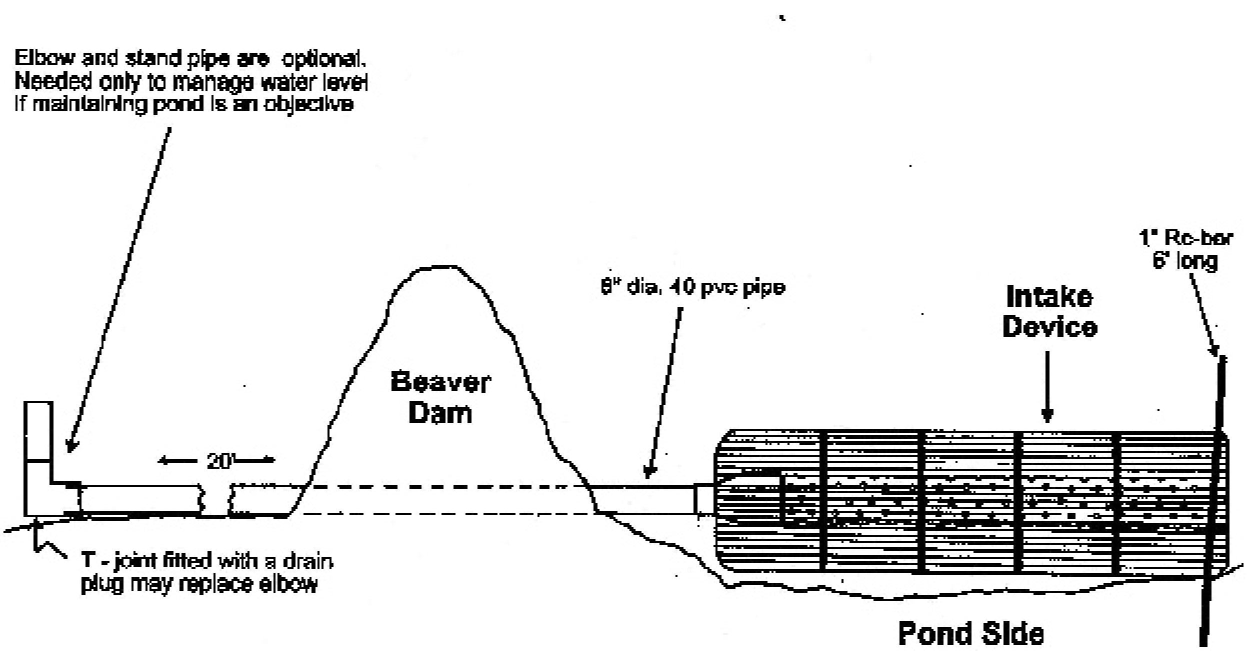
Damage Prevention and Control Methods

High densities of some wetland mammals can create challenges for wetland owners and managers. Landowners are encouraged to enroll the help of local animal damage control agents and wildlife or natural resource professionals to help correctly identify problem species and control methods. For detailed information on population control methods and species-specific signs of damage, see *Prevention and Control of Wildlife Damage—1994* (Hyngstrom et al. 1994).

Trapping can be an efficient and economical method to control overabundant populations of wetland mammals or problem individuals. Hunting and trapping regulations are available through state fish and wildlife

The Clemson Beaver Pond Leveler

The Clemson Beaver Pond Leveler was designed to: 1) reduce problem flooding in agricultural and timber lands, and 2) maintain and/or improve some benefits resulting from beaver ponds. The pond leveler minimizes the sound of current flow, and the probability that the resident beavers will try to plug up the " leak," minimizing dam construction. For more information about The Clemson Beaver Pond Leveler, contact Dr. Gene W. Wood, Mr. Larry A. Woodward, or Dr. Greg Yarrow at the Department of Aquaculture, Fisheries, and Wildlife, G08 Lehotsky Hall, Clemson University, Clemson, South Carolina, 29634 or by phone at (803) 656-3117.



Programs that provide technical and financial assistance to develop fish and wildlife habitat on private lands.

Program	Land eligibility	Type of assistance	Contact
Conservation Reserve Program (CRP)	Highly erodible land, wetland and certain other lands with cropping history. Stream-side areas in pasture land.	50% cost-share for est. permanent cover and conservation practices, and annual rental payments for land enrolled in 10 to 15 year contracts. Additional financial incentives available for some practices.	NRCS or FSA state or local office
Environmental Quality Incentives Program (EQIP)	Cropland, range, grazing land and other agricultrual land in need of treatment.	Up to 75% cost-share for conservation practices in accordance with 10- to 15-year contracts. Incentive payments for certain management practices.	NRCS state or local office
Partners for Fish and Wildlife Program (PFW)	Most degraded fish and/ or wildlife habitat.	Up to 100% finanical and technical assistance to restored widlife habitat under a minimum 10-year cooperative agreement.	Local office of the U.S. Fish and Wildlife Service
Waterways for Wildlife	Private lands.	Technical and program development assistance to coalesce habitat efforts of corporations and private landowners to meet common wateshed level goals.	Wildlife Habitat Council
Wetlands Reserve Program (WRP)	Previously degraded wetland and adjacent upland buffer, with limited amount of natural wetland and existing or restorable riparian areas.	75% cost-share for wetland restoration under 10-year contracts and 30-year easements, and 100% cost-share on restoration under permanent easements. Payments for purchase of 30-year or permanent conservation easements.	NRCS state or local office
Wildlife at Work	Corporate lands.	Technical assistance on developing habitat projects into programs that allow companies to involve employees and the community.	Wildlife Habitat Council
Wildlife Habitat Incentives Program (WHIP)	High-priority fish and wildlife habitats.	Up to 75% cost-share for conservation practices under 5- to 10-year contracts.	NRCS state or local office

State fish and wildlife agencies as well as private groups may have assistance programs.

agencies. Readers are also encouraged to contact local agents of the USDA Animal and Plant Health Inspection Service Wildlife Services and state fish and wildlife agencies to address specific problems.

Landowner Assistance

A number of programs are available that offer financial and technical assistance to improve habitat quality for wetland mammals (see above table). With the help of such programs and assistance from wildlife and natural resource professionals, landowners will be able to devise and implement a successful habitat management plan for wetland mammals and other wildlife.

References

Atwood, E. L. 1950. Life history studies of nutria, or coypu, in coastal Louisiana. Journal of Wildlife Management 14:249-265.

Bluett, R. 1984. The muskrat. Wisconsin Department of Natural Resources, Bureau of Wildlife Management. Publ-WM-00984.

Bolen, E. G., and W. L. Robinson. 1995. Wildlife ecology and management, third edition. Prentice Hall, Upper Saddle River, New Jersey, USA.

Bookhout, T. A. 1996. Research and management techniques for wildlife and habitats. The Wildlife Society, Bethesda, Maryland, USA.

Bounds, D. L. 2000. Nutria: an invasive species of national concern. Wetland Journal 12(3):9-16.

Bounds, D. L., and G. A. Carowan, Jr. Nutria: a nonnative nemesis. Trans. 65th North American Wildlife and Natural Resources Conference.

Burt, W. H. and R. P. Grossenheider. 1980. A field guide to the mammals: North America and Mexico. Houghton-Mifflin, New York, New York, USA.

Cowardin, L. M., V. Carter, F. C. Golet, and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. U.S. Fish and Wildlife Service. FWS/OBS-79/31.

Evans, J. 1970. About nutria and their control. U.S. Fish and Wildlife Service, Resource Publication 86.

Godin, A. J. 1977. Wild mammals of New England. Johns Hopkins University, Baltimore, Maryland, USA.

Hammer, D. A. 1992. Creating freshwater wetlands. Louis Publishers, Chelsea, Minnesota, USA.

Helms, J. A., ed. 1998. The dictionary of forestry. The Society of American Foresters, Bethesda, Maryland, USA.

Hobson, S. S., J. S. Barclay, and S. H. Broderick. 1993. Enhancing wildlife habitats: a practical guide for forest landowners. Northeast Regional Agricultural Engineering Service. NRAES-64. Ithaca, New York, USA.

Hyngstrom, S. E., R. M. Timm, and G. E. Larson., eds. 1994. Prevention and control of wildlife damage—1994. University of Nebraska Cooperative Extension, USDA Animal and Plant Health Inspection Service, and Great Plains Agricultural Council, USA.

Illinois Wildlife. Mink. Illinois Department of Conservation. 20M-7-81.

Kinler, N. W., G. Linscombe, and P. R. Ramsey. 1987. Nutria. Pages 327-342 *in* Wild Furbearer Management and Conservation in North America. M. Novak, J. A. Baker, M. E. Obbard, and B. Mallock, eds.

LeBlanc, D. 1994. Nutria. Animal and Plant Health Inspection Service. Animal Damage Control, Port Allen, Louisiana, B71-B80.

Merritt, J. F. 1987. Guide to mammals of Pennsylvania. University of Pittsburgh, Pittsburgh, Pennsylvania, USA.

Milne, R. C. and T. L. Quay. 1966. The foods and breeding habits of the nutria on Hatteras Island, North Carolina. Proceedings of the Annual Conference of Southeastern Association Fish and Game Commissions 20:112-113.

Mitsch, W. J. and J. G. Gosselink. 1986. Wetlands. Van Nostrand, Reinhold, New York, USA.

Naiman, R. J., J. M. Melillo, and J. E. Hobbie. 1986. Ecosystem alteration of boreal forest streams by beaver (*Castor canadensis*). Oecologia 62:150-55.

National Audubon Society. 1993. Saving wetlands: a citizen's guide for action in the mid-Atlantic region. Mid-Atlantic Regional Office, Camp Hill, Pennsylvania, USA.

Niering, W. A. 1992. Wetlands. Alfred A. Knopf, New York, New York, USA.

Payne, N. F. 1992. Techniques for wildlife habitat management of wetlands. McGraw-Hill, New York, New York, USA.

Willner, G. R., J. A. Chapman, and D. Pursley. 1979. Reproduction, physiological responses, food habits, and abundance of nutria on Maryland marshes. Wildlife Monographs No. 65.

Wood, G. W. and L. A. Woodward. 1992. The Clemson beaver pond leveler. Proceedings Annual Conference Southeast Association Fish and Wildlife Agencies 46:179-187.

Wildlife Habitat Management Institute
100 Webster Circle, Suite 3
Madison, Mississippi 39110
(601) 607-3131

In cooperation with partners, the mission of the Wildlife Habitat Management Institute is to develop and disseminate scientifically based technical materials that will assist NRCS field staffs and others to promote conservation stewardship of fish and wildlife, and deliver sound habitat management principles and practices to America's land users.

www.whmi.nrcs.usda.gov

Wildlife Habitat Council
1010 Wayne Avenue, Suite 920
Silver Spring, Maryland 20910
(301) 588-8994

The mission of the Wildlife Habitat Council is to increase the amount of quality wildlife habitat on corporate, private, and public land. WHC engages corporations, public agencies, and private, non-profit organizations on a voluntary basis as one team for the recovery, development, and preservation of wildlife habitat worldwide.

www.wildlifehc.org

Primary author: Holly L. May, Wildlife Habitat Council

NRCS Natural Resources Conservation Service

Wildlife Habitat Management Institute

WILDLIFE HABITAT COUNCIL

Wading Birds

May 2005 *Fish and Wildlife Habitat Management Leaflet* *Number 16*

General information

Wading birds are most commonly associated with wetlands, streams, and other aquatic habitats. Most wading birds possess long legs and toes, and long and sometimes curved bills – adaptations enabling them to live and feed in shallow-water habitats. This leaflet addresses birds in the orders Ciconiformes (herons and their allies) and Gruiformes (cranes and their allies). Common wading birds of the United States are represented in table 1.

Wading birds rely heavily on wetland habitats including inland and coastal emergent marshes and wooded swamps. Throughout the history of the United States wetlands have been converted for agriculture, residential, commercial, and other land uses. More than half of the country's original wetland acreage has been converted to other land uses in the last two centuries. California leads the United States in wetland acres drained followed by Ohio, each having lost more than 90 percent of their original wetland acreage. Many adjacent native grassland and forest habitats have also undergone significant land use changes. As a result, many species of wading birds that depend on these habitats have suffered significant population reductions, with some populations still in decline. Protecting and properly managing existing wetland communities can help maintain and enhance populations of wading birds and other wildlife species that live in similar habitats.

This leaflet is designed as an introduction to the habitat requirements of wading birds and to assist landowners and managers in developing comprehensive wading bird management plans. The success of any management plan depends on targeting specific needs of the species of interest and analyzing designated habitat areas to ensure all required habitat elements are provided. Practical habitat management activities that can be conducted on private lands to attract wading birds and help maintain existing populations are included. This leaflet encourages involving fish and wildlife professionals to identify and address additional management goals.

Great blue heron (Ardea hedodias)

Range

The ranges of various wading bird species in the United States differ greatly. Some non-migratory species have relatively restrictive ranges, whereas some migratory species have extensive ranges. Migratory waders common to the United States can possess ranges encompassing nearly the entire country.

Habitat requirements

General

Although there are similarities among many species' habitat requirements, management to meet the needs of one species may not benefit other species. It is beyond the scope of this leaflet to identify detailed habitat requirements for individual wading birds in separate regions, but generalizations for groups of wading birds and broad concepts for managing their habitats are presented.

Wading birds are naturally adapted to wetlands, streams, and other aquatic ecosystems in North America. Habitats used by wading birds are diverse - ranging from aquatic complexes to dry upland meadows, pastures, and crop fields (table 2). Inland freshwater ponds, lakes, streams, wetlands with emergent aquatic vegetation, coastal marshes, riparian and wooded wetlands and bogs, mangroves, and estuaries are the most common sites used for feeding and nesting. The cattle egret, a member of the heron family, relies almost totally on pasture and upland grassland habitats. However, the snowy egret seeks nest sites among mangroves and salt marshes. Upland forest communities and small clusters of trees and shrubs near wetland habitats provide nesting and roosting sites for some wading birds. Trees and shrubs are particularly important as nest sites for herons, egrets, and other colonial nesters.

Food

Fish, aquatic and terrestrial invertebrates, amphibians, reptiles, and crustaceans are common foods consumed by wading birds. Diets also include wetland plant seeds, small mammals such as voles, shrews, and pocket gophers, and occasionally other birds. Most waders are opportunistic feeders, capturing food items using bills adapted to probe mud and animal burrows; spear fish, frogs, and other small animals; or to strain aquatic invertebrates and other edible material from the water. Many waders feed standing in or perching over shallow water less than 12 inches deep. Most wading birds are migratory and occupy a variety of habitats ranging from coastal and freshwater shoreline habitats, grassland and scrub communities, and agricultural fields and pastures. Thus food items consumed vary among species, seasons, regions, and habitats.

Colonial and solitary nesting

Some wading bird species nest in colonies while others are solitary nesters. Improving foraging efficiency is the primary advantage of colonial nesting. Young birds of a nesting colony learn from older birds experienced in finding feeding grounds. For herons, foraging success improves with age. Adult great blue herons are twice as successful at locating feeding sites as juveniles. Protection from predators is a secondary benefit of colonial nesting. Individuals or nesting pairs within the colony protect or expose eggs and young to predation, depending on behaviors characteristic to the species. In a "selfish colony," typically comprised of several hundred nesting pairs, protects the eggs and young of the dominant birds nesting in the center of the colony are protected while eggs and young of inexperienced pairs are left more subject to predation. The colonial behavior known as mobbing (where several birds attack as a group) also acts as a defense against predators.

American bittern (Botaurus lentiginosus)

Cover – colonial nesting

Colonial nesting sites hold a few pairs to thousands of pairs of nesting birds. Heronries contain single or mixed species. Ibises, egrets, and herons often nest together in clumps of woody vegetation close to fresh or salt water swamps and marshes, lakes or other bodies of water. Ibises nest in shrubs or low trees, sometimes over water. Egrets choose nesting sites in trees 5 to 40 feet off the ground. Herons nest in shrubs or trees up to 80 feet tall. Great blue herons usually take nesting sites in the tops of the tallest trees in large heronries of mixed species. Nesting cover for members of the order Ciconiiformes varies by region, but ranges from conifer and mixed hardwood forests, to shrubs, mangroves, bulrushes, and rock ledges. Colonial nesting sites can be noisy (especially after young hatch) and have an unpleasant odor. Ground cover under the heronry or rookery is usually splattered with fecal material and feathers.

Cover – solitary nesting

Most solitary nesters are secretive marsh birds of the order Gruiformes (rails and bitterns). Primary social units include the mated pair and brood. These wad-

Table 1 Common wading birds in the United States

Order	Family	Species representatives
Ciconiiformes	Ardeidae	herons, bitterns, egrets
	Ciconiidae	wood stork
	Threskiornithidae	ibis, spoonbill
Gruiformes	Aramidae	limpkin
	Gruidae	cranes
	Rallidae	rails, coot, moorhen
Phoenicopteriformes	Phoenicopteridae	greater flamingo

Table 2 Habitat characteristics of common wading birds in the United States

Species		**Habitat**	**Preference** [1]		**Nesting habits** [2]
	Emergent marsh	**Open water**	**Herbaceous uplands**	**Trees & shrubs**	
American bittern	F, N	F	F		S
least bittern	F, N	F			S
great blue heron	F	F		N	C
great egret	F	F		N	C, S
snowy egret	F	F		N	C
little blue heron	F		F	N	C
cattle egret			F	N	C
green heron	F, N	F		N	S, C
black-crowned night heron	F, N	F		N	C
yellow-crowned night heron	F	F		N	C
white ibis	F, N	F		N	C
white-faced ibis	F			N	C
wood stork		F		N	C
yellow rail	F, N		F		S
black rail	F, N				S
clapper rail	F, N				S
king rail	F, N		N		S
Virginia rail	F, N				S
sora	F, N				S
purple gallinule	F, N				S
common moorhen	F, N	F	F		S, C
American coot	N	F	F		S
sandhill crane	N		F, N		S

[1] F = Feeding, N = Nesting
[2] C = Colonial, S = Solitary

ing birds prefer fresh or salt water marshes, swamps, and wet meadows, and depend on several kinds of emergent vegetation for cover and nest materials. The nests of rails and bitterns are hard to find because they are on the ground and canopied with vegetation. The natural camouflage of grasses and perennial plants in nesting areas and the elusive nature of these webless marsh birds makes estimating populations difficult.

Common wading bird food items

Fishes

- gizzard shad, herring, minnows, dace, shiners, carp, chubs, killifishes, suckers, pickerel, sticklebacks, catfishes, small eels, other small fishes

Aquatic insects

- water boatman, back swimmers, water scorpions, giant water bugs, diving beetles, dragonfly nymphs, caddisflies, mayfly nymphs, pillbugs, mosquito larvae, larvae of: flies, midges, crane flies, soldier flies, dance flies, snipe flies, horseflies, brine flies, flower flies, water beetles

Crustaceans and other aquatic invertebrates

- crayfish, snails, worms, mollusks, amphipods, blue crabs, fiddler crabs, hippa crabs, eggs of horseshoe crabs, shrimp, squid, clams, mussels, leeches

Reptiles and amphibians

- lizards, garter snakes, queen snakes, water snakes, and adults and tadpoles of frogs, toads, and salamanders

Terrestrial invertebrates

- grasshoppers, crickets, beetles, caterpillars, cutworms, earthworms, bloodworms, slugs, spiders, ants

Plants (roots, shoots, tubers, and seeds)

- grasses, sedges, cultivated and wild rice, wild berries, wheat, corn, sorghum, bulrushes, pondweeds, wigeon grass, smartweeds

Birds and mammals

- small birds, mice, voles, lemmings, small rats, shrews, ground squirrels, pocket gophers

Black-crowned night heron (Nycticorax nycticorax)

Sandhill cranes are also solitary nesters and establish nesting territories on prairie potholes, freshwater marshes, open mountain meadows, mixed conifer and hardwood forests, or lowland tundra areas. These wading birds need adequate emergent vegetation to build their nests, 4 to 5 feet in diameter, on mounds above water. Agricultural lands provide the bulk of their food on migration routes, so crop fields interspersed with wetlands create preferred habitat.

Cover – winter

Winter habitat requirements differ little from those of summer months. Combinations of inland freshwater and coastal aquatic systems with grassland, agricultural, and upland habitats are used by wading birds throughout winter months. In the southern United States and California's Central Valley, flooded crop fields (rice) provide extra nutrition to year-round residents and wintering waders.

Water

Foods consumed by wading birds provide an adequate amount of water.

Interspersion of habitat types

Interspersion of aquatic ecosystems and non-aquatic habitats helps maximize habitat quality for many wading bird species. However, many area-sensitive obligate wading species require large, unbroken blocks of aquatic complexes with little or no interspersion of other habitats. For this reason, it is important to consider landowner objectives, local landscape features, and future goals for species of concern when preparing management plans for wading birds.

Wading bird habitat management

Fashion trends in the early 1800s and 1900s nearly led herons, egrets, and others to extinction. The breeding plumage of these wading birds was sought after for decorating hats and dresses. Plumes in good condition from live birds were more highly valued than those found on the ground in heronries and rookeries. In response to the millinery trade and rapidly decreasing populations, the American Ornithologist's Union proposed the Model Law in 1884 drafted "for the protection of North American Birds and their eggs, against wanton and indiscriminate destruction." The Model Law was not a successful solution, but it promoted public awareness and helped jumpstart conservation legislation in North America.

Today, wetland habitat loss and degradation are primarily responsible for declining populations of wading birds. The effects of pesticides and herbicides on wading birds and their food sources also contribute to the decline.

The various species and groups of wading birds require a variety of habitat conditions (table 3). For example, nesting success of rails is directly related to water depth and distance to open water, and they prefer a certain degree of salinity and moderate level of vegetation structure. Habitat management plans designed for rails should focus on maintaining natural structure and function of tidal marshes. Management actions could include maintaining or restoring altered tidal flow. Periodic prescribed burning has been used to reduce overgrown grasses, allowing rails to move freely through vegetative cover.

Sandhill cranes require adequate wetland habitat for pair formation and foraging. The suppression of fire in the southern breeding ranges has increased brush and litter and allowed open lands to convert to pine forests. The accumulation of litter and succession of open lands to forest has reduced food availability and suitable nesting cover for sandhill cranes. Prescribed burning in Florida's Okefenokee Swamp and in Jackson Hole, Wyoming, has been shown to benefit sandhill crane populations. These fires also reduce invading vegetation on sedge meadows and increase earthworm activity, an important food item for juvenile sandhill cranes.

Table 3 General wading bird habitat requirements

Habitat component	Habitat requirements
Food	Fish – gizzard shad, herring, minnows, dace, shiners, carp, and others
	Aquatic invertebrates – midges, mosquito larvae, caddis flies, and others
	Crustaceans and other aquatic invertebrates – crayfish, snails, mollusks, crabs, and others
	Reptiles and amphibians – lizards, snakes, adult and tadpoles of frogs, toads, and salamanders
	Terrestrial invertebrates – spiders, crickets, beetles, caterpillars and others
	Plants – grasses, sedges, rice, wild berries, roots and tubers of aquatic plants, wheat, corn, sorghum, seeds of bulrushes, pondweeds, wigeon grass, and smartweeds
	Birds and mammals – small shore and wading birds and small mammals
Cover – colonial nesting	On the ground in dry uplands or swampy prairies, or along pond or lakeshores; in shrubs or low trees, conifer and mixed hardwood forests, mangroves, or rock ledges; all nesting cover should be in close proximity to water – fresh or salt water swamps and marshes, lakes, rivers, streams, ponds, and coastal tidal marshes
Cover – solitary nesting	Perennial vegetation (bulrushes, cordgrass, etc.) in fresh or salt water marshes and swamps, mudflats, wet meadows, or open prairie adjacent to crop fields
Winter cover	A wetland complex of inland fresh and salt water areas and coastal aquatic systems adjacent to grassland or agricultural areas
Water	Daily foraging activities and the types of foods eaten provide daily water needs
Interspersion	Some wading bird species prefer interspersion of various types of aquatic ecosystems and a mixture of aquatic and non-aquatic habitats
Minimum habitat size	Size of nesting and feeding habitat can vary considerably between different species of wading birds

Conducting appropriate grassland and prairie management practices such as prescribed burning, managed grazing, and rotational mowing can help increase nesting and brood-rearing cover for some species of wading birds. Other waders benefit from wetland management by seasonal water drawdown, planting of native wetland vegetation, and various practices of forest management such as prescribed burning and stand thinning.

Minimum habitat area

The amount of habitat required for nesting and feeding varies among wading bird species. Great blue herons will travel up to 18 miles to find food, but typically forage within three miles of suitable nesting habitat. Some species, like the sora, require little cover and nest in small patches of marsh vegetation. Distribution and interspersion of food and cover resources greatly affect the suitability of wading bird habitat. For colonial and solitary nesters, the proximity of suitable nesting habitat to foraging habitat is usually the main factor affecting wading bird use of the area.

Limiting factors

Based on the above habitat requirement descriptions, use table 4 to rate availability and quality of wading bird habitat in a defined planning area. Habitat communities and components that are absent or rated low are probably limiting habitat quality.

Management prescriptions

Management treatments should address habitat components that are determined as limiting wading bird habitat potential. For planning purposes, select from possible action items listed in table 5 to improve the quality or availability of each limiting habitat component. NRCS Conservation Practices (table 6) and various programs (table 7) may provide financial or technical assistance to carry out specific management practices and are listed where applicable.

Green heron (Butorides virescens)

Available assistance

Corporate and private landowners interested in improving wading bird habitat can work with the Wildlife Habitat Council and NRCS, and encourage interested employees to volunteer. Schools and community groups in conjunction with Federal, state, and non-profit organizations also produce successful habitat projects. Environmental education programs offered by state agencies, universities and non-profit groups heighten public awareness of wading bird habitat and conservation issues. Table 7 provides general information on a variety of assistance programs available through public and private institutions.

Table 4 Limiting factors for habitat components

Habitat Component	Availability/Quality			
	High	Medium	Low	Absent
Food				
Cover – colonial nesting				
Cover – solitary nesting				
Winter cover (may not apply to areas in which wading birds do not winter)				
Interspersion of habitat components				

Table 5 Management options, conservation practices, and assistance programs

Habitat component	Management options for increasing quality or availability	Conservation practices and assistance programs
Food	Protect and restore coastal and freshwater wetlands, marshes, lakes and ponds from siltation and non-point source pollution by fencing livestock and providing bank stabilization through aquatic and bank vegetation plantings	390, 643, 657, WRP, WHIP, EQIP, PFW, CRP
	Restore natural hydrology and vegetation to the previously degraded wetlands	
	Reduce herbicide use on grasslands, especially near water, where application results in reduction of invertebrates (either terrestrial, marine, or freshwater) used for food	
Cover – colonial nesting	Protect large forested tracts that support large colonies of colonial nesting birds	391
Cover – solitary nesting	Encourage native vegetation in grassland meadows and prairies, and conduct appropriate grassland management practices such as prescribed burning, managed grazing, and rotational mowing	327, 338, 528A, 645 WHIP, EQIP, PFW
	Restore natural hydrology and vegetation to the previously degraded wetlands	
	Reduce herbicide use when application results in loss of nesting, loafing, brood-rearing, or winter cover	
Winter cover	Protect and restore coastal and freshwater wetlands, marshes, lakes and ponds from siltation and non-point source pollution via fencing of livestock	390, 643, 657 WHIP EQIP, PFW, CRP, WRP
	Restore natural hydrology and vegetation to the previously degraded wetlands	
Interspersion and minimum habitat size	Combine above prescriptions to increase interspersion of habitat components and amount of suitable habitat.	

Table 6 NRCS conservation practices that may apply to wading bird management

Code	Conservation practice
327	Conservation cover
338	Prescribed burning
390	Riparian herbaceous cover
391	Riparian forest buffer
528A	Prescribed grazing
643	Restoration of declining habitats
645	Upland wildlife management
657	Wetland restoration

Table 7 Financial and technical assistance available to landowners to develop habitat

Program	Land eligibility	Type of assistance	Contact
Conservation Reserve Program (CRP)	Highly erodible land, wetland and certain other lands with cropping history Streamside areas in pasture land	50% cost-share for establishing permanent cover and conservation practices, and annual rental payments for land enrolled in 10- to 15-year contracts. Additional financial incentives available for some practices	NRCS or FSA state or local office
Environmental Quality Incentives Program (EQIP)	Cropland, range, grazing land and other agricultural land in need of treatment	Up to 75% cost-share for conservation practices in accordance with 5- to 10-year agreements. Incentive payments for certain management practices	NRCS state or local office
North American Waterbird Conservation Plan	Corporate, private, or public lands, or individuals and organizations	Provides technical expertise and implementation plan to meet regional and national waterbird conservation goals	Local office of the U.S. Fish and Wildlife Service
Partners for Fish and Wildlife Program (PFW)	Most degraded fish and/ or wildlife habitat	Up to 100% financial and technical assistance to restore wildlife habitat under minimum 10-year cooperative agreements	Local office of the U.S. Fish and Wildlife Service
Waterways for Wildlife	Private land	Technical and program development assistance to coalesce habitat efforts of corporations and private landowners to meet common watershed level goals	Wildlife Habitat Council
Wetlands Reserve Program (WRP)	Previously degraded wetland and adjacent upland buffer, with limited amount of natural wetland, and existing or restorable riparian areas	75% cost-share for wetland restoration under 10-year contracts and 30-year easements, and 100% cost-share on restoration under permanent easements. Payments for purchase of 30-year or permanent conservation easements	NRCS State or local office
Wildlife Habitat Incentives Program (WHIP)	High-priority fish and wildlife habitats	Up to 75% cost-share for conservation practices under 5- to 10-year agreements.	NRCS state or local office
Wildlife at Work	Corporate lands	Technical assistance on developing habitat projects into programs that allow companies to involve employees and the community	Wildlife Habitat Council
State fish and wildlife agencies and private groups may have assistance programs or other useful tools in your area.			State or local contacts

References

Ehrlich, P.R., D.S. Dobkin, and D. Wheye. The Birder's Handbook: A Field Guide to North American Birds. Simon & Schuster, Inc., New York. 785 pp.

Gough, G.A., J.R. Sauer, and M. Iliff, 1998, Patuxent Bird Identification InfoCenter, *http://www.mbr-pwrc.usgs.gov/Infocenter/infocenter.html*.

Mattheissen, P. Wildlife in America. The Viking Press, New York. 304 pp.

Sauer, J.R., J.E. Hines, I. Thomas, J. Fallon, and G. Gough. 1999. The North American Breeding Bird Survey, Results and Analysis 1966 - 1998. Version 98.1, USGS Patuxent Wildlife Research Center, Laurel, MD

Tacha, T.C. and C.E. Braun, eds. 1994. Migratory Shore and Upland Game Bird Management in North America. Allen Press, Lawrence, Kansas. 223 pp.

Terres, J.K. 1991. The Audubon Society Encyclopedia of North American Birds. Wings Books, New York. 1110 pp.

Wildlife Habitat Management Institute
100 Webster Circle, Suite 3
Madison, Mississippi 39110
(601) 607-3131

In cooperation with partners, the mission of the Wildlife Habitat Management Institute is to develop and disseminate scientifically based technical materials that will assist NRCS field staffs and others to promote conservation stewardship of fish and wildlife, and deliver sound habitat management principles and practices to America's land users.

www.whmi.nrcs.usda.gov

Wildlife Habitat Council
8737 Colesville Road, Suite 800
Silver Spring, Maryland 20910
(301) 588-8994

The mission of the Wildlife Habitat Council is to increase the amount of quality wildlife habitat on corporate, private, and public land. WHC engages corporations, public agencies, and private, nonprofit organizations on a voluntary basis as one team for the recovery, development, and preservation of wildlife habitat worldwide.

www.wildlifehc.org

<u>Great Trinity Forest Management Plan</u>

Wetlands

Waterfowl Management Handbook

13.1.1. Nutritional Values of Waterfowl Foods

Leigh H. Fredrickson and Fredric A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri–Columbia
Puxico, MO 63960

Over 40 species of North American waterfowl use wetland habitats throughout their annual cycles. Survival, reproduction, and growth are dependent on the availability of foods that meet nutritional requirements for recurring biological events. These requirements occur among a wide variety of environmental conditions that also influence nutritional demands. Recent work on nesting waterfowl has identified the female's general nutrient needs for egg laying and incubation. Far less is known about nutritional requirements for molt and other portions of the life cycle, particularly those during the nonbreeding season. Although information on specific requirements for amino acids and micronutrients of wild birds is meager, the available information on waterfowl requirements can be used to develop waterfowl management strategies. For example, nutrient content of foods, nutritional requirements of waterfowl, and the cues waterfowl use in locating and selecting foods are all kinds of information that managers need to encourage use of habitats by feeding waterfowl. Waterfowl nutritional needs during the annual cycle and the nutritional values of natural foods and crops will be discussed below.

Composition of Waterfowl Foods

Compared to the nutritional information on many agricultural crops, the composition of wild foods is poorly documented. Nevertheless, the available information on nutritional quality of wild foods, in conjunction with known waterfowl requirements, provides general guidelines for management. Terminology commonly used when discussing the nutritional values of foods or requirements for waterfowl include the following:

Basal metabolic rate (BMR)—The lowest level of metabolism necessary for basic body functions for an animal at rest.
Gross energy—The amount of energy (often expressed in 1000 calories = 1 kcal) produced when a food sample is ignited in a bomb calorimeter. Gross energy represents the most common nutritional information available, because techniques to determine gross energy are relatively simple and costs are minimal.
Metabolizable energy—The amount of energy that can be utilized for metabolic processes by an animal. Metabolizable energy is more complicated to determine than gross energy—animals must be fed a diet of food containing a known amount of gross energy, and the portion excreted as feces, urine, and gases must be identified and quantified.
Proximate analysis—A chemical process to identify the major components in foods. Samples must be handled carefully to ensure that chemical composition represents the nutritional content. The food is first ground to a fine homogenate, then dried to determine water content. Components identified by proximate analysis include the following:

- *Fats or lipids* —The most concentrated energy sources in foods. Fats occur as structural components and serve as insulation or as energy stores.
- *Ash*—Mineral content.

- *Crude Fiber*—Least digestable fraction in foods that includes cellulose, hemicellulose, or lignin. Waterfowl lack rumens; thus, little fiber is digested.
- *Nitrogen-free extract* (*NFE*)—Highly digestible carbohydrates.
- *Protein*—Compounds containing nitrogen that are major components of muscle tissue, animal cell membranes, and feathers; also active as enzymes, hormones, and clotting factors in blood. These serve many different functions.

More sophisticated testing provides identification of the specific composition of proteins and fats:

- *Amino acids*—Mixtures of 20 to 25 different amino acids, linked by peptide bonds, form plant and animal proteins.
- *Essential amino acids* —The 10 amino acids that must come from the diet because of the inability of an animal's metabolic pathway to produce them.
- *Fatty acids*—Components of fats with varying molecular weight and number of double bonds. Unsaturated fatty acids such as palmitoleic, oleic, and linoleic acids are important in waterfowl.

Information is generally available on the gross energy of foods (Tables 1 and 2), but metabolizable energy and outputs of proximate analyses including the amount of fat, fiber, ash, or nitrogen-free extract of these same foods are rarely identified (Table 3). Proteins supply the essential amino acids and are in high demand during egg laying and molt. Fats or lipids serve as energy reserves, as structural elements in cells, and as sterol hormones. Ash indicates the mineral content. Crude fiber is a measure of the least digestible food components, whereas NFE provides an estimate of the highly digestible carbohydrates.

Food quality is best predicted when information is available on metabolizable energy, ash, protein, fat, and NFE. Protein values are reported for about half of the foods that have energy values, but the content of fat, fiber, ash, or NFE is identified for less than one-third. Foods with a very high fiber content generally have lower levels of metabolizable or usable energy because fiber is poorly digested by waterfowl. In some cases, values from chemical analyses can be misleading. Crude protein content may be high, but the form of the protein or chemical inhibitors within the food may reduce the amount usable by the bird. For example, soybeans have a high level of crude protein, but only a small portion is available to waterfowl because of inhibitors. Waterfowl require a balance of amino acids. Some foods, such as crustaceans, usually have a better balance of amino acids than do insects and spiders. Certain

Table 1. *Chemical composition of some common waterfowl plant foods. Values represent averages from the literature.*

Common name[a]	Gross energy (kcal/g)	Fat	Fiber	Ash	NFE	Protein
Sticktights	5.177	15.0	19.7	7.2	27.5	25.0
Schreber watershield	3.790	2.9	36.7	4.8	45.9	9.3
Pecan hickory	7.875	40.8	19.0	12.6	35.1	8.4
Chufa flatsedge (tubers)	4.256	6.9	9.0	2.5	55.4	6.7
Hairy crabgrass	4.380	3.0	11.1	9.7	59.4	12.6
Barnyardgrass	3.900	2.4	23.1	18.0	40.5	8.3
Rice cutgrass	3.982	2.0	10.6	9.5	57.8	12.0
Fall panicum	4.005	3.1	16.8	16.1	50.1	12.3
Smartweed	4.423	2.8	22.0	7.5	—	9.7
Pennsylvania smartweed	4.315	2.3	21.8	4.9	65.3	9.0
Pin oak	5.062	18.9	14.7	1.6	58.6	6.4
Willow oak	5.296	20.6	14.0	1.7	55.3	5.1
Curly dock	4.278	1.2	20.4	6.9	—	10.4
Duck potato	4.736	9.0	10.8	4.9	55.5	20.0
Milo	4.228	3.1	6.0	3.5	72.2	10.2
Corn	4.435	3.8	2.3	1.5	79.8	10.8
Common soybean	5.451	20.5	5.4	6.2	27.1	39.6
Common duckweed	4.235	3.5	11.3	10.7	49.8	25.7
River bulrush (rhizomes)	4.010	—	—	—	—	—

[a] For alternative common names and scientific names consult Appendix.

Table 2. *Chemical composition of some common waterfowl invertebrate foods.*

Invertebrate	Gross energy (kcal/g)	Protein (%)
Water boatmen	5.2	71.4
Back swimmers	5.7	64.4
Midges	4.6	61.2
Water fleas	4.0	49.7
Amphipods (*Hyallela azteca*)	4.9	47.6
Amphipods (*Gammarus* spp.)	3.8	47.0
Cladocera (unclassified)	2.7	31.8
Pond snails	1.0	16.9
Orb snails	1.0	12.2

amino acids can be synthesized by waterfowl, but the essential amino acids must be acquired in the diet.

Because values for metabolizable energy are reported for individual food items rather than as combinations of foods normally consumed by wild waterfowl, nutritional information is not always accurate. Synergistic interactions among foods during digestion are more difficult to identify compared to the usable energy available from a single food item fed separately. Thus, providing a nutritionally balanced diet from wild and domestic foods, alone or in combination, continues to be a perplexing challenge facing wetland managers.

The Energetic Costs of Waterfowl Activities

Wild animals must provide for general body maintenance and for processes that require additional nutrients, such as growth, reproduction, and migration. The BMR includes the demands for energy of an animal that is at rest. Basal costs for locomotion, digestion, reproduction, or thermoregulation at extreme temperature ranges are not included. Large body sizes allow waterfowl to use their body reserves to meet the demands of maintenance and other demanding processes. For example, arctic–nesting geese transport all of their protein and energy needs for laying and incubation with them to arctic nesting grounds. Such species may lose nearly 50% of their body weight by the time their clutches hatch. Reserves for migration are particularly important in some waterfowl such as Pacific populations of brant. In their 3,000–mile journey from Alaska to Mexico, they lose one-third of their body weight (about 1.87 lb of fat) in a few days.

Waterfowl engage in a variety of activities that have high energetic costs. The locality and the environmental conditions under which these activities occur determine the energetic expenditures for each event. These are usually expressed in relation to the basal metabolic rate for an animal at rest.

Activities such as swimming, preening, foraging, or courtship are more energetically costly. Flight is the most expensive activity with estimates ranging from 12–15 × BMR. Diving is less costly (i.e., 3.5 × BMR). Furthermore, temperatures have important effects on energetic requirements. For example, captive mallards will increase their metabolic rate above the basal level by 2.1 × at 0°C and by 2.7 × at –20°C. Wild ducks and geese reduce the frequency of their feeding flights under extreme cold to conserve energy. Determining actual energetic costs of activities is difficult in the field; hence, the values for wild birds are usually based on estimates rather than actual measurements.

The general nutritional requirements for biological events in the annual cycle are known for an increasing number of waterfowl. The best estimates are those for breeding birds (Table 4), whereas far less is known about nonbreeding requirements.

Table 3. *Metabolizable energy of some common waterfowl foods.*

Taxon	Test animal	Metabolizable energy (kcal/g)
Water flea	Blue-winged teal	0.82
Amphipod (*Gammarus* spp.)	Blue-winged teal	2.32
Pond snail	Blue-winged teal	0.59
Coast barnyardgrass	Duck (male)	2.63
Coast barnyardgrass	Duck (female)	2.99
Rice cutgrass	Duck (male)	3.00
Common duckweed	Blue-winged teal	1.07
Pennsylvania smartweed	Dabbling duck (male)	1.12
Pennsylvania smartweed	Dabbling duck (female)	1.10

Table 4. *Nutritional requirements for breeding waterfowl compared to the composition of corn and common native foods.*

	Requirements breeding ducks/geese	Plants Foods			
		Corn	Acorns	Barnyardgrass	Pigweed
Energy	2,900[a]	3,430[a]	5,577[b]	4,442[b]	4,623[b]
Protein (%)	19	8.7	6.0	12.5	22.0
Methionine[c]	2.0	0.18	—	—	—
Ca (%)	2.7	0.02	0.24	0.13	1.72
Mg (ppm)	350	5	—	69	35

[a] = kcal ME/kg
[b] = Gross energy (not metabolizable energy)
[c] = % of protein

Note that no single food supplies a diet that meets all energy, protein, or micronutrient needs of breeding waterfowl. Likewise, activities other than breeding have varying costs in relation to specific nutrient energy and differ greatly from reproduction, where a mix of energy, minerals, and protein are required to supply the needs of egg-laying females.

Food Quality in Relation to Deterioration and Habitat Conditions

The quality of plant foods is largely determined by heredity, but other factors, such as soil nutrients and environmental conditions during the growing season, are important. For example, seeds having a high fat content may vary greatly in energy content among seasons because of environmental conditions. The supply of minerals is closely related to the mineral concentrations in water.

One of the major problems facing waterfowl managers is deterioration of seeds during flooding, but information on rates of deterioration is only available for a few seeds. Soybeans break down very rapidly; nearly 90% of the energy content is lost during 3 months of flooding, whereas corn loses only 50% during a similar period of flooding (Table 5). Breakdown of wild seeds is variable. Hard seeds such as bulrush decompose slowly, whereas softer seeds such as common barnyardgrass deteriorate 57% after 90 days under water. Such variations have important implications for the timing of flooding for waterfowl (Table 6). If some seeds are submerged for a month or more before waterfowl are present, much of the food value will be lost because of deterioration.

Supplying Nutritional Needs for Waterfowl

The large body sizes of waterfowl enable them to store nutrients as body reserves. In some cases nutrients for an upcoming stage in the life cycle are acquired at a distant wetland and transported as body reserves. The best known examples are the transport of fats, calcium, and protein by arctic-nesting geese from wintering and migrational stopovers to breeding habitats. Because waterfowl store body reserves, managers should make an effort to supply required nutrients throughout the annual cycle rather than supplying nutrients solely for events at the time they occur.

Identifying shortfalls in nutritional needs is becoming more of a reality as the requirements for free-living animals are identified. Waterfowl are well adapted to the dynamics of natural wetland systems. Mobility and foraging adaptability are behav-

Table 5. *Deterioration of selected seeds after 90 days of flooding.*

Plant name	Decomposition (%)
Soybean	86
Barnyardgrass	57
Corn	50
Common buckwheat	45
Milo	42
Giant bristlegrass	22
Pennsylvania smartweed	21
Cultivated rice	19
Water oak (acorns)	4
Hemp sesbania	4
Horned beakrush	2
Saltmarsh bulrush	1

Table 6. *Comparison of deterioration of 100 lb of five selected seeds in relation to different flooding schedules. Estimates assume a constant daily rate of deterioration.*

	Percent Remaining			
	15 September	15 October	15 Novemeber	15 December
Flooding Date				
18 August				
Soybeans	71	43	14	0
Corn	83	67	50	33
Millet	81	62	43	24
Giant bristlegrass	93	85	78	71
Smartweed	93	85	79	72
Total percent remaining	84	68	53	40
15 September				
Total percent remaining		84	68	53
15 October				
Total percent remaining			84	68
15 November				
Total percent remaining				84

ioral characteristics that enable waterfowl to acquire needed resources. Dynamic wetlands supply a variety of food resources that allow waterfowl to feed selectively and to formulate nutritionally adequate diets from a variety of sites. Although a single wetland site may not provide adequate food for all requirements, management areas with a variety of wetlands or flooding regimes usually have a mix of habitats that provide all nutritional requirements.

Because a variety of strategies exists within and among waterfowl species (wintering, migration, or breeding), not all individuals or species require similar resources simultaneously. Thus, a diverse habitat base is a logical approach to meet the various needs of waterfowl. Furthermore, when suitable food and cover are within daily foraging range, acquisition of required resources is enhanced. A good rule of thumb is to provide many wetland types or food choices within a 10-mile radius of waterfowl concentrations. Some species such as snow geese have far greater foraging ranges, but they are the exception rather than the rule.

Appropriate management requires preservation, development, and manipulation of manmade and natural wetland complexes. Such an approach provides nutritionally balanced diets for diverse waterfowl populations. Where natural wetlands remain intact, they should be protected as unique components of the ecosystems. The protection of natural systems and the development and management of degraded systems increases choices of habitats and foods for waterfowl. Likewise, the provision of adequate refuge areas where birds are protected from disturbance is an essential ingredient to ensure that food resources are available to waterfowl and can be used efficiently.

Suggested Reading

Hoffman, R.B., and T.A. Bookhout. 1985. Metabolizable energy of seeds consumed by ducks in Lake Erie marshes. Trans. N. Am. Wildl. Nat. Resour. Conf. 50:557–565.

National Research Council. 1977. Nutrient requirements of domestic animals. No. 1. Nutrient requirements of poultry. Natl. Acad. Sci., Washington, D.C. 62 pp.

Neely, W.W. 1956. How long do duck foods last underwater? Trans. N. Am. Wildl. Conf. 21:191–198.

Prince, H.H. 1979. Bioenergetics of postbreeding dabbling ducks. Pages 103–117 *in* T.A. Bookhout, ed. Waterfowl and wetlands: an integrated review. Proc. 1977 Symp., North Cent. Sect., The Wildl. Soc., Madison, Wis. 147 pp.

Robbins, C.T. 1983. Feeding and wildlife nutrition. Academic Press, New York. 343 pp.

Sugden, L.G. 1971. Metabolizable energy of small grains for mallards. J. Wildl. Manage. 35:781–785.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Common name	Scientific name
Plants	
Pigweed	*Amaranthus* sp.
Devils beggarticks *or* sticktights	*Bidens frondosa*
Schreber watershield	*Brasenia schreberi*
Pecan hickory	*Carya illinoensis*
Chufa flatsedge	*Cyperus esculentus*
Hairy crabgrass	*Digitaria sanguinalis*
Common barnyardgrass *or* Japanese millet	*Echinochloa crusgalli*
Coast barnyardgrass, wild millet, *or* watergrass	*Echinochloa walteri*
Common buckwheat	*Fagopyrum esculentum*
Common soybean	*Glycine max*
Rice cutgrass	*Leersia oryzoides*
Common duckweed	*Lemna minor*
Cultivated rice	*Oryza sativa*
Fall panicum *or* panic grass	*Panicum dichotomiflorum*
Curltop ladysthumb *or* smartweed	*Polygonum lapathifolium*
Pennsylvania smartweed	*Polygonum pensylvanicum*
Pin oak	*Quercus palustris*
Willow oak	*Quercus phellos*
Water oak	*Quercus nigra*
Horned breakrush	*Rhynchospora corniculata*
Curly dock	*Rumex crispus*
Common arrowhead *or* duck potato	*Sagittaria latifolia*
River bulrush *or* three-square bulrush	*Scirpus fluviatilus*
Saltmarsh bulrush *or* bulrush	*Scirpus robustus*
Hemp sesbania	*Sesbania exalta*
Giant bristlegrass *or* giant foxtail	*Setaria magna*
Common sorghum *or* milo	*Sorghum vulgare*
Indian corn *or* corn	*Zea mays*
Birds	
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Brant	*Branta bernicla*
Snow goose	*Chen caerulescens*
Invertebrates (Families)	
Midges	Chironomidae
Water boatmen	Corixidae
Water fleas	Daphnidae
Pond snails	Lymnaeidae
Back swimmers	Notonectidae
Orb snails	Planorbidae

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.1.2 Life History Traits and Management of the Gadwall

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Road
Fort Collins, CO 80526

Species Profile—Gadwall

Scientific name: *Anas strepera*
Weight in pounds (grams):
Adults—male 2.1 (953), female 1.8 (835)
Immatures—male 1.9 (858), female 1.7 (776)
Age at first breeding: 1 or 2 years
Clutch size: 10, range 5 to 13
Incubation period: 25 days
Age at fledging: 48–52 days
Nest sites: Tall, dense herbaceous vegetation or small shrubs within 1,000 feet of water, often near the site used the previous year
Food habits: Herbivorous, except during spring when some aquatic invertebrates are consumed

The gadwall is widely distributed throughout the western two-thirds of North America. Although its primary breeding habitat is in the drought-prone and degraded waterfowl habitats of the northern Great Plains, its continental population has remained relatively stable while those of most other dabbling ducks have declined. Some unique life history traits may in part be responsible for the resilience of gadwall populations. These unique attributes, which are important for gadwall management, are the subject of this leaflet. Readers interested in general references on gadwall biology and natural history are referred to Bellrose (1980) or Palmer (1976).

Distribution

Gadwall breeding populations reach their highest densities in the mixed-grass prairies of the northern Great Plains and the intermountain valleys of the western United States (Fig. 1). The parklands and shortgrass prairies contain relatively fewer breeding birds. Some portions of the Pacific, Atlantic, and Alaskan coasts also have important breeding populations.

The primary migration corridor for gadwalls originates in the prairies and extends through the low plains region of the United States, including Nebraska, Kansas, eastern Colorado, Oklahoma, Texas, Louisiana, and into Mexico. Secondary migration routes link the prairies with the Pacific Northwest, northern and central California, and northern Utah. From Utah, birds migrate to wintering areas in central and southern California and Mexico. Gadwall also migrate along diagonal routes from the Great Plains to the central and southern Atlantic coast.

Major wintering areas include coastal areas of Louisiana and Texas, south along the east coast of Mexico to the Yucatan Peninsula; the central and southern Atlantic coast; the Central Valley of California; and much of the west coast of Mexico.

Population Status and Harvest

Despite drought and widespread waterfowl habitat destruction in the 1970's and 1980's, the size of the gadwall population in North America has re-

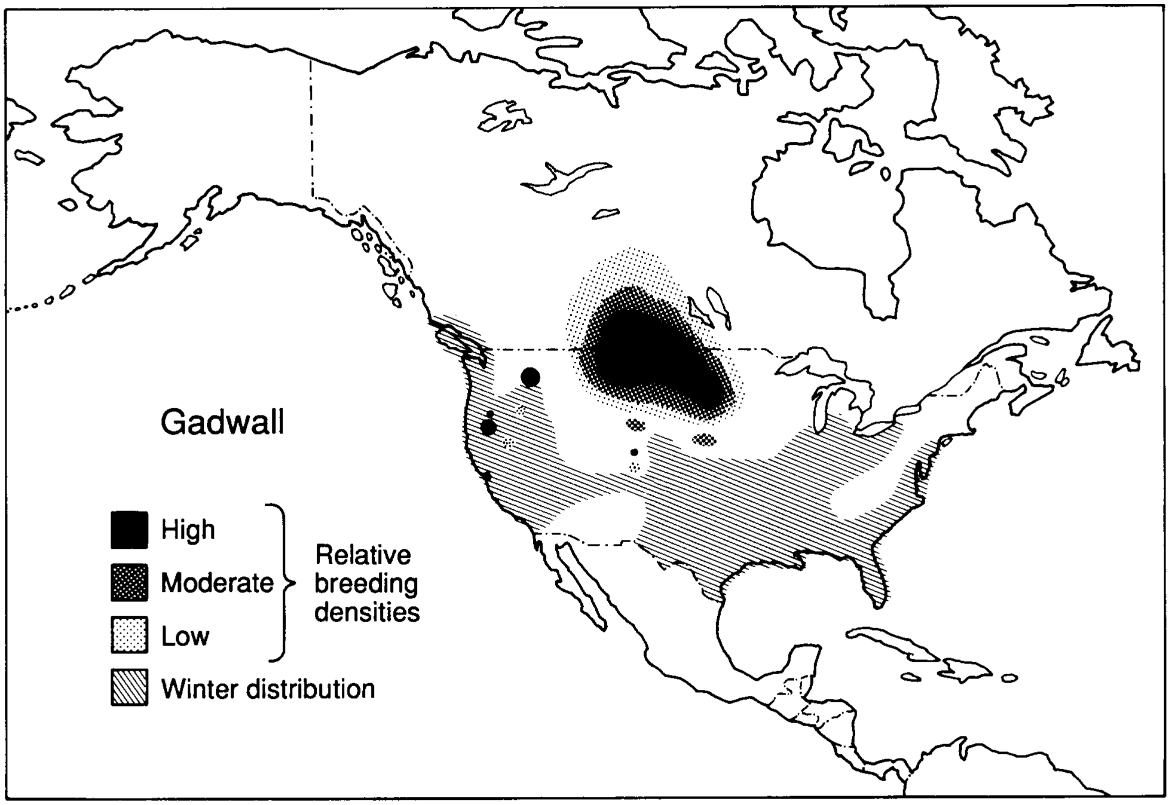


Fig. 1. Distribution of breeding and wintering gadwalls in North America.

mained relatively stable compared with populations of mallards and northern pintails (Fig. 2). Breeding gadwall are increasing in the Great Basin region, the intermountain valleys of the Rocky Mountains, and in the Pacific Flyway. The reproductive success of gadwall may be enhanced because of the tendency of this species to use semipermanent wetlands, home to traditional nesting sites where hens were previously successful, and to concentrate in secure nesting locations such as islands. The gadwall is also a lightly-harvested species; gadwall make up 4.2% of the continental population of breeding ducks but compose only 2.5% of the duck harvest.

Spring Migration and Breeding

Gadwalls depart wintering areas by March or early April (Fig. 3). They are among the last birds to arrive on the nesting grounds, and yearlings usually arrive later than older birds. Three to four weeks pass before most birds begin laying, during which time females acquire the fat and protein reserves needed for egg production. Compared to other dabbling ducks, a high percentage of yearling gadwalls do not attempt to nest. Birds older than one year initiate nests first, often in mid-May. Most female gadwall that nest successfully return to areas used the previous year. When drought occurs on their prairie breeding grounds, many gadwalls migrate north into central and northern Canada.

Shortly after arrival on the nesting grounds, pairs establish territories on seasonal and semipermanent wetlands. Gadwall also tend to use open

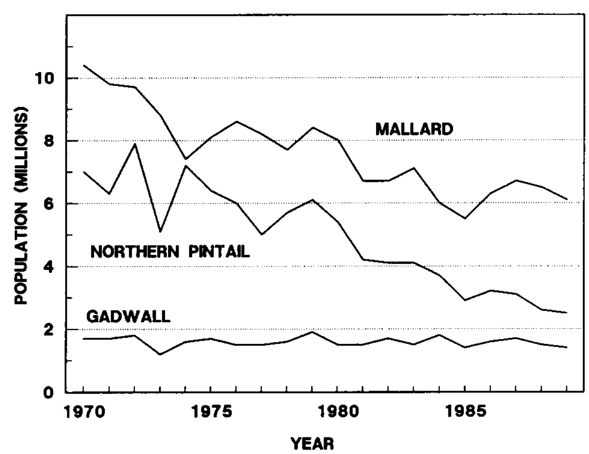


Fig. 2. Continental breeding population of gadwalls (1970–89) compared with breeding populations of mallards and northern pintails.

brackish or alkaline waters. Since semipermanent ponds are less susceptible to annual drought events than are ephemeral and temporary wetlands, the gadwall's preference for deepwater habitats may be beneficial during drought.

Aquatic invertebrates make up about half of the gadwall's diet during spring and summer (Table 1), and up to 72% during egg laying. Gadwalls consume the green portions of aquatic plants almost exclusively during the non-nesting season (Table 1). Most plants and animals consumed by gadwalls are adapted to semipermanent or permanent wetlands, so drawdowns of managed impoundments should be infrequent (6–8 years) in wetlands managed for this species. A small percentage of ponds in a wetland community should be drawn down during a single season, so that several "familiar" wetlands remain within the home range of gadwall pairs.

Nests are usually located in dry upland sites under clumps of shrubs or in herbaceous vegetation. Although nests average 1,000 feet (300 m) from water, sites up to 1.2 miles (1.9 km) away may be used. Nests in the valleys of the intermountain West are commonly found in baltic rush, nettle, and under small shrubs. In the northern Great Plains, fields of seeded native grasses usually receive the greatest use, followed by introduced grasses and unplowed, native prairie. Shrubs such as western snowberry and Woods rose also provide attractive nesting cover. Growing grainfields receive little use, and gadwalls avoid stubble and summer fallow areas.

Areas of dense vegetation, such as a grass-legume mixture, provide beneficial nesting cover for gadwalls. Residual cover from the previous year's growing season, although not as important for the late-nesting gadwalls as it is for other early-nesting

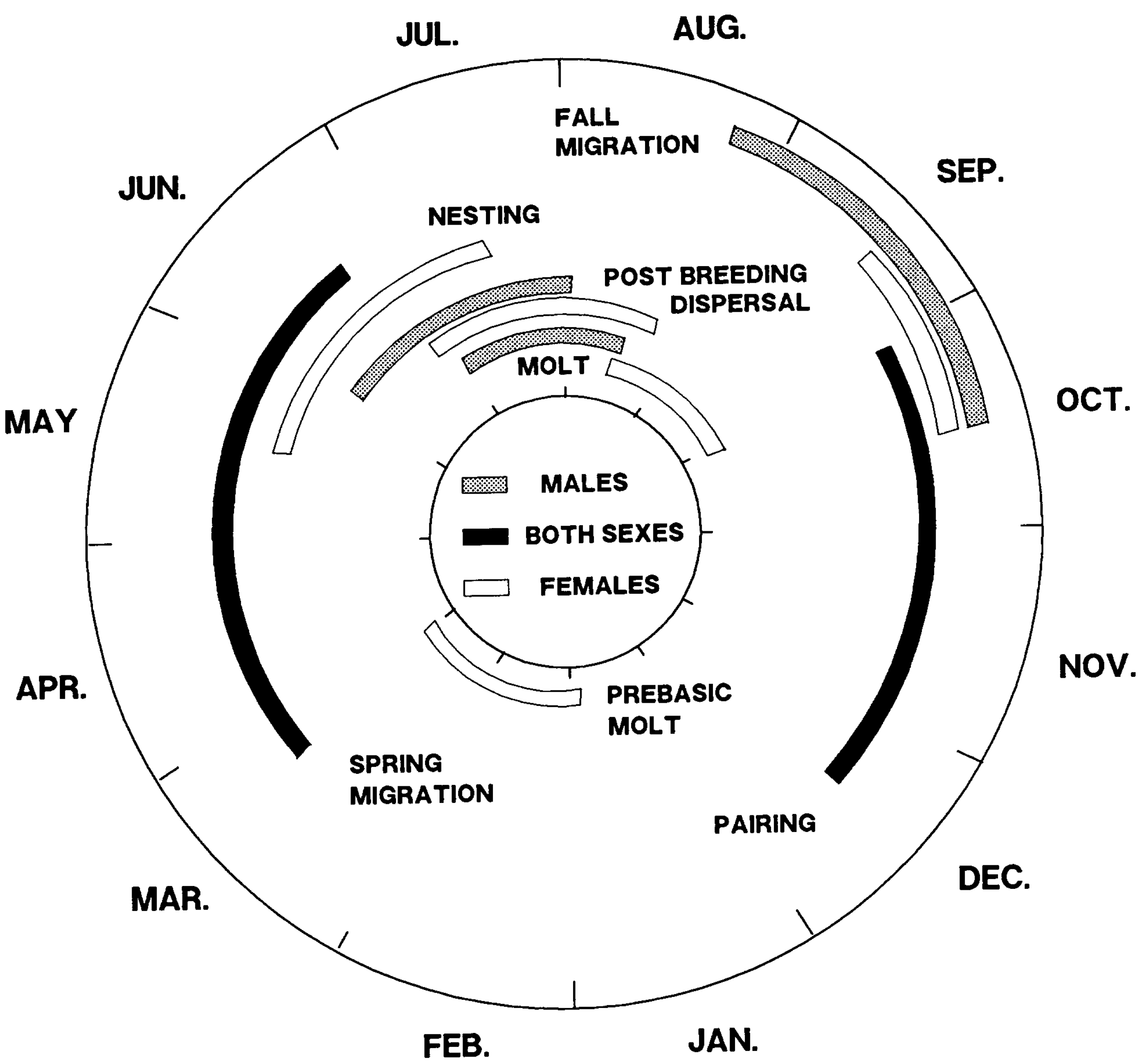


Fig. 3. The chronology of important life history events in the annual cycle of the gadwall.

Table 1. *Seasonal food habits of adult gadwall. Within seasons, the list of food items is arranged in order of importance in the diet.Vegetative foods refer to green portions of plants unless otherwise noted.*

Season, food type, and % volume in diet	Common name	Habitat and location
Spring and summer		
Plant foods (54%)	Filamentous algae	Brackish, subsaline, and saline wetlands of North Dakota.
	Widgeongrass	
	Muskgrass	
	Sago pondweed	
	Elodea	
Animal foods (46%)	Fairy shrimp	
	Seed shrimp	
	Water fleas	
	Midges	
	Beetle larvae	
Fall and winter		
Plant foods (95%)	Filamentous algae	Fresh, intermediate, and brackish marshes in Louisiana
	Dwarf spikerush	
	Widgeongrass	
	Spiked watermilfoil	
	Baby pondweed	
Animal foods (5%)	Seed shrimp	
Plant foods (91%)	Fragrant flatsedge	Fresh and brackish tidal impoundments in South Carolina
	Redroot sedge	
	Widgeongrass	
Animal foods	none listed	

ducks, nonetheless affords important cover in many nesting habitats. Residual cover can become lodged and matted over several years, so burning or mechanical manipulations are sometimes needed to rejuvenate nesting areas.

Gadwalls often use islands as nesting sites because the water barrier reduces nest losses from mammalian predators. The high nest success typical of islands, coupled with the homing tendencies of gadwalls, contribute to nesting densities as high as 200 nests/acre (493 nests/ha). Suitable nesting islands should be 0.2–1.2 acres (0.1–0.5 ha) in size, elongated in shape, and separated from the mainland by at least 500 feet (150 m) of water that remains 3 feet (0.9 m) deep during the nesting season. Although islands can be incorporated into the initial impoundment designs or constructed when a wetland has been dewatered, the construction cost is high even when amortized over the expected life of the island. Additionally, vegetation can be difficult to establish on newly constructed islands. A more cost-effective approach is to cut-off an existing peninsula from the mainland, thereby saving most of the cost of earth moving and vegetation establishment. As valuable as nesting islands can be, managers must provide a diversity of wetlands for pairs and broods to complement the secure nesting habitat afforded by islands.

Brood-rearing hens will move ducklings up to 1.2 miles (1.9 km) to brood habitat. Gadwall ducklings initially consume equal amounts of plant and animal foods, but consumption of animal food peaks at 2 weeks of age as vegetative matter begins to dominate their diet (Table 2). The average brood size at time of fledging (50 days old) is 6.2 ducklings per brood.

Post-breeding Dispersal

After hens have incubated for about 2 weeks, males abandon their breeding territories and concentrate on large permanent or semipermanent wetlands near the nesting area. Males, which are flightless for 25–28 days beginning in mid-July, form molting rafts of several hundred to thousands of individuals. These birds often occupy open water areas that contain beds of submersed aquatic vegetation, their primary food (Table 1). Unlike mallards and other secretive species that seek heavy vegetative cover when flightless, gadwalls often associate with American wigeons and diving ducks and loaf on the bare shorelines of islands or main-

Table 2. *Food habits of gadwall ducklings. The list of food items is arranged in order of importance in the diet. Vegetative foods refer to green portions of plants unless otherwise noted.*

Food type and % dry weight in diet	Common name	Habitat and location
Plant foods (90%)	Baby pondweed	Freshwater prairie wetlands in southern Alberta
	Filamentous algae	
	Slough grass seeds	
	Duckweed	
	Muskgrass	
	Coontail	
Animal foods (10%)	Beetle larvae	
	Midges	
	Water fleas	

land stretches that are free from human disturbance. Female gadwalls molt 20–40 days after the males, usually singly or in small flocks. However, moderate- to large-sized wetlands of a permanent or semipermanent nature, expanses of open water with submersed vegetation, and open shorelines secure from human disturbance are important characteristics of molting habitat for both sexes.

Fall Migration

Most gadwalls begin their fall migration in early September, and none remain on northern breeding grounds by late October. However, because of their late breeding and molt chronology, some females remain flightless into late September and early October. These birds, which are probably hens that successfully completed second nests after their first clutch was destroyed, may be subject to hunting before they fully regain flight capabilities. Since opening of the hunting season typically occurs as early as possible (the first week in October) in the northern Great Plains and intermountain basins of the West, some local populations of late-molting female gadwalls may be subject to high hunting mortality during early fall.

Because gadwall consume a diet composed almost exclusively of green, submersed aquatic vegetation during fall (Table 1), traditional wetland management techniques such as moist-soil impoundments, which encourage the production of seed producing annuals, are not as attractive to gadwalls as they are to most other dabbling ducks. Cereal grains and row crops so highly sought by mallards, pintails, and green-winged teal also receive little use by gadwalls, but flooded ricefields are used by gadwalls in the Central Valley of California. Wetland management to benefit gadwall should be directed at maintaining large wetlands with stable water levels suitable for the growth of submersed aquatic vegetation. Although it is most desirable to promote the growth of native vegetation present in a wetland, managers can establish stands of submersed vegetation by seeding or transplanting tubers and whole plants. Wildlife plant nurseries sell seeds and tubers for this purpose. Extreme water level fluctuations or poor water quality may inhibit the growth of submersed vegetation. Stabilization of water levels through control structures or augmentation of water flows during dry periods may be necessary. Removal of rough fishes, which increase water turbidity and degrade water quality, often dramatically improves stands of submersed vegetation.

Winter

Gadwalls reach their highest winter densities on the fresh, intermediate, and brackish marshes of the Louisiana coast. There, as elsewhere, their diet is composed almost entirely of vegetative foods (Table 1) obtained in water 6–26 inches (15–66 cm) deep. Plant foods consumed by gadwalls are lower in protein and energy and higher in fiber than the seeds and animal foods eaten by other ducks. Because gadwalls rely on low-quality foods, they feed throughout the day and night. Their strategy for nutrient acquisition is therefore more similar to that of geese than to other ducks; they consume large quantities of food to meet nutritional and energetic demands. Unlike geese, however, gadwalls do not have the capacity to store food obtained during intermittent feeding bouts. Wintering gadwalls may be susceptible to nutritional deficiencies if continual disturbance alters their feeding regimes.

Suggested Reading

Bellrose, F. C., editor. 1980. Ducks, geese, and swans of North America. 3rd ed. Stackpole Books, Harrisburg, Pa. 540pp.

Crabtree, R. L., L. S. Broome, and M. L. Wolfe. 1989. Effects of habitat characteristics on gadwall nest predation and nest-site selection. J. Wildl. Manage. 53:129–137.

Gates, J. M. 1962. Breeding biology of the gadwall in northern Utah. Wilson Bull. 74:43–67.

Lokemoen, J. T., H. F. Duebbert, and D. E. Sharp. 1990. Homing and reproductive habits of mallards, gadwalls, and blue-winged teal. Wildl. Monogr. 106. 28pp.

Palmer, R. S., editor. 1976. Handbook of North American birds. Vol. 2. Waterfowl. Yale University Press, New Haven, Conn. 521pp.

Paulus, S. L. 1982. Feeding ecology of gadwalls in Louisiana in winter. J. Wildl. Manage. 46:71–79.

Serie, J. R., and G. A. Swanson. 1976. Feeding ecology of breeding gadwalls on saline wetlands. J. Wildl. Manage. 40:69–81.

Sugden, L. G. 1973. Feeding ecology of pintail, gadwall, American widgeon and lesser scaup ducklings in southern Alberta. Can. Wildl. Serv. Rep. Ser. 24. 44pp.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Slough grass	*Beckmannia syzigachne*
Coontail	*Ceratophyllum* spp.
Muskgrass	*Chara* spp.
Filamentous algae	Chlorophyceae
Fragrant flatsedge	*Cyperus odoratus*
Dwarf spikerush	*Eleocharis parvula*
Baltic rush	*Juncus balticus*
Redroot sedge	*Lachnanthes caroliniana*
Common duckweed	*Lemna minor*
Spiked watermilfoil	*Myriophyllum spicatum*
Sago pondweed	*Potamogeton pectinatus*
Baby pondweed	*Potamogeton pusillus*
Woods rose	*Rosa woodsii*
Widgeongrass	*Ruppia maritima*
Western snowberry	*Symphoricarpos occidentalis*
Stinging nettle	*Urtica dioica*
Birds	
Northern pintail	*Anas acuta*
American wigeon	*Anas americana*
Green-winged teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*
Invertebrates	
Fairy shrimp	Anostraca
Midges	Chironomidae
Water fleas	Cladocera
Beetles	Coleoptera
Seed shrimp	Ostracoda

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Fish and Wildlife Leaflet 13
Washington, D.C. • 1990

13.1.3. Life History Strategies and Habitat Needs of the Northern Pintail

Leigh H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri–Columbia
Puxico, MO 63960

and

Mickey E. Heitmeyer
Ducks Unlimited
9823 Old Winery Place, Suite 16
Sacramento, CA 95827

Species Profile—Northern Pintail

Scientific name: *Anas acuta*
Weight in pounds (grams):
Adults—male 2.3 (1,040 g), female 1.9 (860 g)
Immatures—male 2 (910 g), female 1.8 (820 g)
Age of first breeding: 1 year
Clutch size: 8, range 3–14
Incubation period: 22–23 days
Age at fledging: 36–43 days in Alaska, 42–57 days on prairies
Nest sites: Low, sparse vegetation, often far from water
Food habits: Omnivore; primarily moist-soil seeds, as well as chufa nutlets; cultivated grains, especially rice and barley. Animal foods: aquatic insects, especially chironomids, snails, terrestrial earthworms, and spiders.

The northern pintail (hereafter pintail) is a common dabbling duck distributed throughout the Northern Hemisphere. Since 1955, the breeding population in North America has averaged 5,566,000, fluctuating between 10,124,000 (1956) and 2,471,000 (1989; Fig. 1). Pintail numbers are especially sensitive to habitat conditions that reflect the wet–dry cycle in the shortgrass prairie breeding areas of south-central Canada and the northern Great Plains of the United States. Populations of pintails also are affected by habitat conditions in key wintering areas, such as the Central Valley of California and Gulf Coast marshes. When wintering areas are fairly dry, birds have fewer resources and subsequent spring recruitment is lowered.

Through the 1970's, continental populations recovered when wetland conditions on breeding and wintering areas were good but fell when the prairies were dry and wetland conditions in wintering areas were poor. Unfortunately, habitat losses and degradation of prairie habitats caused by agricultural practices have coincided with prolonged drought since the early 1980's. This combination of detrimental factors resulted in declining pintail numbers in the past decade. The long-term downward trend in pintail numbers has focused renewed attention on this species.

This leaflet describes aspects of pintail life history that may be important for pintail management. It is not intended as a general reference on pintail biology. Readers interested in this should consult Bellrose (1980).

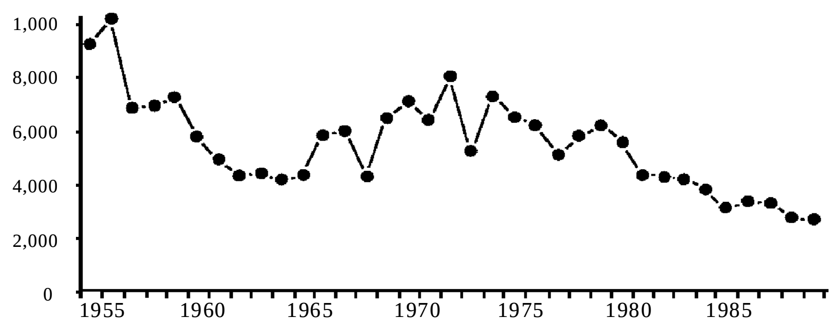


Fig. 1. Fluctuations in the continental population of northern pintails based on breeding population estimates, 1955–90.

Distribution

The northern pintail is the most widely distributed dabbling duck in the Northern Hemisphere. Although pintails regularly breed in the shortgrass prairies of the northern United States and southern Canada, their breeding distribution in North America extends from the Great Basin into the northern boreal forest and the arctic coastal plain of Alaska and Canada (Fig. 2).

In recent years, about 16% of the continental population of pintails (counted in May) occurred on the 26,000 square miles of high-latitude wetlands along the arctic coastal plain in Alaska. Pintails compose 90% of the dabbling ducks that use these habitats; thus, they are the most abundant dabbling duck in this region. Drakes account for about 32% of this total, whereas pairs account for

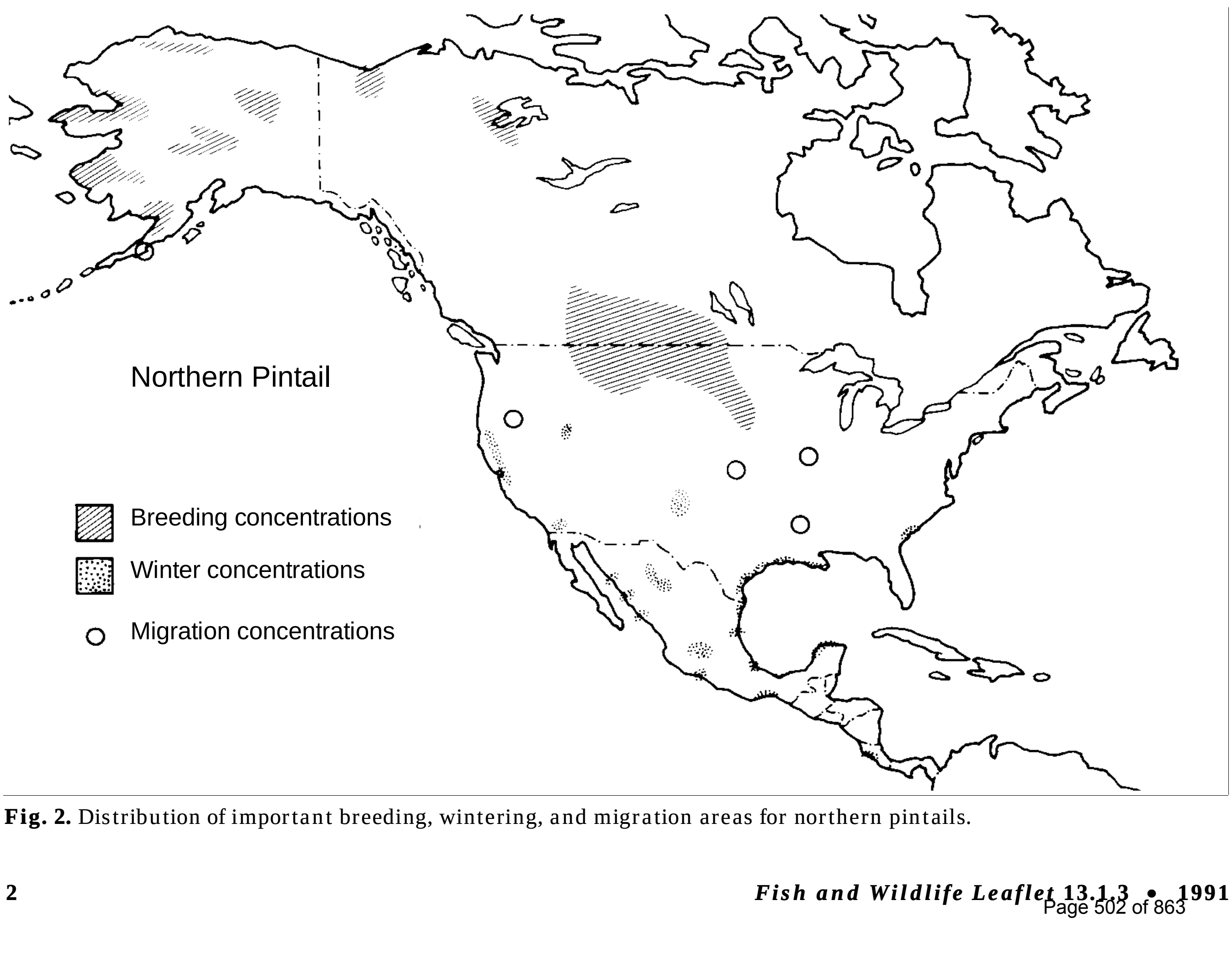


Fig. 2. Distribution of important breeding, wintering, and migration areas for northern pintails.

12% and groups about 57%. Pintails are well known for overflight into more northern wetland habitats when wetland habitat conditions on more southern habitats are poor; therefore, their numbers fluctuate erratically in Alaska.

Most pintails in the Pacific Flyway have traditionally wintered from the Central Valley of California to the west coast of Mexico, but the river deltas of the Pacific Northwest also provide important habitats. Large numbers of pintails also winter in coastal marshes and rice belt habitats in Texas, Louisiana, Arkansas, and the Atlantic Coast, especially South Carolina.

Spring Migration and Breeding

Pintails migrate early in spring and move northward as soon as wetlands become ice-free. They normally initiate nesting earlier in spring and summer than other dabblers (Fig. 3). These early-nesting females often encounter light snowfall while laying and incubating. Open habitats with sparse, low vegetation provide favored nesting sites. The shortgrass habitats of the Canadian prairie provinces have traditionally held the highest breeding populations. In the northern United States and southern Canada, first nests appear in early April during normal years, but inclement weather can delay nesting until the second week of May. Nesting activity in the more northern prairies peaks during the first 2 weeks of May. Pintails nest later in the boreal forest; the peak of first nests in Alaska's interior occurs during mid-May. Birds moving to tundra habitats on the Yukon–Kuskokwim Delta and the North Slope do not nest until late May or as late as mid-June.

Pintails lay an average clutch of 8 eggs, but clutch size ranges from 3 to 14. Incubation lasts 22 or 23 days. Pintail broods can move long distances between the nest site and rearing habitats or among different brood habitats. Recent studies suggest that pintails are well adapted to making these movements and that neither mortality nor

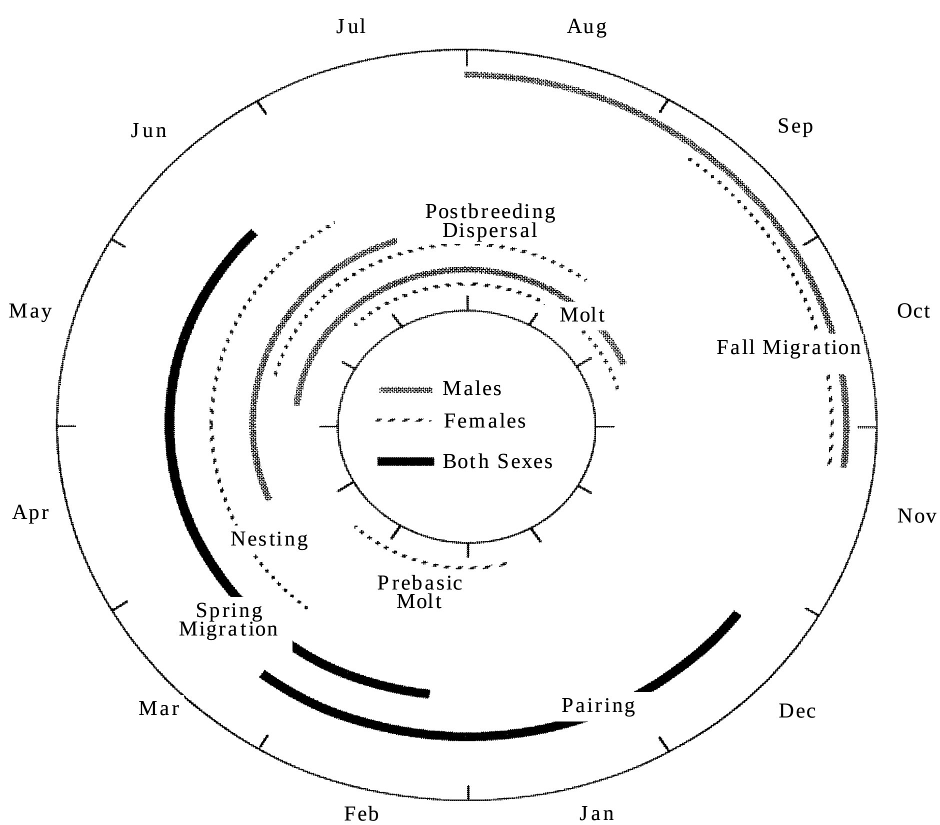


Fig. 3. The chronology of important life history events in the annual cycle of the northern pintail.

body condition of ducklings is greatly influenced by movements of less than 3 miles. Fledging time varies with latitude and is undoubtedly influenced by the length of daylight and the daily time available to forage. Females stay with the brood until the young reach flight stage. Soon after, the female initiates the summer molt and becomes flightless (Fig. 3).

Postbreeding Dispersal and Fall Migration

Males congregate in postbreeding flocks once females begin incubation (Fig. 3). Males may move to southern or northern habitats, where they often form large aggregations and begin the Prebasic molt, becoming flightless for about 3 weeks. After regaining flight in August, they often migrate south to the ultimate wintering areas. For some pintails, the fall migration is a more gradual shift south that extends over several months. Early migrant males begin to move southward in abundance in late August or early September and usually concentrate on seasonally flooded wetlands, where they select seeds from native vegetation or from agricultural crops, especially rice.

Following brood rearing, successful females form small flocks, enter the molt, become flightless, and regrow their flight feathers in rapid succession (Fig. 3). Because males generally leave the breeding area before females are flightless, the latter use habitats distinctly different than those used by males for several months. During this time, females remain on more northern habitats and feed in semipermanent marshes, where invertebrates are important in their diet (Fig. 4). Females gradually join males on migratory and winter sites in October and November. As fall progresses, the two sexes gradually intermix and pair formation begins.

Winter Behavior and Pairing

Pintails are highly social and have loosely formed pair bonds compared to mallards and most other Northern Hemisphere dabblers. Pair formation by pintails begins on the wintering

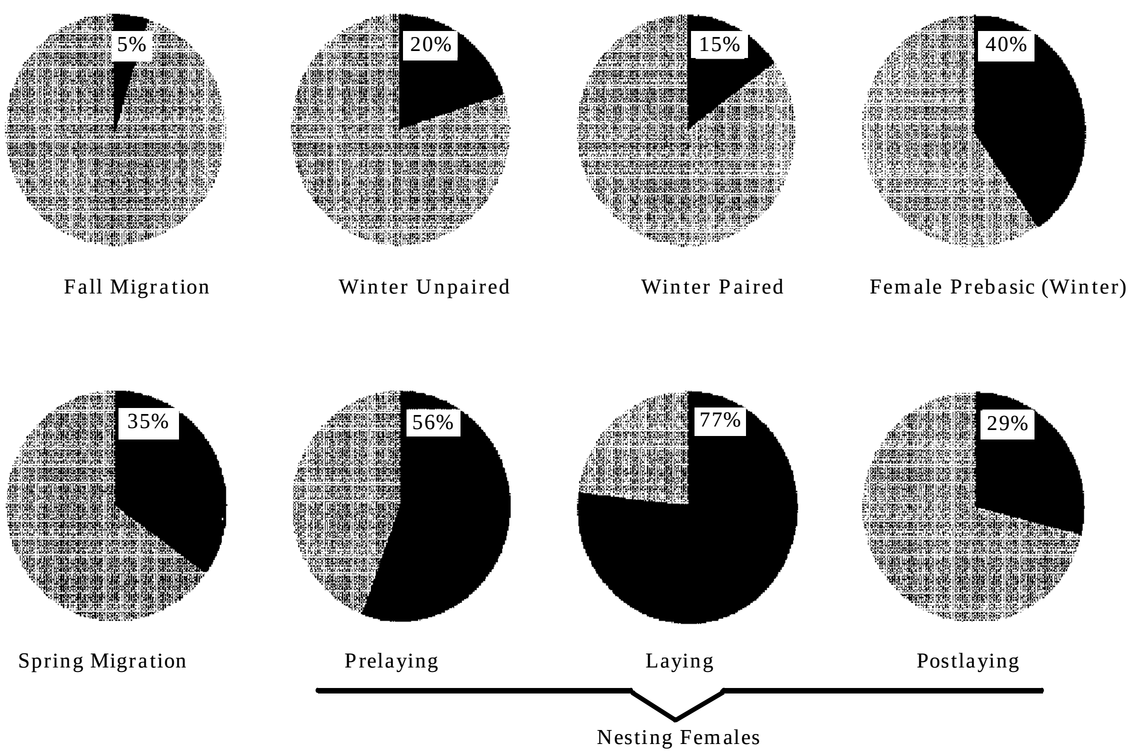


Fig. 4. Invertebrate consumption by northern pintails during selected events in the annual cycle. Includes both sexes unless indicated otherwise.

grounds, and most females are paired by January. Courtship flights often contain large numbers of males and traverse great distances, reach great heights, and last for extended periods. On the breeding grounds, these spectacular flights were once believed to distribute the nesting pairs widely among available habitats, but recent studies have not always confirmed this assumption—instead, they suggest active competition in mate selection and breeding opportunities among males in spring.

During winter, pintails undergo several important events in the annual cycle (Fig. 3). After completing the Prealternate molt, they form pairs; then, females initiate the Prebasic molt. By late winter and early spring, both sexes have accumulated large body fat reserves subsequently used in migration and for breeding. Females departing from the Central Valley of California to Tule Lake in late winter reach weights of 950 g, and of this total, 220 g is fat necessary to fuel migration and eventual reproduction.

Pintails are early migrants in spring and are especially attracted to large expanses of shallow open water where visibility is good and small seeds and invertebrates are readily available. Their preferred prairie nesting areas are short grasses where temporary ponds are abundant nearby. Nesting habitat requirements in boreal forest and tundra habitats are less well known.

Foraging Ecology

Pintails are opportunistic omnivores. They primarily consume small seeds, but underground plant parts or small tubers, such as chufa nutlets, also are important (Table 1). If available, native foods are predominant in the diet, especially those associated with moist-soil habitats, including millet, smartweed, bulrush, toothcup, panicum, and swamp timothy. Pintails also exploit seeds and tubers of aquatic pondweeds and bulrushes. Although they consume seeds of all sizes, they are particularly adept at harvesting smaller seeds such as toothcup, panicum, swamp timothy, and sprangletop. These native foods provide a well-balanced diet to meet nutritional needs (Table 2). Favored cereal grains include rice and barley; pintails are less likely to eat corn than are mallards.

Animal foods are important throughout the life cycle but particularly so during molt and egg laying (Fig. 4). Some of the more important invertebrates

Table 1. *Foods appearing in northern pintail diets during different events in the annual cycle.*

Food	Fall migration	Winter		Prebasic molt	Spring migration	Nesting	Ducklings	Summer molt	Fall staging
		Unpaired	Paired						
Plant									
Millet	++	++	++	++	++	+			+
Swamp timothy	++	++	++	++					
Smartweed	++	++	++	++	++	+			+
Sprangletop	+	++	++	++	++		+	+	
Toothcup	+	++	++	++	+	+			
Curly dock	+				+	+			
Panicum	++	++	++	++	++	+	+		+
Bulrush	++	+	+	+	++	++		++	++
Chufa	+	++	++	++					
Pondweeds	+				+	++	++	++	++
Sedges	+				++	++	+	++	++
Agricultural grains	++	++	++	+	+				++
Animal									
Chironomids	++	++	++	++	++	++	++	++	++
Snails			++	++	+	++	++	++	+
Odonates			+	+					
Ostracods				+					

consistently appearing in the diet are snails and chironomids. Chironomids, especially, are preferred by pintails and are extremely abundant on emergence from shallow wetlands immediately after ice-out. The arrival of pintails on many migration and breeding habitats tends to coincide with this period of emergence, and pintails forage voraciously on chironomids in such newly thawed wetlands.

Pintails strip seeds from the culms of native vegetation before seeds drop in fall. Once seeds have dropped onto the substrates, pintails dabble for these foods in shallow water (4 to 6 inches). As water deepens, pintails forage by upending, but this mode of feeding is restricted to waters <18 inches deep. Pintails have a tendency to avoid areas that are flooded too deeply if shallow sites also are present.

Habitat Management

Migration and Winter

Pintails are noted for their use of large expanses of shallow, open habitats. These wetlands often provide an abundance of food and good visibility for avoidance of predators and other disturbances during the day. At night, habitats with greater, robust cover are often sought. Although they forage in openings in southern hardwoods, pintails generally do not use flooded sites in the forest interior. Similarly, they are less apt to use woody riparian corridors than are mallards or wood ducks.

Many well-managed wetlands have the potential to provide an abundant supply of high-energy and nutritionally complete foods for pintails when water depths are <18 inches and preferably <6 inches. Gradual flooding and draining of impoundments at appropriate times during spring and fall migration create conditions that allow optimal foraging opportunities over extended periods. When impoundments vary in depth by more than 18 inches, gradual flooding increases the potential for pintails to consume more available seeds. Waters >18 inches can still provide important roost sites and give security from predators. Newly developed wetland areas are more easily managed for pintails if levees and other water control structures are configured to provide the maximum area in optimal foraging depths of ≤18 inches.

Table 2. *Nutritional values[a] of some important foods consumed by northern pintails.*

	Energy kcal/g		Percent				
Plant foods	Gross	Metabolized	Fat	Fiber	Ash	NFE[b]	Protein
Nodding smartweed	4.6	—	2.7	22.0	7.5	—	9.7
Big-seeded smartweed	4.3	1.1	2.6	19.1	3.8	67.3	10.6
Wild millet	3.9	—	2.4	23.1	18.0	40.5	9.1
Walter's millet	4.5	2.8	3.9	13.7	5.8	55.7	16.8
Sticktights	5.0	—	13.2	20.9	8.9	27.5	23.1
Rice cutgrass	3.9	3.0	2.0	10.6	9.3	57.8	12.0
Fall panicum	4.0	—	6.1	16.8	16.1	50.1	12.0
Hairy crabgrass	4.4	—	3.0	11.1	9.7	59.4	12.6
Redrooted sedge	5.2	—	—	—	—	—	—
Curly dock	4.3	—	1.2	20.4	6.9	—	10.4
Bulrush	3.5	0.8	3.0	23.6	4.3	59.1	7.2
Pondweed	3.9	0.4	2.1	20.6	15.0	50.6	14.0
Chufa seeds	—	—	22.0	5.6	5.1	58.9	8.4
Chufa tubers	4.3	—	10.6	7.3	3.1	57.1	7.0
Barley	—	2.9	2.1	7.1	3.1	—	20.0
Rice	—	2.3	9.3	11.4	9.7	73.5	10.8
Corn	4.4	3.7	4.0	2.3	1.5	77.4	11.6

[a] Values are averages calculated from published information. Because of wide variation in values for some seeds and inconsistency in sample sizes for each nutrient, the sum of values may not be 100%.
[b] NFE = Nitrogen-free extract (highly digestible carbohydrates)

Because waste grains from agricultural production are of great importance to pintails, refuge or farm programs that make these grains available after harvest have special value for pintails in certain areas. Pintail use is increased by shallow flooding of any crop or by manipulating rice stubble by rolling or burning. Barley and rice usually are preferred over corn, although corn is consumed extensively in some locations such as the Sacramento–San Joaquin Delta of California. Maintaining ideal foraging conditions throughout winter and during spring migration provides required resources for molt, migration, and deposition of reserves for breeding. Stable water levels are undesirable, but gradual drawdowns have the potential to increase the vulnerability of invertebrate prey and to make seeds within mud substrates accessible. Furthermore, some good foraging sites should be protected from disturbance by hunters, bird watchers, aircraft, and boaters, as well as from management activities throughout fall and winter.

Breeding

The highest nesting densities occur in open habitats where vegetation is low and sparse. Common plants in these locations include prairie grasses, whitetop, nettle, spike rush, rushes, and buckbrush. Pintails nest in agricultural lands more frequently than other dabblers and readily use pastures, stubble fields, roadsides, hayfields, fallow fields, and the edges or margins around grain fields. In the boreal forest, nesting is concentrated on more open areas with sedge or grass meadows.

Establishment of tall, dense cover is a common practice to provide nesting sites for some dabblers. This practice is less valuable for pintails because they prefer sparser cover for nesting. Grazing programs that leave good residue ground cover but remove robust growth can enhance nesting cover for pintails. Well-conceived farm programs that protect habitats and ephemeral wetlands are especially important for breeding pintails. Because pintails regularly nest in agricultural lands, programs that provide benefits to farmers for delaying haying or for protecting nesting cover surrounding wetlands have the greatest potential to increase pintail recruitment.

Summary

Pintails offer a great challenge to waterfowl managers because they associate with many habitats that are used intensively by agricultural interests. Their preference for open areas and small, shallow wetlands in areas with little rainfall and recurring droughts puts a large part of their breeding area in jeopardy regarding consistent conditions. Developing farm programs compatible with pintail life history requirements offers the greatest opportunities for habitat enhancement, and therefore population recoveries by pintails on the prairies. Northern boreal and tundra habitats must be protected from loss or degradation.

Adequate migration and wintering habitats must be protected, restored, and enhanced. This will require continued acquisitions or other means of protection of key habitats and more effective management of public and private wetlands. One of the greatest opportunities to enhance wintering and migration habitats is to identify scenarios that will benefit rice culture and simultaneously provide needed resources for pintails. This adaptable, highly mobile species has a history of responding rapidly to good habitat conditions across the continent. By providing these habitats to pintails, we can assure their survival and abundance in the future.

Suggested Reading

Bellrose, F. C., editor. 1980. Ducks, geese, and swans of North America. 3rd ed. Stackpole Books, Harrisburg, Penn. 540 pp.

Fredrickson, L. H., and F. A. Reid. 1988. Nutritional values of waterfowl foods. U.S. Fish Wildl. Serv., Fish Wildl. Leafl. 13.1.1. 6 pp.

Krapu, G. L., and G. A. Swanson. 1975. Some nutritional aspects of reproduction in prairie nesting pintails. J. Wildl. Manage. 39:156–162.

Miller, M. R. 1986. Northern pintail body condition during wet and dry winters in the Sacramento Valley, California. J. Wildl. Manage. 50:189–198.

Raveling, D. G., and M. E. Heitmeyer. 1989. Relationships of population size and recruitment of pintails to habitat conditions and harvest. J. Wildl. Manage. 53:1088–1103.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Toothcup *or* Ammania	*Ammania coccinea*
Sticktights	*Bidens* sp.
Sedges	*Carex* spp.
Redroot flatsedge	*Cyperus erythrorhizos*
Chufa flatsedge	*Cyperus esculentus*
Hairy crabgrass	*Digitaria sanguinalis*
Japanese millet	*Echinochloa crusgalli*
Walter's millet *or* wild millet	*Echinochloa walteri*
Spike rush	*Eleocharis* sp.
Swamp timothy	*Heleochloa schoenoides*
Barley	*Hordeum vulgare*
Rush	*Juncus* sp.
Rice cutgrass	*Leersia oryzoides*
Sprangletop	*Leptochloa* spp.
Rice (cultivated)	*Oryza sativa*
Panicum *or* panic grass	*Panicum* spp.
Nodding smartweed *or* smartweed	*Polygonum lapathifolium*
Big-seeded smartweed *or* Pennsylvania smartweed	*Polygonum pensylvanicum*
Pondweeds	*Potamogeton* spp.
Curly dock	*Rumex* spp.
Bulrush	*Scirpus* sp.
Whitetop	*Scolochloa festucacea*
Buckbrush *or* snowberry	*Symphoricarpos* spp.
Nettle	*Urtica* spp.
Corn *or* Indian corn	*Zea mays*
Birds	
Wood duck	*Aix sponsa*
Northern pintail	*Anas acuta*
Mallard	*Anas platyrhynchos*
Invertebrates (Families)	
Chironomids	Chironomidae
Earthworms	Lumbricidae

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1991

13.1.6. Life History and Habitat Needs of the Wood Duck

Katie M. Dugger
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri—Columbia
Puxico, Missouri 63960

and

Leigh H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri—Columbia
Puxico, Missouri 63960

Species Profile—Wood Duck

Scientific name: *Aix sponsa*
Weight in pounds (grams):
Adults—male 1.5 (682), female 1.5 (673)
Immatures—male 1.5 (668), female 1.4 (614)
Age at first breeding: 1 year
Clutch size: 12, normal range 7–15
Incubation period: 30 days, range 26–37
Age at fledging: 56–70 days
Nest sites: Tree cavities or artificial nest boxes within about 0.6 mi (1 km) of water.
Food habits: Omnivorous. Plant foods include primarily acorns, maple samaras, elm seeds, and moist-soil plant seeds. Animal foods consist mainly of aquatic-associated and nonaquatic insects, but also some aquatic invertebrates.

The wood duck is North America's most widely distributed endemic species, and most of its wintering and breeding range falls within the 48 contiguous states (Fig. 1). The wood duck inhabits forested wetlands and, because of its need for nest cavities, is closely tied to North America's remaining forest resources. Habitat destruction, market hunting, and liberal hunting seasons contributed to drastic declines and, in some cases, regional eradication of local wood duck populations. Subsequent implementation of hunting restrictions and the high reproductive rate of the species are responsible for the recovery of wood duck populations to current stable levels.

As prairie duck populations continue to decline, hunting pressure on the wood duck continues to increase. The wood duck is popular with hunters and consistently ranks high among species in Atlantic and Mississippi flyway duck harvests. Harvest pressure and continued degradation of riparian and lowland hardwood forests increases the need for a thorough understanding of wood duck population dynamics. Equally important to sustaining current wood duck population levels is an understanding of annual life cycle events and requirements.

Distribution

Three distinct wood duck populations occur in North America: the Atlantic, Interior, and Pacific. The Atlantic population includes states of the

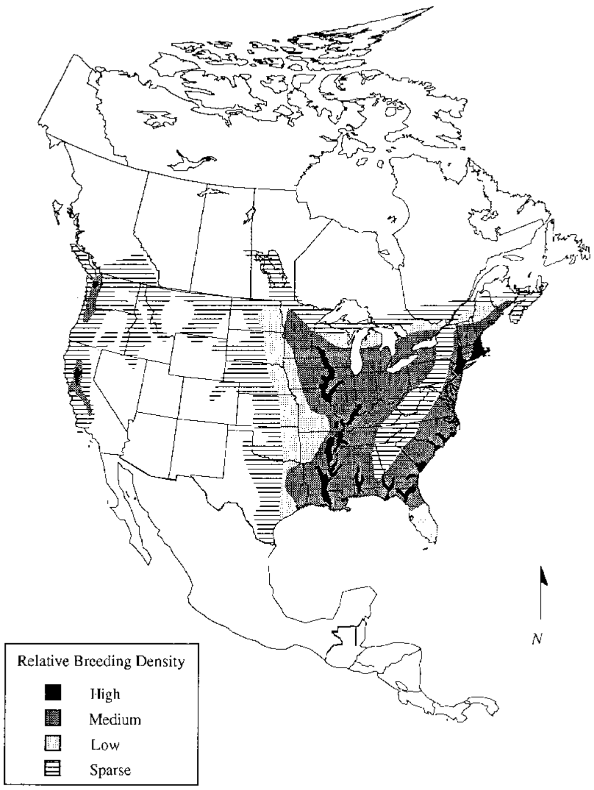


Fig. 1. Current wood duck breeding distribution (after Fredrickson et al. 1990).

Atlantic Flyway and southeastern Canada, the extreme northern range of the wood duck. The Interior population includes wood ducks throughout the Mississippi Flyway, part of Ontario, and the eastern tier of states in the Central Flyway. Historically, the Rocky Mountains and treeless portions of the Great Plains created a discontinuity between the Interior and Pacific populations. As woody riparian corridors developed in the plains, a westward expansion by breeding wood ducks occurred throughout the Great Plains states after the 1960's (Fig. 1). Currently, northern portions of the Pacific and Interior populations are contiguous. The Pacific population ranges principally from British Columbia southward into Washington, Oregon, California, northwestern Idaho, and western Montana, but small numbers of breeding wood ducks are also present in Nevada, Utah, New Mexico, and Arizona. Wood ducks breed throughout most of their range but are at particularly high breeding densities in the Mississippi alluvial valley (Fig. 1). Wintering wood ducks use the more southern habitats throughout their range; habitats of greatest importance include California's Central Valley and the southern states of the Mississippi and Atlantic flyways (Fig. 2).

Population Status and Harvest

Traditional aerial census techniques are ineffective in forested habitats; thus, the current status of wood duck populations can only be approximated.

The average annual wood duck harvest before 1963 was <165,000 birds, but during 1980–1989, an annual average of 1,067,000 wood ducks was harvested in the United States (Frank Bellrose, personal communication). While the dramatic increase in wood duck harvest levels since the 1960's can be attributed to an overall increase in the continental wood duck population, the interactions between wood duck population

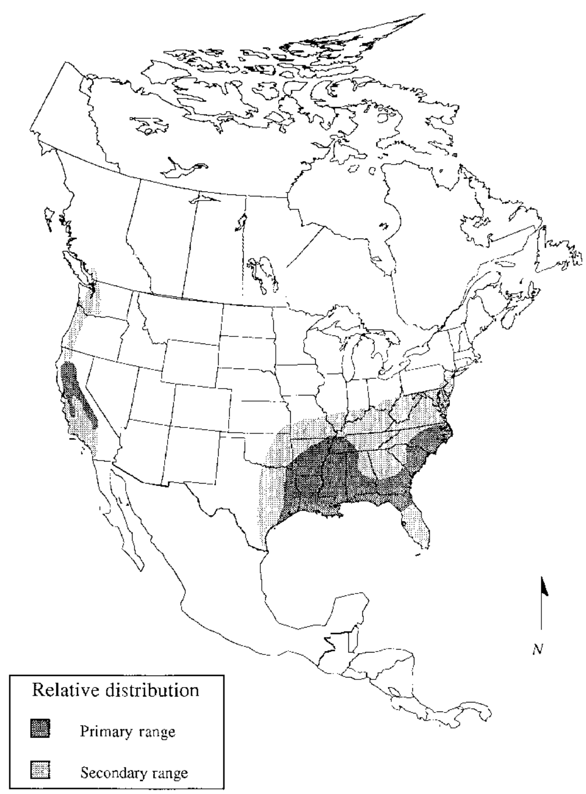


Fig. 2. Wood duck winter distribution (after Bellrose 1980).

dynamics and harvest levels is poorly understood. Current research and historic events suggest harvest regulations can have an effect on wood duck populations in some situations. For example, female wood ducks breeding in northern areas are extremely susceptible to hunting during early seasons that open before the onset of migration. In addition, northern birds are subjected to continued harvest pressure as they migrate southward to winter because waterfowl hunting seasons open in succession from north to south.

Spring Migration and Breeding

In southern regions, wood ducks breed and winter in essentially the same areas. Birds that nest farther north begin northward movements in late winter. Wood duck nests are initiated as early as late January in the South, early March in the Midwest, and mid March to early April in the North. Migrating female wood ducks lack the fat and protein reserves necessary for egg production when they arrive on the breeding grounds. Therefore, upon arrival, wood duck pairs disperse into forested and riparian habitats where females forage intensively in preparation for egg laying.

During this time, nesting pairs also begin searching for suitable cavities, primarily in tracts of forest adjacent to important waterways. Although natural cavities within 0.3 mile (0.5 km) of water and near forest canopy openings are preferred, wood ducks will nest ≥0.6 mile (1 km) from water when necessary. The availability of suitable cavities varies within the wood duck's range (Table 1) because some tree species develop cavities more readily than others. Large trees, ≥12 inches (30 cm) dbh (diameter breast height), produce the most important cavities for wood ducks. Cavities with an entrance size of ≥3.5 inches (8.9 cm), an interior basal area of ≥40 square inches (258 cm^2), and height ≥6 feet (2 m) above the ground are preferred for nesting.

Average clutch size is 12 eggs, but more than one female may contribute to a clutch (dump nest), which can result in clutches of more than 60 eggs. These huge clutches are rarely incubated, but successful dump nests of less than 30 eggs are common in nest boxes. A wood duck clutch is incubated for an average of 30 days at middle latitudes and a few days less in the South.

Female wood ducks and their broods are highly mobile. Initial movements by broods after leaving a nest can be up to 2.4 miles (4 km) but average 0.8 mile (1.3 km), mostly along waterways. Shallowly flooded habitat with good understory cover, such as shrub–scrub or emergent vegetation, is the most important habitat for wood duck broods. Duckling survival ranges from 36 to 65% with most mortality (86–91%) occurring the first week after hatching. Common duckling predators include mink, raccoon, snapping turtle, bullfrog, largemouth bass, and other large predatory fishes.

The bond between the female and her brood begins to weaken after about 4 weeks; ducklings fledge between 6 and 8 weeks. Some early-nesting

Table 1. *Nest cavity density in some North American tree species.*

Location	Species	Cavity density	
		Number/acre	Number/hectare
Southeastern Missouri	Blackgum, green ash, pumpkin ash, red maple	0.13	0.33
Illinois	Black oak, bitternut hickory, mockernut hickory, blackjack oak, red oak, American elm, hackberry	0.21	0.51
Massachusetts	Apple, ash, maple	—	—
New Brunswick	Silver maple, American elm	2.23	5.50
Indiana	American beech, American sycamore, red maple	0.50	1.23
Minnesota	Quaking aspen, American elm, sugar maple, basswood	1.70	4.20
Wisconsin	Silver maple, sugar maple, basswood, quaking aspen	0.26	0.65
Mississippi	American sycamore, American beech, blackgum, shagbark hickory, water oak, cherrybark oak	0.08	0.19
	Overcup oak, slippery elm, sugarberry	0.09	0.23

females in southern latitudes renest, successfully producing two broods before finishing the Prebasic molt (Table 2). Females begin the Prebasic molt in early spring, but it is interrupted during nesting and is not completed until late summer (Fig. 3), when the females regain their flight feathers. Conversely, males may acquire their eclipse plumage as early as mid-May. After the female begins incubation, the male wood duck begins the Prebasic molt and becomes flightless about 3 weeks later. After regaining flight (in about 22 days), the male begins the Prealternate molt and returns to Alternate plumage by late summer.

Post-breeding Dispersal and Fall Migration

After completing the Prebasic molt and before southward migration begins, adult and immature males, as well as some immature females, disperse radially from their breeding and natal areas into new habitats. At southern latitudes, this dispersal tends to be lateral, but in central and northern regions, northward dispersal is most common. In late September, wood ducks begin migrating south. During peak migration in October and November, wood duck numbers fluctuate erratically at migration stopovers where they form large roosting flocks (>100 birds). On the wintering grounds, smaller groups (<30 birds) are more common.

Behavior and Pairing

Wood ducks begin courting before fall migration. Courting activity drops off during harsh weather in winter and resumes in spring. Courtship activity is more intense in fall than in spring; courting parties are larger and displays are longer and more frequent. Wood ducks breed as yearlings, but evidence suggests that only about 40% of the surviving yearling females nest each season. Yearling females produce smaller clutches and fledge fewer young than experienced nesters. The productivity of young male wood ducks may also be low. When compared with adult drakes, yearling males do not perform courtship displays with the proper orientation and timing. Thus, early pairing by inexperienced males is unlikely.

Table 2. *Length of breeding season and frequency of double brooding in wood ducks.*

Location	Mean length of breeding season (days)	Captured females (*n*)	Double-brooding females (%)	Mean interval between clutches (days)
Alabama	159	231	9.2	37
South Carolina	157	275	7.6	47
California	134	1,540	3.6	26 ± 1.7
Missouri	132	924	2.2	33 ± 1.8
Massachusetts	95	—	—	—

Foraging Ecology

Food habits of adult wood ducks are sex related and seasonally driven (Fig. 4). During winter, nearly 100% of the diet of wood ducks consists of plant foods, of which 75% may be acorns. An increase in animal foods in the diet (to about 35%) occurs in both sexes in early spring. This percentage remains constant for the male wood duck through summer and fall while undergoing the Prebasic and Prealternate molts, but increases to about 80% for the female during egg laying. Female wood ducks increase the amount of invertebrates in the diet to meet daily protein needs during egg laying. After egg-laying, animal foods compose less of the female's diet, while consumption of high-energy seeds increases to meet the daily dietary requirements of incubation (Fig. 4).

Wood ducks consume a variety of plant and animal foods (see Appendix), typically by pecking or dabbling at foods on the surface. Subsurface and bottom feeding are rare. Therefore, shallow depths are important to make food available to foraging wood ducks. Because wood ducks feed mainly on the surface or at the edge of wetlands, nonaquatic and aquatic-associated invertebrates make up a large percentage of the invertebrates consumed. Live-forest and emergent vegetation are common wood duck foraging habitats. Wood ducks do not forage readily in agricultural fields unless shallowly flooded, live-forest habitats are not available.

Habitat Management

The wood duck carries out its entire annual cycle within a forested wetland complex, including a mixture of habitats such as live forest, greentree

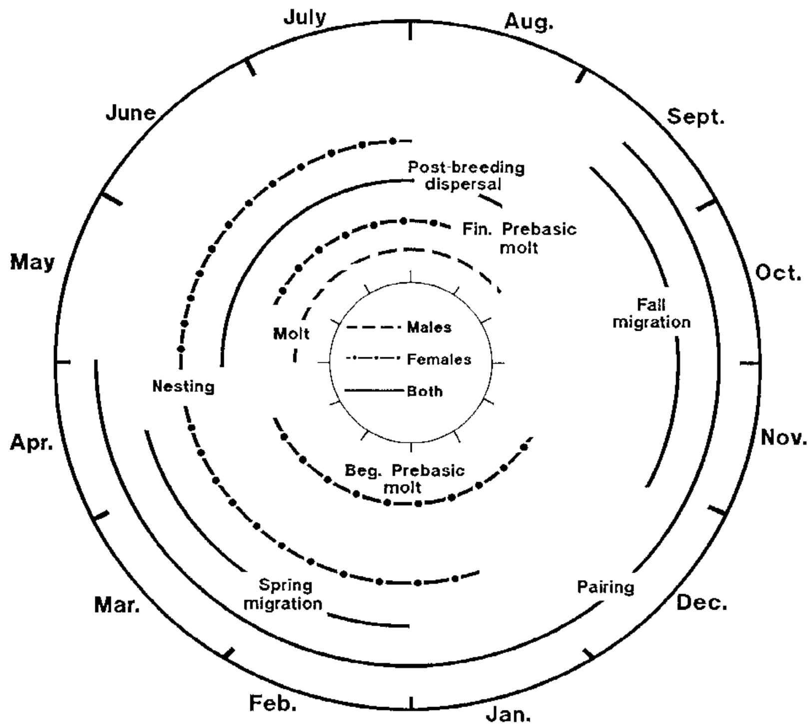


Fig. 3. The chronology of important life history events in the annual cycle of the wood duck.

reservoirs, rivers, oxbows, riparian corridors, beaver ponds, shrub–scrub, and robust emergent vegetation. Such habitats have been destroyed or modified across the continent. For example, only 17% of the original forest acreage remains in the Mississippi alluvial valley today. In addition, certain management practices have detrimental effects on tree vigor and mast production. Flooding before fall senescence or beyond dormancy into the growing season reduces mast production, causes tree damage, and may eventually kill trees. Improper flooding regimes change tree species composition in a stand from desirable oak species that produce small acorns, easily eaten by waterfowl, to the more water-tolerant overcup oak, which produces very large acorns that are unsuitable for waterfowl food. Water depths ≤8 inches (20 cm) are ideal for foraging wood ducks, while loafing and roosting sites can be maintained where water levels are higher.

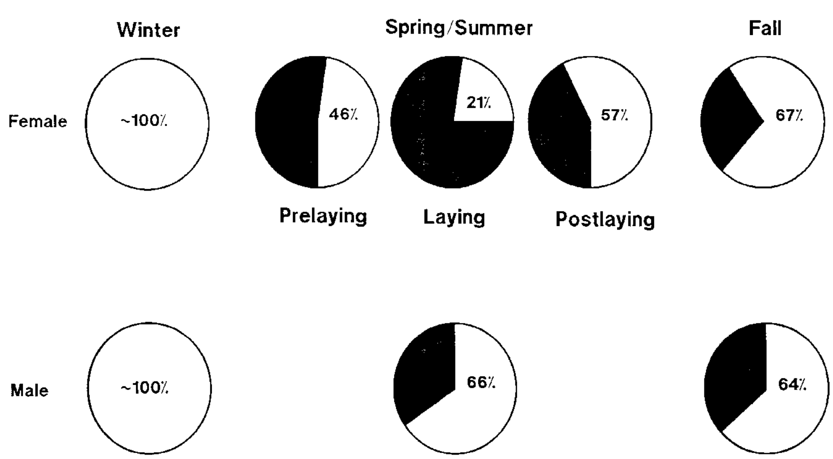


Fig. 4. Proportion of plant (open) and animal (dark) foods consumed by wood ducks throughout their annual cycle.

Timber management within greentree reservoirs and naturally flooded forests is an important component of habitat management for wood ducks. Most timber harvest practices remove large, overmature trees, the primary source of wood duck nest cavities. Although selective thinning within a stand promotes regeneration of desirable shade-intolerant red oak species, some large and overmature trees should be preserved as potential wood duck nest sites. In addition, a mix of species within a stand should be encouraged because desirable mast species may not form cavities. Elm and maple are important components of most wood duck habitat because they provide protein-rich samaras in spring and suitable nest cavities (Table 1).

Nest boxes are a useful management tool where natural cavities are scarce but good brood habitat is available. Currently, nest box management may contribute approximately 150,000 juvenile wood ducks to fall flights in the Mississippi and Atlantic flyways. Although this constitutes only a small portion of the juvenile component in the eastern fall flight, nest boxes, when properly erected and maintained, can substantially increase local populations.

Wood ducks will readily nest in boxes constructed of wood, metal, or plastic. Rough-cut cypress boxes are durable, economical, and blend well with the environment within a few years. Although plastic and metal boxes are durable, internal temperatures of boxes placed in the direct sun in the South are high enough to kill developing embryos.

Whatever the construction material, boxes must be predator-proof. Inverted conical shields or smooth, wide pieces of metal wrapped around the pole or tree beneath a box can keep raccoons and some snakes from entering boxes. Predation can also be discouraged by placing boxes on poles over water or by mounting boxes on bent metal brackets that suspend them 2 feet (0.6 m) from a tree or post.

Annual maintenance and repair of boxes is necessary for continued use by wood ducks. Boxes with unsuccessful nests are unavailable for use until debris from the nest is removed. The frequency of box checks necessary for maintenance depends on climatic conditions and the types of use boxes receive during winter (e.g., screech-owl roosts, squirrel or raccoon dens).

Number and placement patterns of nest boxes within habitats influence box use, nest success, and dump-nesting rates. When box management began 50 years ago, some local wood duck populations were small, and box use was higher when boxes were placed in highly visible, clumped arrangements rather than as widely spaced single units. As wood duck populations grew, high dump-nesting rates, nesting interference, and overall decreases in production occurred. In some situations, single, well-spaced boxes may decrease dump-nesting and nesting interference; however, in prime wood duck breeding habitats hidden boxes simply require more effort to maintain. Boxes acceptable to nesting wood ducks must also be accessible to managers for maintenance and data collection. Although wood duck boxes can increase local production, the preservation of bottomland hardwoods and proper water and timber management in these habitats are paramount to the continued success of continental wood duck populations.

Summary

Although current wood duck populations are stable, continued preservation and proper management of bottomland hardwood and riparian forest resources are imperative. Wood duck population estimates are inaccurate; hence, managers have little knowledge about population cycles or the effect of increased hunting pressure on the continental population. Moreover, protecting North America's remaining forest resources in the face of increasing agricultural and commercial development remains difficult. In particular, forest resources in the lower Mississippi alluvial valley must be carefully preserved and managed to continue providing wintering habitat for a large percentage of the continental wood duck and mallard populations.

At the local level, wood duck populations can be boosted by production from nest boxes, but more information is needed on the density-dependent effects of box placement on nesting interference. Nest box maintenance can be expensive and time consuming. Thus, management for natural cavities should be encouraged. Flooding of greentree reservoirs should simulate natural hydrology and reflect wood duck water depth needs. Remaining forested habitats should be protected and maintained in the best possible condition to sustain larger numbers of birds throughout their annual cycle as high quality habitat continues to disappear.

Suggested Reading

Bellrose, F. C. 1980. Ducks, geese and swans of North America. Third ed. Stackpole Books, Harrisburg, Penn. 540 pp.

Delnicke, D., and K. J. Reinecke. 1986. Mid-winter food use and body weights of mallards and wood ducks in Mississippi. Journal of Wildlife Management 50:43–51.

Fredrickson, L. H., G. V. Burger, S. P. Havera, D. A. Graber, R. E. Kirby, and T. S. Taylor, editors. 1990. Proceedings of the 1988 North American Wood Duck Symposium, St. Louis, Mo. 390 pp.

Grice, D., and J. P. Rogers. 1965. The wood duck in Massachusetts. Massachusetts Division of Fish and Game, Final Report Federal Aid in Wildlife Restoration Project W-19-R. 96 pp.

Trefethen, J. B., editor. 1966. Wood duck management and research: a symposium. Wildlife Management Institute, Washington, D.C. 212 pp.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants

Red maple	*Acer rubrum*
Silver maple	*Acer saccharinum*
Sugar maple	*Acer saccharum*
*Maple	*Acer* spp.
*Asiatic dayflower	*Aneilema keisak*
*Beggarticks	*Bidens* spp.
*Watershield	*Brassenia schreberi*
Bitternut hickory	*Carya cordiformis*
Shagbark hickory	*Carya ovata*
Mockernut hickory	*Carya tomentosa*
Sugarberry	*Celtis laevigata*
Hackberry	*Celtis occidentalis*
*Buttonbush	*Cephalanthus occidentalis*
*Barnyard grass	*Echinochloa crusgalli*
*Barnyard grass	*Echinochloa muricata*
American beech	*Fagus grandifolia*
Green ash	*Fraxinus pennsylvanica*
*Ash	*Fraxinus* spp.
Pumpkin ash	*Fraxinus tomentosa*
*Soybeans	*Glycine max*
*St. John's-wort	*Hypericum walteri*
*Rice cutgrass	*Leersia oryzoides*
*Sweetgum	*Liquidambar stryraciflua*
*Primrose willow	*Ludwigia leptocarpa*
*Water milfoil	*Myriophyllum pinnatum*
*White waterlily	*Nymphaea odorata*
Blackgum	*Nyssa sylvatica*
*Panic grasses	*Panicum* spp.
*Floating paspalum	*Paspalum fruitans*
American sycamore	*Platanus occidentalis*
*Smartweeds	*Polygonum* spp.
Quaking aspen	*Populus tremuloides*
*Pondweeds	*Potamogeton* spp.
Apple	*Pyrus malus*
Cherrybark oak	*Quercus falcata*
Overcup oak	*Quercus lyrata*
Blackjack oak	*Quercus marilandica*
*Water oak	*Quercus nigra*
*Nuttall oak	*Quercus nuttallii*
*Pin oak	*Quercus palustris*
*Willow oak	*Quercus phellos*
Red oak	*Quercus rubra*
*Post oak	*Quercus stellata*
Oak	*Quercus* spp.

Black oak	*Quercus velutina*
*Blackberry	*Rubus cuneifolius*
*Sassafras	*Sassafras albidum*
*Slough grass	*Sclera reticularis*
*Big duckweed	*Spirodela polyrrhiza*
*Baldcypress	*Taxodium distichum*
Basswood	*Tilia americana*
American elm	*Ulmus americana*
Slippery elm	*Ulmus rubra*
Elm	*Ulmus* spp.
Black haw	*Viburnum prunifolium*
Grapes	*Vitus* spp.
Vertebrates	
Wood duck	*Aix sponsa*
Mallard	*Anas platyrhynchos*
Snapping turtle	*Chelydra serpentina*
Largemouth bass	*Micropterus salmoides*
Mink	*Mustela vison*
Screech-owl	*Otus* spp.
Raccoon	*Procyon lotor*
Bullfrog	*Rana catesbeiana*
Invertebrate taxa	
*Spiders	Araneida
*Crayfish	Astacidae
*Midges	Chironomidae
*Water boatmen	Corixidae
*Scuds	*Gammarus* sp.
*Whirligig beetles	Gyrinidae
*Sowbugs	Isopoda
*Back swimmers	Notonectidae
*Damselflies	Odonata
*Dragonflies	Odonata
*Orb snails	*Planorbis* sp.
*Caddis flies	Trichoptera

*Common wood duck foods.

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

U.S. Department of the Interior
National Biological Service
Waterfowl Management Handbook 13

13.1.8. Life History and Management of the Blue-winged Teal

James H. Gammonley
Colorado Division of Wildlife
317 W. Prospect Road
Fort Collins, CO 80526

and

Leigh H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri-Columbia
Puxico, MO 63960

The blue-winged teal is a small dabbling duck that is common in North America and northern South America. The species is highly mobile and has an opportunistic life history strategy. Breeding populations respond to variable wetland conditions in the drought-prone prairie regions of the north-central United States and southern Canada. Extensive habitat loss and degradation has occurred on the prairies and on neotropical wintering areas in recent decades. Renewed interest in the ecology and management of blue-winged teal has resulted from these environmental pressures. We review life history characteristics of blue-winged teal that are important to managers. Readers should consult Bennett (1938) and Bellrose (1980) for general references on the biology of blue-winged teal.

Species Profile—Blue-winged Teal

Scientific Name: *Anas discors*
Weight in pounds (grams):
Adults—male 1.0 (454), female 0.9 (410)
Immatures—male 1.0 (454), female 0.9 (410)
Age at first breeding: 1 year
Clutch size: 10, range 6 to 15
Incubation period: 23 days
Age at fledging: 35–44 days
Nest sites: Herbaceous vegetation, primarily grasses and sedge meadows, at variable distances from water up to 1 mile (1.6 km)
Food habits: Omnivorous; plant foods include vegetative parts of duckweeds, coontail, muskgrass and pondweeds, and seeds of bulrushes, sedges, spikerushes, water lilies, and grasses. Animal foods predominate in diet during breeding and include snails, aquatic insects, fairy shrimp, and crustaceans

Distribution

Blue-winged teal concentrate breeding in the Prairie Pothole Region (PPR) of the north-central United States and southern Canada (Fig. 1). Breeding pairs are especially abundant in mixed-prairie grasslands of North and South Dakota and southern Canada, and highest densities occur in southwestern Manitoba. The proportion of blue-winged teal breeding in the PPR

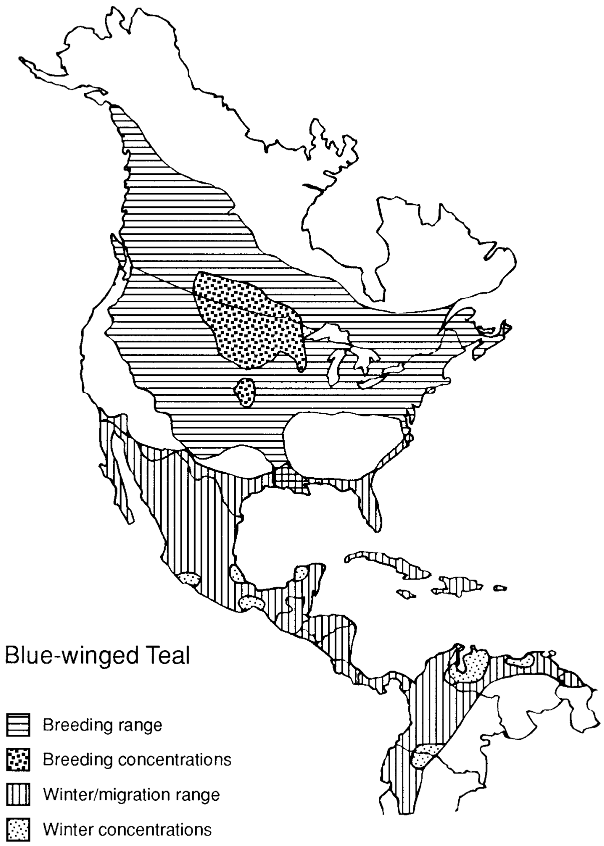


Fig. 1. Breeding, wintering, and migration areas for blue-winged teal.

is correlated with annual numbers of ponds in May. Blue-winged teal are also common in parts of the northeastern United States and the Great Lakes region. Few blue-winged teal nest in northern boreal forest or arctic habitats, although some birds are displaced to these areas when drought conditions occur in the PPR. Significant breeding populations also occur in Kansas and Nebraska, and blue-winged teal regularly breed along the Gulf Coast of the United States. Blue-winged teal are largely replaced by the cinnamon teal in the Great Basin and western intermountain regions, but small breeding populations are present.

Blue-winged teal winter farther south than other ducks that breed in North America. Major wintering concentrations occur along the Gulf Coast of Mexico and in Caribbean coastal areas of Venezuela, Colombia, and Guyana (Fig. 1). In these areas, blue-winged teal occupy coastal lagoons and lowland marshes, as well as large interior wetland systems. In recent decades, large numbers of blue-winged teal have wintered along the Gulf Coast of the United States.

Spring Migration and Breeding

Blue-winged teal are one of the last species of ducks to arrive on northern breeding areas. Those wintering in South America begin moving north through Mexico in January, but the majority of spring migrants does not arrive on prairie breeding areas until late April or May (Fig. 2). Courtship occurs on wintering areas and continues during spring migration, and most blue-winged teal are paired before arrival at the nesting location. Nest initiation begins shortly after arrival; peak nesting usually occurs in late May in the United States and in early June in Canada. Most yearling females nest.

Blue-winged teal have low rates of breeding philopatry when compared with other dabbling ducks. Females change breeding sites from year to year in response to changes in wetland conditions. When habitat conditions in the PPR are unfavorable, large portions of the breeding population may occupy other parts of the breeding range. Males defend discrete breeding territories, usually consisting of one or two small ponds within the home range. Breeding pairs prefer shallowly flooded temporary and seasonal wetlands, and pair densities are correlated with densities of flooded wetland basins. In years when temporary and seasonal wetlands are dry, gently sloping semipermanent basins that provide shallow water are important.

Typically, nests are located in upland grasses or wet meadow sedges. Nest cover is provided by matted residual herbacous vegetation. Nests usually are located near water, but may be as far as 1 mile (1.6 km) from the nearest wetland. Cereal grain and forage production and livestock grazing limit available nesting cover throughout the prairie region, although alfalfa and bluegrass in cultivated or grazed areas can provide suitable nesting cover. Blue-winged teal seem to prefer to nest in native grass communities in good range condition. Success of breeding pairs is higher in native plant communities than in exotic vegetation communities.

Clutch size ranges from 6 to 15 eggs, and averages 10. Females incubate for 23 days. As with most upland-nesting ducks in the PPR, large numbers of nests are lost to mammalian and avian predators. Nests in hay fields (e.g., alfalfa) often are destroyed during harvest. Females commonly

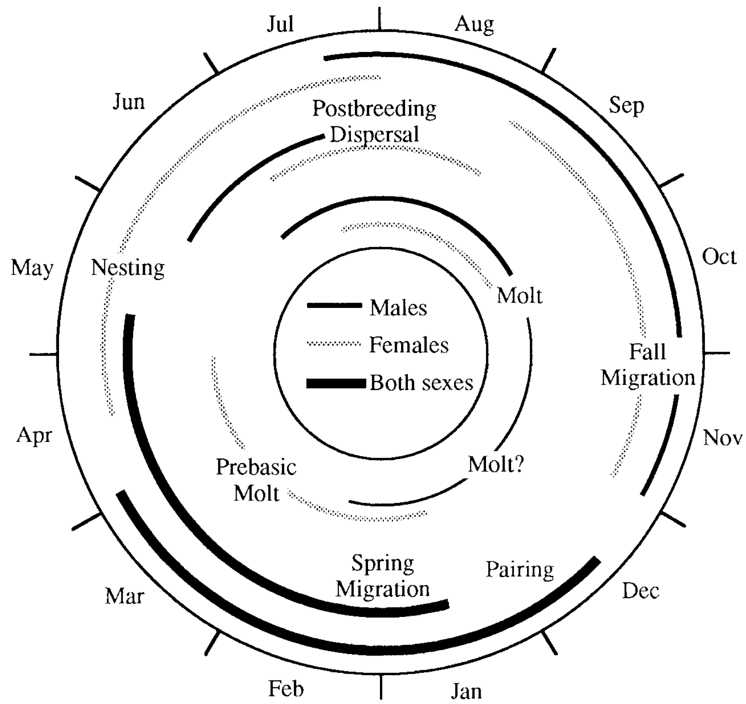


Fig. 2. Important life history events in the annual cycle of the blue-winged teal.

renest if nest loss occurs early in laying, but hens that lose clutches during incubation are less likely to renest. Renesting, even by hens losing clutches late in incubation, is more likely to occur when wetland conditions are good.

Semipermanent wetlands located near nests are important habitats for broods. Stock ponds with well-developed emergent vegetation provide locally important brood habitat. Seasonal wetlands also provide excellent brood habitat, but because blue-winged teal are relatively late nesters, seasonal wetlands are often unavailable when ducklings leave nests. Females lead newly hatched ducklings overland to wetlands with suitable brood habitat. Broods are more active and more easily observed in early morning and late afternoon. Most duckling mortality occurs within the first 14 days after hatch. Young are able to fly at 35–44 days of age.

Postbreeding Dispersal and Fall Migration

Males leave breeding territories 2 to 3 weeks after incubation begins to molt (Fig. 2). Males form groups on some breeding areas during molt, or congregate in large flocks of hundreds or thousands on large marshes away from areas used during breeding. Males remain flightless for 26–36 days, feed at night, and conceal themselves in wetland vegetation during the day. Females begin wing molt after young are fledged, although some females may initiate molt in late stages of brood-rearing.

Blue-winged teal begin fall migration earlier than most other duck species. Upon regaining flight in mid- to late August, males begin moving southward in small groups. Males begin the prealternate molt in early fall, but often lack their characteristic white facial crescent during migration (Fig. 2). Successfully breeding females migrate after most males, and by late September migrating flocks are comprised primarily of adult females and immatures (Fig. 2). Most migrant blue-winged teal arrive at wintering areas along the U.S. Gulf Coast by late summer. Large numbers move through Mexico in August, and most continue on to wintering areas in Central and South America.

Winter

As on breeding areas, winter distribution is variable in response to habitat conditions. Standardized counts of wintering populations in Central and South America are lacking. In some years, relatively large numbers remain on the lagoons and marshes of the Gulf Coast of Mexico (Tabasco and Yucatan). January surveys of wetlands in Mexico show wide fluctuations in numbers of blue-winged teal, due to annual differences in the chronology of spring migration from South American wintering areas. Blue-winged teal also pioneer into new winter habitats; after hurricanes opened marshes along the U.S. Gulf Coast in the 1950s, many thousands of teal began wintering in these habitats far north of traditional wintering sites.

Feeding

Blue-winged teal are omnivorous, and usually feed in portions of wetlands that are flooded less than 8 inches (20 cm) deep. During breeding, aquatic invertebrates provide most of the protein and minerals required for egg production. Endogenous lipid reserves contribute about 40% of egg lipid requirements. Additional lipids are obtained from foods consumed on wetlands used for breeding. Blue-winged teal do not store significant nutrient reserves on wintering areas, so most lipid storage apparently occurs during spring migration.

Diverse and abundant invertebrate populations develop in temporary and seasonal wetlands and are available to teal feeding in these shallow basins. Snails, midge and mosquito larva and adults, fairy shrimp, beetles, amphipods, and isopods in these habitats are important foods for blue-winged teal during spring migration and breeding (Table). As seasonal wetlands dry over the summer, teal move to semipermanent wetlands to feed. Although diversity and availability of aquatic invertebrates is relatively low in more permanently flooded basins, emerging aquatic insects provide food for blue-winged teal in these wetlands.

During the postbreeding period, snails, midge and mosquito larva, water fleas, and amphipods were consumed by molting males on Delta Marsh in Manitoba (Table). Seeds and aquatic vegetation comprised 43% of these birds' diets. In Texas, fall migrants primarily consumed seeds of wild millet, milo, and other plant foods (Table).

Wintering blue-winged teal spent up to 50% of daylight hours feeding on marshes along the west coast of the Yucatan Peninsula in Mexico. Small snails (98%) and widgeongrass seeds were consumed early in winter, whereas muskgrass (98%), snails, odonates, and corixids comprised diets in late winter (Table). In Costa Rica, blue-winged teal fed at night on rice seeds (92%) and insects in cultivated rice fields (Table). In Colombia, blue-winged teal fed predominantly (54%) on plant foods (primarily water lily seeds) during one year, but switched to animal-dominated

Table. Percentage of animal foods in the diet of blue-winged teal during the annual cycle.

Season and sex	Animal diet (%)	Location
Spring migration Both sexes	65	Moist-soil impoundments Missouri
Breeding season Both sexes	89	Prairie wetlands North Dakota
Spring and summer Laying females	99	Prairie wetlands North Dakota
Post-breeding period Males	57	Delta Marsh, Manitoba Canada
Fall migration Both sexes	8	Playa wetlands Texas
Early winter Both sexes	98	Celestun Estuary Mexico
Late winter Both sexes	2	Celestun Estuary Mexico
Winter (Dec–Feb) Both sexes	8	Palo Verde refuge Costa Rica
Winter 1979–80 Females	46	Cienaga Grande Colombia
Winter 1985–88 Both sexes	73	Cienaga Grande Colombia

diets (snails, corixids, and insects) in years when water salinity increased (Table).

Population Status and Harvest Management

The target population for blue-winged teal in the North American Waterfowl Management Plan is 5,300,000 birds. Breeding population estimates have averaged 4,138,000 since 1955, ranging from 5,829,000 in 1975 to 2,776,000 in 1990 (Fig.3). These estimates are subject to considerable bias and error, however. Annual surveys are conducted in May to coincide with the peak of mallard nesting, and in some years many blue-winged teal do not arrive on surveyed areas until after counts are conducted. Furthermore, significant proportions of the blue-winged teal breeding population may occupy locations outside the surveyed area, particularly in years when habitat conditions are poor in the PPR (e.g., the 1980s).

Based on annual breeding ground estimates, blue-winged teal comprise over 14% of the continental duck population. This species is lightly hunted, averaging less than 6% of the total annual duck harvest in the United States. Because blue-winged teal migrate earlier in fall than most other North American ducks, special harvest regulations have been used in some years since the 1960s to increase hunting opportunities for teal. September teal-only seasons of up to 9 days and bonus blue-winged teal bag limits have been used in some states in the Central, Mississippi, and Atlantic flyways. When offered, the teal harvest in September has averaged 201,991 birds, or 32% of the total blue-winged teal harvested in the United States. Most blue-winged teal are harvested in the Mississippi (61%) and Central (21%) flyways during the combined September and regular seasons. September teal seasons were suspended in 1988, but were reinstated in many states in 1992.

Harvest rates south of the United States are less well-documented. Through 1980, 21% of all reported recoveries of leg-bands from blue-winged teal were from south of the United States. Most (37%) of these recoveries were from South America, followed by Mexico (28%), the Caribbean (25%), and Central America (10%). Many bands recovered in the neotropics may go unreported, however, complicating the use of banding data to determine blue-winged teal distribution and harvest.

Relatively low harvest and band recovery rates have also limited estimates of annual survival for blue-winged teal. Available estimates are similar to but slightly lower than those reported for other dabbling ducks: adult females—0.52, adult males—0.59, juvenile females—0.32, juvenile males—0.44. Females are more vulnerable to predators than males during nesting, but do not seem to suffer significantly greater mortality than females of other dabbling duck species. Factors affecting survival rates in winter are not well known.

Habitat Management

Blue-winged teal exploit a diversity of wetland habitats to meet their nutritional and behavioral requirements during the annual cycle. During spring migration and nesting, pairs find an

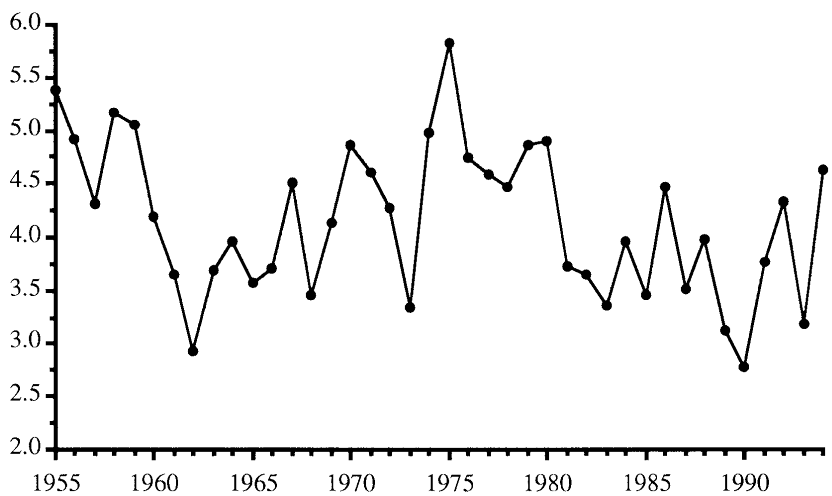


Fig. 3. Estimates of the continental breeding population (millions of birds) of blue-winged teal, 1955–1994.

abundance of aquatic invertebrates in highly productive temporary and seasonally flooded wetlands. Semipermanent wetlands with gently sloping basins and both emergent and submergent vegetation provide foraging and brood-rearing sites, and are very important in dry years on the drought-prone prairies. High densities of these wetland types in areas with high-quality nesting cover allow teal to establish nesting territories and avoid long overland brood movements. Restoration of temporary and seasonal wetlands is particularly needed in agricultural landscapes.

Breeding success of blue-winged teal is enhanced when extensive areas of suitable upland nesting cover are available near wetlands used by pairs and broods. In native prairie grass communities, dead vegetation should accumulate over several growing seasons to provide matted mulch used for nest sites. Periodic disturbance is required to keep grass cover from becoming too dense. Burning, mowing, and grazing can be used effectively to maintain range condition for blue-winged teal nesting. Optimal intervals between grassland disturbance are dependent upon local conditions. When possible, grassland disturbance should be performed after the peak hatching period of blue-winged teal. Seeded dense nesting cover used by mallards and gadwalls seems to be less attractive to blue-winged teal.

The high mobility and low breeding philopatry of blue-winged teal are important to the development and evaluation of management strategies for breeding populations. Breeding pairs may select home ranges opportunistically in response to wetland conditions encountered during spring moves. Use by blue-winged teal of areas that have undergone intensive habitat management may depend largely upon habitat quality in the surrounding regional landscape.

Development of partnerships by agencies in numerous countries is essential to ensure the long-term availability of high-quality wetland systems for use by blue-winged teal. Wetland loss and degradation in neotropical wintering areas have been as great or greater than in northern prairie breeding habitats. Effective wetland management, protection, and restoration are important throughout the range of the blue-winged teal.

Suggested Reading

Bellrose, F. C., editor. 1980. Ducks, geese, and swans of North America. 3rd ed. Stackpole Books, Harrisburg, Penn. 540 pp.

Bennett, L. J. 1938. The blue-winged teal: its ecology and management. Collegiate Press, Inc., Ames, Iowa. 144 pp.

Botero, J. E., and D. H. Rusch. 1994. Foods of blue-winged teal in two neotropical wetlands. Journal of Wildlife Management 58:561-565.

Dubowy, P. J. 1985. Feeding ecology and behavior of postbreeding male blue-winged teal and northern shovelers. Canadian Journal of Zoology 63:1292-1297.

Kaiser, P. H., S. S. Berlinger, and L. H. Fredrickson. 1979. Response of blue-winged teal to range management on waterfowl production areas in southeastern South Dakota. Journal of Wildlife Management 32:295-298.

Swanson, G. A., M. I. Meyer, and J. R. Serie. 1974. Feeding ecology of breeding blue-winged teals. Journal of Wildlife Management 38:396-407.

Swanson, G. A., and M. I. Meyer. 1977. Impact of fluctuating water levels on feeding ecology of breeding blue-winged teal. Journal of Wildlife Management 41:426-433.

Taylor, T. S. 1978. Spring foods of migrating blue-winged teals on seasonally flooded impoundments. Journal of Wildlife Management 42:900-903.

Weller, M. W. 1979. Density and habitat relationships of blue-winged teal nesting in northwestern Iowa. Journal of Wildlife Management 43:367-374.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Muskgrass	*Chara* spp.
Duckweed	*Lemna* spp.
Coontail	*Ceratophyllum* spp.
Pondweed	*Potamogeton* spp.
Bulrush	*Scirpus* spp.
Sedge	*Carex* spp.
Spikerush	*Eleocharis* spp.
Water lily	*Nymphaea* spp.
Alfalfa	*Medicago sativa*
Bluegrass	*Poa pratensis*
Millet	*Echinochloa crusgalli*
Milo	*Sorghum vulgare*
Rice	*Oryza sativa*
Widgeongrass	*Ruppia maritima*
Birds	
Blue-winged teal	*Anas discors*
Cinnamon teal	*Anas cyanoptera*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*
Invertebrates	
Snails	Gastropoda
Midges	Chironomidae
Isopods	Isopoda
Beetles	Coleoptera
Mosquitos	Culicidae
Fairy shrimp	Anostraca
Water fleas	Cladocera
Dragonflies	Odonata
Water boatmen	Corixidae

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL BIOLOGICAL SERVICE
WATERFOWL MANAGEMENT HANDBOOK 13
Washington, D.C. • 1995

13.1.11. Life History Traits and Habitat Needs of the Redhead

Christine Mitchell Custer
U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
P.O. Box 2226
La Crosse, Wisconsin 54602

Species Profile—Redhead

Scientific name: *Aythya americana* (Eyton)
Weight in pounds (grams):
Adults—male 2.4 (1,087), female 2.1 (953)
Immatures—male 2.1 (953), female 1.9 (862)
Age at first breeding: 1 or 2 years
Clutch size: 7–10 eggs
Incubation period: 24–25 days
Age of fledging: 10–12 weeks
Nest sites: Semipermanently and seasonally flooded palustrine wetlands with persistent emergent vegetation.
Food habits: Omnivorous, except in winter; shoalgrass rhizomes and wildcelery winter buds during winter; tubers, rhizomes, and parts of aquatic vegetation, and aquatic invertebrates (insects, crustaceans, and mollusks) during spring, summer, and fall.

Redheads are one of five common diving duck species in North America. They are in the same taxonomic group as the pochards or bay ducks and are most similar in appearance and behavior to the canvasback. Smaller body size, late breeding, wintering in southern areas, and tolerance to salt in winter and in breeding areas differentiate the redhead from the canvasback and suggest an evolutionary origin in the arid areas of the West. Parasitism of other waterfowl nests is more pronounced in redheads than in other North American waterfowl. These and other aspects of the biology of the redhead are the subject of this leaflet. Readers who are interested in general references on redheads are referred to Palmer (1976) or Bellrose (1980).

Distribution

Redheads breed in unforested areas with semipermanently to permanently flooded palustrine wetlands that support persistent emergent vegetation. The highest numbers of redheads breed in the prairies and parklands of Manitoba, Saskatchewan, North Dakota, and South Dakota (nest densities = 10–25/mile^2 [4–10/km^2]). Nest densities are highest in the marshes of Nevada and Utah (180–550/mile^2 [69–214/km^2]; Fig. 1) where this species may have first evolved.

Redheads winter on brackish to hypersaline waters in the southern United States and in Mexico. An estimated 80% of redheads winter on the hypersaline Laguna Madre along the Gulf Coast of northern Mexico and southern Texas, but some select other parts of the Gulf Coast and the southern Atlantic Coast (Fig. 1). Migration routes to

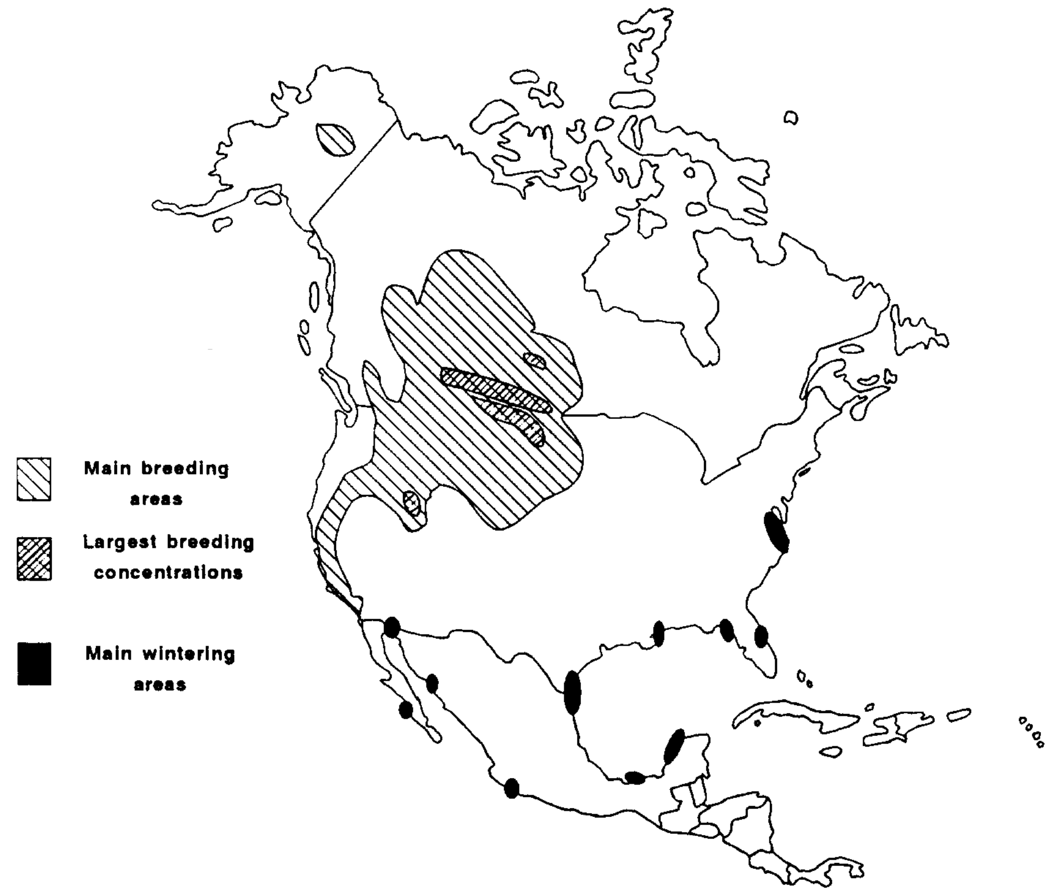


Fig. 1. Distribution of important breeding and wintering areas of redheads.

these wintering areas do not follow flyways. Redheads that breed in the Pacific Flyway and in the Central Flyway winter in the Central Flyway. Few redheads migrate through the Mississippi Flyway.

Spring Migration

Most redheads depart wintering areas in the Laguna Madre within 2 weeks in early March and wintering areas on the Atlantic Coast in mid-March (Fig. 2). They move through Iowa, Kansas, and Nebraska in March and reach Canada by mid-April. They are considered midseason migrants because they migrate later than mallards, green-winged teals, and northern pintails but earlier than gadwalls and ruddy ducks.

Breeding

Wetland Habitats

In the prairie potholes of Montana and northwestern Iowa and in the intermountain West, redheads use two types of permanently and semipermanently flooded palustrine wetlands for breeding. When they first arrive (prelaying period), redheads feed in large, deep, open areas (>1 acre [0.4 ha]) with submersed aquatic vegetation (Fig. 2). They use smaller, more shallow permanent to semipermanent wetlands with blocks of dense emergent vegetation for nesting (laying and incubating eggs). Wetlands that redheads use during prelaying and brood rearing are similar. Essential elements include a good supply of preferred foods such as invertebrates and submergent plants, ample water depth for escape

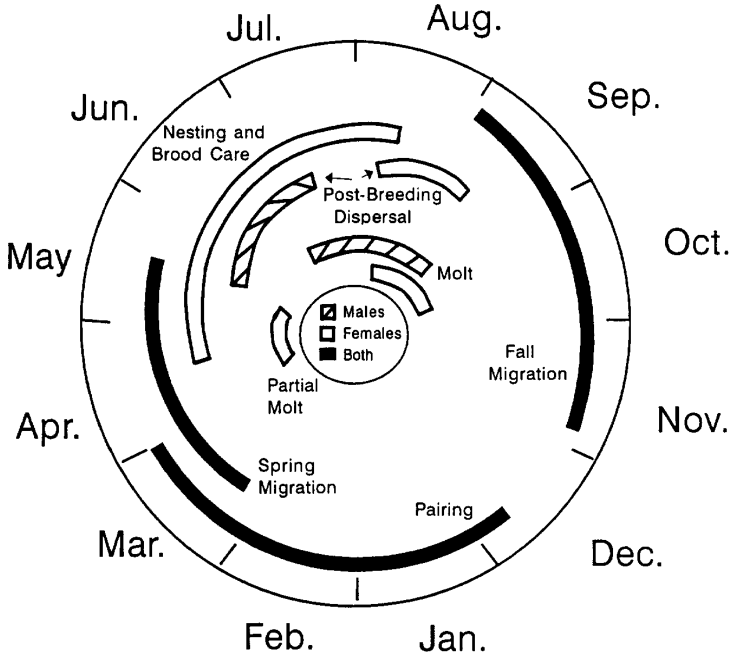


Fig. 2. The chronology of important life history events in the annual cycle of the redhead.

(>4 ft [>1.2 m]), and large open areas where approaching predators are visible.

Redheads use widgeongrass in saline lakes or energy-rich seeds in shallow, temporary ponds during the prelaying and laying periods in North Dakota. They rely on deep, open areas during droughts when shallow-water areas are not available. Because of low rates of nutrient recycling and a scarcity of feeding areas in open water, the quantity of food may not be as great as in shallow-water areas. Broods in all areas use shallow (<2 ft [<0.6 m]) ponds if emergent vegetation is available for escape cover.

Impoundments and other intensively managed wetland complexes in California and Wisconsin are used by redheads. In Wisconsin, redheads nest in semipermanently flooded cattail marshes or hardstem-bulrush marshes but feed in nearby seasonally flooded impoundments managed for moist-soil plants (rice cutgrass and smartweed). Initially, broods use areas with abundant insect larvae (such as seasonally flooded impoundments) and later move to more open areas (such as semipermanent impoundments) with pondweeds and duckweed.

Nest Site Requirements

Wetlands that are 5 acres (2.0 ha) or larger and not farther than 0.25 miles (0.4 km) from large permanent or semipermanent lakes provide optimum nesting habitat. Females usually place nests in dense bulrush or cattail stands that are interspersed with small (2–3 yd^2 [1.7–2.5 m^2]) areas of open water. Wetlands that are smaller than 1 acre (<0.4 ha) must contain large blocks of emergent vegetation for adequate seclusion and protection of nesting redheads.

Redheads begin building nests over water with remnants of the previous year's vegetation and use new vegetation as it becomes available. Redheads seem to prefer to nest in hardstem, slender, and Olney bulrushes but also use river and awned sedges, narrow-leaved and common cattails, and whitetop. These plants offer a firm structural framework for the nest and cover for above the nest. A residual stem density of 35–45 bulrush stems/ft^2 (350–450 stems/m^2) or 3–5 cattail stems/ft^2 (32–52 stems/m^2) provides adequate cover and a foundation for the nest.

The presence of water seems more important than specific vegetation for nesting. Although redheads do not always nest over water, their nests are usually placed within 10–13 ft (3–4 m) of open water. However, redhead nests have been reported as far away as 755 ft (230 m) from open water. Stable water levels are important to nesting success. The bottom of the nest is usually between 2 and 10 inches (4–24 cm) above the water. If water levels rise, nests may be lost to flooding if females cannot raise the level of the nests. If the wetland dries, nests may be destroyed by predators or deserted.

Brood Size and Chronology

The brood size of redheads averaged 7 in Iowa and 5 in Nevada; most losses of young occurred within the first few days of life. The female usually deserts her brood when the ducklings are about 8 weeks old and still flightless. In contrast, ring-necked ducks and many dabbling duck species do not desert their yet-flightless young. Young redheads fly at 10–12 weeks.

Food Habits

During spring migration and the breeding season, adult redheads are opportunistic and omnivorous. In spring in North Dakota and Canada, redheads feed primarily on protein-rich invertebrates, including Diptera larvae and Trichoptera (>50% by volume). Much of their remaining diet consists of bulrush seeds and sago pondweed buds (≤15% by volume). In North Dakota and Wisconsin, breeding redheads may rely on seeds of moist-soil plants (smartweed, rice cutgrass, bulrush) when invertebrates are scarce. In Nevada, adult redheads consume bass eggs, odonate nymphs, and seeds and vegetative parts of sago pondweed, alkali bulrush, and muskgrass.

Studies in North Dakota did not reveal diet shifts, but some studies in Wisconsin revealed different proportions of invertebrates, seeds, and vegetation in the diet among prelaying, laying, and postlaying females. Redheads may have a physiological need for a seasonal shift in diet, but such a shift may not always occur because the desirable foods are not available.

Redhead ducklings eat a wide variety of foods, including insect larvae, seeds, muskgrass oogonia, and tubers. The ducklings usually move from a diet that is high in animal matter just after they hatch to a diet of almost exclusively plant matter as they approach fledging. In Wisconsin, ducklings eat mainly Hemiptera nymphs and adults, Diptera larvae, and bulrush seeds during the first 3 weeks of life. As they grow older, ducklings switch to a diet of mainly vegetation such as sago and slender pondweed, duckweed, and bulrush achenes.

Reproductive Strategy

Redheads may lay as much as 75% of their eggs in the nests of other waterfowl; as much as 50% of a redhead's production is from parasitic eggs. Redheads seem to follow a dual strategy. In favorable years (abundant food, normal water levels and weather conditions), redheads increase their fecundity by laying 6–10 parasitic eggs before they initiate normal nesting. Parasitic eggs are produced without the time, energy, and risk associated with nest building, incubation, and brood rearing. In poor years (less abundant food or drier water conditions), younger females usually are entirely parasitic and older females nest normally, but neither age class does both. Although the hatching rate of parasitic eggs is about half that of nonparasitic eggs (90% hatching rate), females that also nest normally increase their fecundity with parasitic eggs.

The number of parasitic eggs per host nest averages between 3 and 5 in nests of canvasbacks, 4 in nests of lesser scaups, and 3 in nests of other species. Parasitism lowers the productivity of the host species because there are fewer host eggs in parasitized nests. Some of the host's eggs are pushed from the nest during the intrusion by the parasitic redhead. Redhead parasitism rates increase with increasing densities of other duck species. Redheads also parasitize nests of mallards, northern pintails, northern shovelers, gadwalls, American wigeons, blue-winged and cinnamon teals, ruddy ducks, and other redheads. The selection of host species may result from overlapping nest chronologies and selection of similar nesting habitat.

Postbreeding Dispersal and Fall Migration

The postbreeding dispersal of males and nonbreeding females begins in June (Fig. 2), and breeding females disperse when their young are 8 weeks old or older. Redheads of both sexes and all ages usually move north from their breeding locations to large lakes and reservoirs before molting and the subsequent fall migration. Large lakes may provide molting, flightless redheads with protection from predators and a rich food source. One very important lake for staging and molting, especially for males, is Lake Winnipegosis in Manitoba. At peak migration in 1975, an estimated 144,000 redheads were on that lake. In Utah, flightless adults usually remain in the wetland complex where they nested.

Males are flightless during late July and early August. Females become flightless approximately 6 weeks after they desert their broods. Flightless redheads usually swim or dive to escape; unlike many dabbling ducks, they rarely flap across the water.

Postbreeding adults in Manitoba eat primarily winter buds and parts of sago pondweed and muskgrass. They also ingest lesser amounts (<5% dry weight) of bulrush achenes, widgeongrass, and midge larvae and adults.

Winter Habitats and Behavior

Eighty percent of all redheads winter on the Laguna Madre of Texas and Mexico. When redheads first arrive on the hypersaline Laguna Madre, they make daily trips to adjacent freshwater ponds. They also select feeding sites with the lowest possible salinities (approximately ≤30 ppt) in the Laguna Madre. As their salt glands increase in size, the requirement for fresh water daily diminishes. By mid- to late December, fewer redheads travel to freshwater wetlands each day. The number of redheads that seek fresh water later in winter is determined by salinities in the Laguna Madre. Where salinities are high (45–60 ppt), 50% or more of the redheads are on fresh water daily throughout winter. Where salinities are lower (30–35 ppt), fewer than 15% visit fresh water daily. Freshwater sites that redheads frequent usually have salinities of less than 15 ppt and are usually within 2–4 miles (4–7 km) of feeding areas. Redheads use freshwater sites for drinking, preening, and bathing but not for feeding.

Although redheads are diving ducks, they feed most often by head dipping or tipping up (>75% of the time) in 5–12-inch-deep (12–30-cm) water on the Gulf Coast. Redheads spend about 5 h each day feeding in this manner. Feeding by diving requires about 3 times as much time and costs more energy than feeding by head dipping or tipping up. Redheads may dabble for food during the breeding season.

Food Habits

During winter, redheads in the Laguna Madre eat shoalgrass rhizomes almost exclusively, even though other vegetation is also available. As much as 15% of the food by volume (approximately 20% by weight) can be mollusks, mainly small snails such as dovesnails, variable ceriths, and virgin nerites. Whether these mollusks are ingested selectively or only incidentally to rhizome gathering is not known. In the Chesapeake Bay, wintering redheads eat winter buds of wildcelery and sago pondweed.

Courtship and Pairing

Redheads begin pairing during winter. In southern Texas, approximately 30% of the redhead females were already paired by late December and nearly 50% by late February. Females are the more aggressive member of the pair and are usually responsible for pair defense. Paired redheads continue their courtship on the breeding areas but do not copulate until the pair bond is well established.

Population Status and Harvest

The target of the North American Waterfowl Management Plan for redheads is a population size of 760,000 birds. The average population size has been at this level for the past 2 decades (759,800 during 1970–79 and 825,800 during 1980–89). The successful maintenance of redhead populations at targeted levels may have been in part the result of closed seasons and restricted bag limits for this species. Populations also may be stable because redheads use permanent and semipermanent wetlands for breeding. Because these wetland types usually persist during droughts, redheads are more likely to have a place to nest than are other waterfowl species that rely on temporarily or intermittently flooded wetlands. Furthermore, redheads are less traditional than canvasbacks in their choice of breeding areas and are therefore more likely to move into different breeding areas to take advantage of adequate water conditions.

Redheads make up 2% of the North American ducks but less than 1% of the harvested ducks in the United States. The average number of harvested redheads per year was 184,000 during 1971–79 and 171,100 in 1982 and 1983 but only 37,400 during 1989–91. The reduction in number of harvested redheads between the 1970's and 1989–91 is paralleled by a reduction in the number of hunter days and the size of the seasonal bag per hunter. Most redheads are harvested in the Central Flyway (1–3% of the total duck harvest), and fewest are taken in the Atlantic Flyway (0.1–0.6% of the total duck harvest).

Implications for Management

Because redheads need a combination of habitats during the breeding season and are specialists during the postbreeding and wintering portions of their life cycle, they offer a challenge to managers. Management for redheads in the prairies should focus on wetland complexes. Deeper water with invertebrates or shallow water with moist-soil plants should be made available during the prelaying period. Water levels should be kept constant during the laying and incubation periods to reduce losses of clutches from flooding or from predators if the area becomes too dry. Recently flooded areas with high invertebrate populations should be available during the first few weeks of the brood period and should be followed by access to deeper water with ample pondweeds.

The parasitic nature of redheads also offers a challenge to managers. An increase in the numbers of nesting redheads may be at the expense of other waterfowl species. Females whose nests are parasitized by redheads have a lower productivity than conspecifics whose nests are not parasitized.

Large concentrations of postbreeding redheads occur on only a few large lakes that provide protection from predators, a rich food supply, and minimal human disturbance. Because these traditional postbreeding areas are limited, they have to be preserved.

During winter, redheads on the Laguna Madre prefer shallow (5–12 inches [12–30 cm] deep), open water with shoalgrass on the bottom. Especially early in winter before they have acclimated to hypersaline conditions, redheads also require a source of fresh drinking water within 4–5 miles (6–8 km) of their feeding sites. Since the 1960's, monotypic shoalgrass meadows declined by over 50% in certain parts of the Laguna Madre. Concurrently, recreational and industrial uses of these coastal areas increased. Important areas for redheads, especially areas in shallow water, need to be identified and protected from human disturbance and further loss of shoalgrass. When wildcelery disappeared from the Chesapeake Bay, redheads (unlike canvasbacks) did not switch to an alternate food such as Baltic macomas—they abandoned the area. This may indicate their lack of flexibility in food choice during winter and emphasize the need to protect remaining wintering habitat.

Suggested Reading

Bellrose, F. C., editor. 1980. Ducks, geese & swans of North America. 3rd ed. Stackpole Books, Harrisburg, Pa. 544 pp.

Howard, R. J., and H. A. Kantrud. 1983. Habitat suitability index models: redhead (wintering). U.S. Fish and Wildlife Service, FWS/OBS–82/10.53. 14 pp.

Lokemoen, J. T. 1966. Breeding ecology of the redhead duck in western Montana. Journal of Wildlife Management 30:668–681.

Low, J. B. 1945. Ecology and management of the redhead, *Nyroca americana*, in Iowa. Ecological Monographs 15:35–69.

Mitchell, C. A., T. W. Custer, and P. J. Zwank. 1994. Herbivory on shoalgrass by wintering redheads in Texas. Journal of Wildlife Management 58:131–141.

Palmer, R. S., editor. 1976. Handbook of North American birds. Vol. 3. Yale University Press, New Haven, Conn. 560 pp.

Sorenson, M. D. 1991. The functional significance of parasitic egg laying and typical nesting in redhead ducks: an analysis of individual behavior. Animal Behavior 42:771–796.

Weller, M. W. 1964. Distribution and migration of the redhead. Journal of Wildlife Management 28:64–103.

Woodin, M. C., and G. A. Swanson. 1989. Foods and dietary strategies of prairie-nesting ruddy ducks and redheads. Condor 91:280–287.

Appendix. Common and Scientific Names of the Plants and Animals Named in the Text.

Plants	
Awned or slough sedge	*Carex atherodes*
River sedge	*C. lacustris*
Muskgrass	*Chara* sp.
Shoalgrass	*Halodule wrightii*
Rice cutgrass	*Leersia oryzoides*
Duckweeds	*Lemna* spp.
Smartweeds	*Polygonum* spp.
Sago or fennelleaf pondweed	*Potamogeton pectinatus*
Slender pondweed	*P. pusillus*
Widgeongrass	*Ruppia maritima*
Hardstem bulrush	*Scirpus acutus*
Slender bulrush	*S. heterochaetus*
Olney bulrush	*S. olneyi*
Alkali bulrush	*S. paludosus*
Whitetop	*Scolochloa festucacea*
Narrow-leaved cattail	*Typha angustifolia*
Common cattail	*T. latifolia*
Wildcelery	*Vallisneria americana*
Invertebrates—Arthropoda	
Flies, midges	Diptera
True bugs	Hemiptera
Dragonflies and damselflies	Odonata
Caddisflies	Trichoptera
Invertebrates—Mollusca	
Greedy dovesnail	*Anachis avara*
Variable cerith (sometimes called horn shell)	*Cerithium lutosum*
Baltic macoma (sometimes called Baltic clam)	*Macoma balthica*
Lunar dovesnail	*Mitrella lunata*
Virgin nerite	*Neritina virginea*
Birds	
Northern pintail	*Anas acuta*
American wigeon	*A. americana*
Northern shoveler	*A. clypeata*
Green-winged teal	*A. crecca*
Cinnamon teal	*A. cyanoptera*
Blue-winged teal	*A. discors*
Mallard	*A. platyrhynchos*
Gadwall	*A. strepera*
Lesser scaup	*Aythya affinis*
Redhead	*A. americana*
Canvasback	*A. valisineria*
Ruddy duck	*Oxyura jamaicensis*
Fish	
Largemouth bass	*Micropterus salmoides*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

13.1.15. Life History and Habitat Needs of the Black Brant

Dirk V. Derksen and David H. Ward
U.S. Fish and Wildlife Service
Alaska Fish and Wildlife Research Center
1011 East Tudor Road
Anchorage, AK 99503

Species Profile—Black Brant

Scientific name: *Branta bernicla nigricans*
Weight* in pounds (grams):
Adults—male 3.6 (1,802), female 3.3 (1,648)
Immatures—male 3.4 (1,710), female 2.9 (1,456)
Age at first breeding: 2–4 years
Clutch size: 3.3–3.5, range 1–7
Incubation period: 24 days
Age at fledging: 45–50 days
Nest sites: Grass–sedge tundra communities on islands or peninsulas in large, shallow ponds along low coastal floodplains to 5 miles inland
Food habits: Predominantly herbivorous, except for small amounts of fish eggs, crustaceans, and mollusks

*October weights at Izembek Lagoon, Alaska

The black brant is a sea goose that depends on coastal habitats from high arctic nesting sites in Canada, Alaska, and Russia to wintering areas in the Pacific coastal states, the Baja California peninsula, and mainland Mexico estuaries. Population estimates are based on aerial surveys in Mexico, California, Oregon, and Washington during mid-winter. Despite much annual variability in estimates, a plot of the counts from 1964 to 1992 reveals a significant downward trend in the winter populations (Fig. 1). Three of four major colonies on the Yukon–Kuskokwim (Y–K) delta declined an average of 60% during the first half of the 1980's. This is significant because about 79% of the world population of the black brant nest in these colonies (Table). Because few other breeding colonies have been consistently monitored, we have little understanding of their dynamics.

Spring subsistence harvest in western Alaska coupled with fox predation on reduced Y–K delta populations, has limited the recovery of key nesting colonies. Degradation and loss of important staging and winter estuarine habitats from commercial and recreational development and disturbance are largely responsible for population reductions in British Columbia and the Pacific coastal states. In Mexico, industrial and recreational development in several estuaries may further limit winter habitats. Wildlife conservation agencies in Canada, Mexico, Russia, and the United States recently cooperated to examine population dynamics and factors that limit recovery of the black brant. This examination revealed important discoveries for management. This leaflet is a summary of these findings. More complete information on the life history of the black brant is in Bellrose (1980) and Palmer (1976).

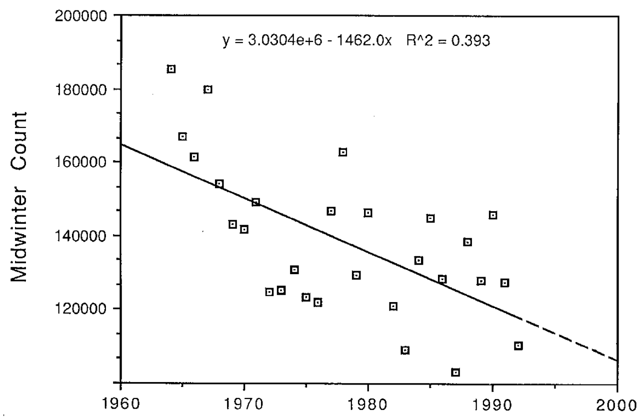


Fig. 1. Status of the black brant based on midwinter aerial surveys with the calculated regression line indicated.

Distribution

The black brant nests from Prince Patrick and Melville islands in the western Canadian high arctic and the Beaufort Sea islands to the coastal plain of Canada and Alaska. Small colonies occur on the north side of the Chukotka Peninsula in Russia and on Wrangel Island. The largest concentration of nesting brants is on the delta of the Yukon and Kuskokwim rivers in western Alaska (Table; Fig. 2).

In the arctic, molting areas support as many as 32,000 birds near Teshekpuk Lake on Alaska's coastal plain and 4,000 birds on Wrangel Island (Fig. 2). Brants also molt in large but uncounted flocks on the Y–K delta.

A major shift in the winter distribution of the black brant occurred during the 1950's and 1960's. The species traditionally wintered on the Pacific coast from Puget Sound south to Baja California. In 1958, black brants were discovered using lagoons on the Mexican mainland bordering the Gulf of California. Concomitantly, the number of wintering birds in California declined drastically from a 10-year (1949–1958) mean of 42,000 to a mean of 6,800 between 1959 and 1968. In two years since 1968, no brants have wintered in California. Since 1965, in excess of 80% of the black brants counted during winter surveys in Mexico, California, Oregon, and Washington were observed in Mexico. From 1981 to 1988, an average of 4,400 brants wintered in the Izembek Lagoon area of the Alaska Peninsula. Whether these wintering brants are from specific breeding colonies or their physiological condition prevents them from migrating from Izembek Lagoon to more southerly habitats is not clear.

Table. *Number of nests and percent of total nests in colonies throughout the population of the black brant.*

Location and colony	Number of nests	Percent of total
Alaska		
Yukon–Kuskokwim Delta		
Kigigak Island	1,050	
Baird Inlet	10,122	
Tutakoke River	6,591	
Kokechik Bay	5,874	
Small colonies	4,163	
Subtotal	27,800	78.9
Seward Peninsula–Chukchi Sea		
Arctic Lagoon	50	
Nugnugaluktuk River	100	
Kasegaluk Lagoon	50	
Subtotal	200	0.6
North Slope Coastal Plain		
Meade River Delta	50	
Teshekpuk Lake	200	
Colville River	400	
Prudhoe Bay	500	
Subtotal	1,150	3.3
Russia		
Wrangel Island	100	
Ayon Island	50	
Anadyr Basin	170	
Subtotal	320	0.9
Canada		
Low Arctic		
Liverpool Bay	300	
Banks Island	2,250	
Victoria Island	1,200	
Subtotal	3,750	10.6
High Arctic		
Prince Patrick Island	500	
Melville Island	1,500	
Subtotal	2,000	5.7
Total	35,220	

Spring Migration and Breeding

Spring migration occurs during a 4-month period (Fig. 3) starting in mid-February when the birds begin northward movement from winter areas to staging habitats in California, Oregon, Washington, and British Columbia. Eelgrass and

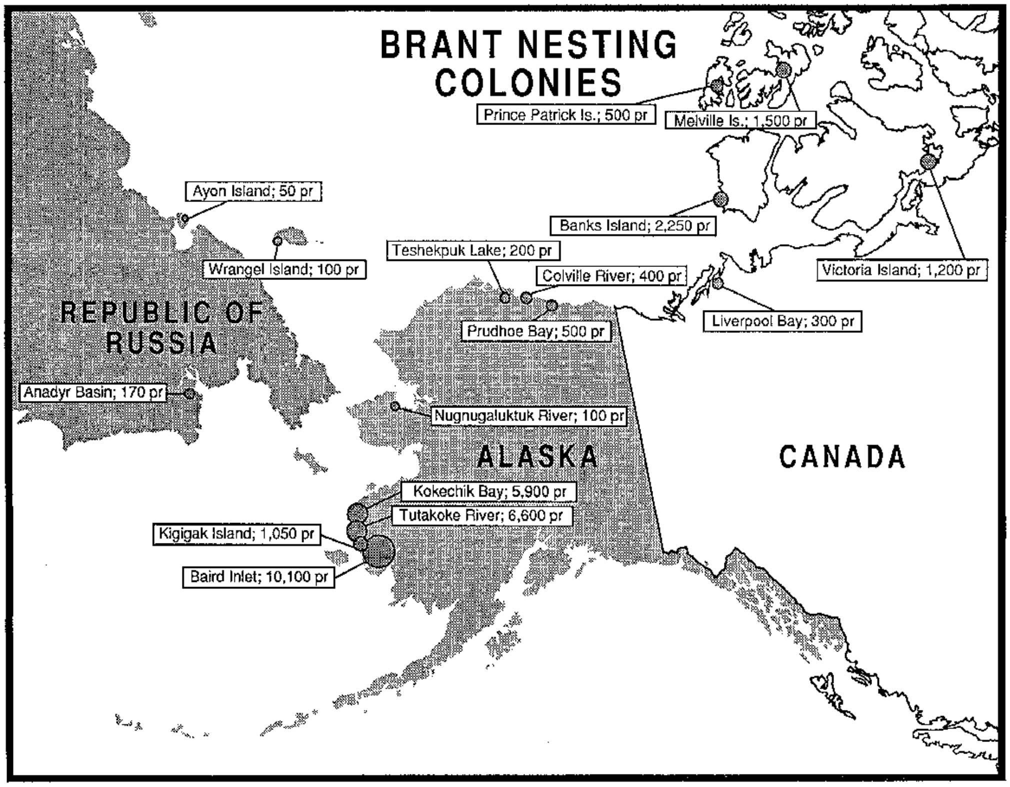


Fig. 2. Distribution of major black brant colonies and number of nesting pairs.

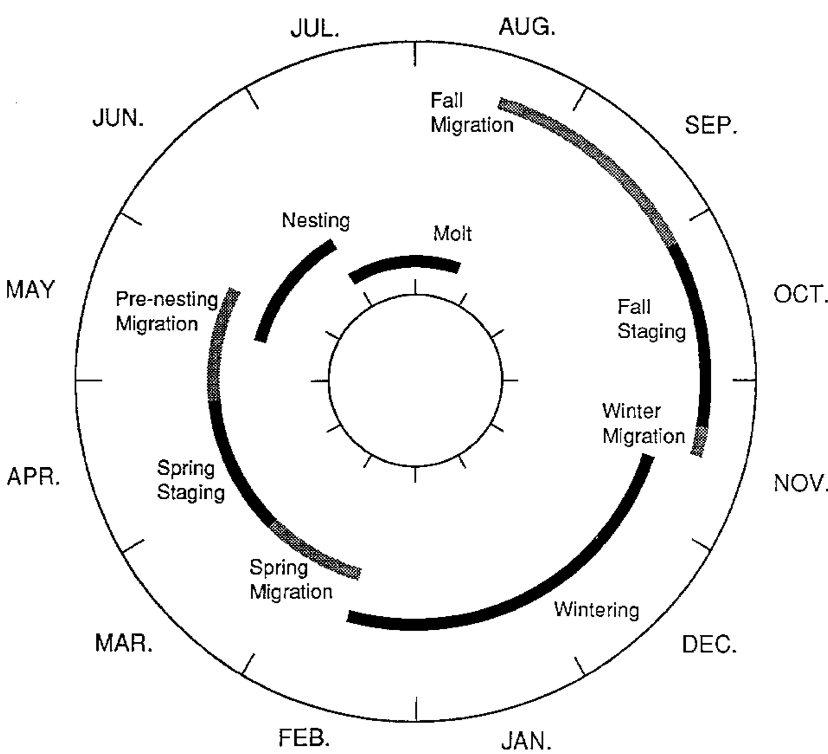


Fig. 3. The chronology of important life history events in the annual cycle of the black brant (irrespective of sex).

sea lettuce and other marine algae are important in the diet of migrants at these staging habitats; they also feed on roe of Pacific herring, on crustaceans, and on mollusks. By late April, brants reach Izembek Lagoon, Alaska, where they may spend from 2 to 4 weeks feeding on eelgrass before emigration to nesting areas.

The birds establish bonds during the winter and arrive at breeding areas as pairs. They attain maximum numbers on the Y–K delta in late May and in arctic and western Canada by mid-June. Preferred nest sites are on peninsulas or islets in large wetland complexes, some of which are subject to tidal action. Most brants first breed when they are 3 years of age; fewer than 50% nest at age 2.

Brants lay from one to seven eggs and an average clutch of 3.5 eggs at Y–K delta colonies and 3.8 eggs at Colville River delta colonies in northern Alaska. The mean incubation period is 24 days. The arctic fox is the most important predator of eggs and goslings on the Y–K delta colonies. Control measures to eliminate foxes enhanced nesting success and significantly increased nesting brants at the Tutakoke River colony on the Y–K delta. Glaucous gulls and parasitic jaegers also take eggs and goslings.

Adults with broods move from colony sites to rearing habitats along tidal flats. Broods sometimes congregate in large creches. Creeping alkali grass and Hoppner sedge are the most important plants in the diet of adults and developing young. Adults with broods begin to molt their flight feathers in the second week of July, and most can fly by the second week of August. Young fledge in 45–50 days, and most birds are capable of flight by mid-August (Fig. 3). Brants remain in family groups throughout the brood-rearing period.

Postbreeding Dispersal and Fall Migration

Brants that lose their clutches or do not nest undertake a molt migration, usually in late June, to secluded areas in the high arctic. They congregate in large numbers on molting areas for a month or more (Fig. 3) until new flight feathers are grown. Important molting areas have been discovered on Alaska's north slope and Wrangel Island (Fig. 2). These areas, dominated by large freshwater lakes and ocean estuaries, provide essential habitat for tens of thousands of brants from many different nesting colonies during the annual wing molt. At the Teshekpuk Lake molting area, there are more males (57.2%) than females and more After Second Year (76.6%) than Second Year birds. Failed breeding birds are 61.7% and non-breeding birds are 38.3% of the molting population.

Molt is a nutritionally demanding process in many species of birds, including the black brant. During the molt at Teshekpuk Lake, adult females lose more carcass mass, lipid, and protein than adult males and subadults. Males lose an average 122 g and females 141 g of lipid during the molt process. For brants to complete the molt and regain the necessary lipid reserves for migration, managers must insure minimal disturbance in molting areas. Feeding is the predominant behavior (52% of all activities) of molting brants throughout the 24-h cycle. Protein-rich tufted hairgrass and sedges are the most important plants in the diet of molting brants at Teshekpuk Lake.

Adults with fledged young follow traditional routes from breeding areas to fall migration staging sites along the Siberian, Beaufort, Chukchi, and Bering seas (Fig. 2). The single most critical fall staging habitat is near the tip of the Alaska Peninsula at Izembek Lagoon. Nearly the entire world population of the black brant spends as long as 9 weeks there feeding on the extensive beds of eelgrass. Eelgrass is as much as 99% of their diet during this period. In the Izembek Lagoon complex, brants from high arctic colonies (e.g., Prince Patrick and Melville islands) are spatially segregated from birds that nest in western colonies (Mackenzie and Y–K deltas). This behavior allows assessment of productivity and age ratios of two distinct breeding stocks. Managers can establish appropriate harvest regulations and management for each stock.

Disturbance of staging brants is of concern because it could reduce foraging time and increase energetic costs and thus lower fat deposition, which may compromise successful migration to distant winter habitats. At Izembek Lagoon, aircraft flights were the most frequent (0.57 events/h) type of anthropogenic disturbance. Bald eagles caused 0.25 disturbances/h. All disturbances occurred at 1.07/h. A predictive model shows that if brants were exposed to 45–50 daily disturbances by aircraft, they would not gain any weight at Izembek Lagoon.

In late October or early November, brants depart Izembek Lagoon during low pressure systems that generate the favorable southerly winds for transoceanic migration. When meteorological conditions are appropriate, nearly all brants leave Izembek Lagoon within about 12 h, usually at night.

Winter Ecology

Black brants arrive in winter habitats in Baja California within 60–95 h of departure from Izembek Lagoon. They metabolize nearly one-third of their body mass during the 2,600 nautical mile flight across the Pacific Ocean to San Quintin Bay, Baja California, Mexico.

Most brants from the Y–K delta, low arctic Canada, and Russia winter in estuaries on the Baja California peninsula and mainland Mexico. Birds that nest in high arctic colonies in Canada winter in the Puget Sound area.

Black brants forage most (58–87%) of the day on marine plants to replace fat reserves expended during migration. Eelgrass is the primary food in San Quintin Bay. Farther south on the Baja California peninsula at San Ignacio Lagoon, Scammons Lagoon, and Magdalena Bay, brants feed on eelgrass and widgeongrass.

At San Quintin Bay, disturbances by hunters, aircraft, vessels, and avian predators occurred at an average rate of 1.21/h. Boat traffic caused 65% and hunters caused 23% of all disturbances. The level of disturbance is greater in this bay than in molting, staging (see above), and other winter habitats. Disturbance during winter is of special concern because it could harm the physiological condition of prenesting brants and thus lower reproductive success.

Management

Effective management must focus on conservation of the terrestrial and marine habitats on which black brants depend during nesting, staging, and wintering. Some of these areas are protected as state and federal refuges, but many critical habitats remain outside conservation units. Even some habitats that are inside refuge boundaries are not free from activities that may affect brants. Management of refuges and other key habitats should include monitoring and, if necessary, regulation of disturbances, especially from vessel and aircraft traffic, that may displace birds from traditional foraging areas.

The quality and quantity of important marine food plants such as eelgrass, widgeongrass, and sea lettuce must be maintained. Threats to these resources include increasing pollution, dredging, and other industrial and recreational development in estuaries in British Columbia, the Pacific coastal states, Baja California, and mainland Mexico.

Habitats in Alaska, Russia, and northern Canada are presently relatively secure, but petroleum and related development should be monitored and strategies developed for the protection of colonies, molting areas, and staging sites that are not managed for waterfowl. Methods to protect habitats include acquisitions, land exchanges, easements, and cooperative management agreements.

Suggested Reading

Anthony, R. M., P. L. Flint, and J. S. Sedinger. 1991. Arctic fox removal improves nest success of black brant. Wildlife Society Bulletin 19:176–184.

Bellrose, F. C., editor. 1980. Ducks, geese, and swans of North America. 3rd ed. Stackpole Books, Harrisburg, Penn. 540 pp.

Dau, C. P. 1992. The fall migration of Pacific Flyway brant *Branta bernicla* in relation to climatic conditions. Wildfowl 43: In press.

Derksen, D. V., W. D. Eldridge, and M. W. Weller. 1982. Habitat ecology of Pacific black brant and other geese moulting near Teshekpuk Lake, Alaska. Wildfowl 33:39–57.

Kramer, G. W., L. R. Rauen, and S. W. Harris. 1979. Populations, hunting mortality and habitat use of black brant at San Quintin Bay, Baja California, Mexico. Pages 242–254 *in* R. L. Jarvis and J. C. Bartonek, editors. Management and biology of Pacific Flyway geese: a symposium. Oregon State University Book Stores, Inc., Corvallis.

Mickelson, P. G. 1975. Breeding biology of cackling geese and associated species on the Yukon–Kuskokwim Delta, Alaska. Wildlife Monographs 45. 35 pp.

Palmer, R. S., editor. 1976. Handbook of North American birds. Vol. 2. Waterfowl. Yale University Press, New Haven, Conn. 521 pp.

Reed, A., R. A. Stehn, and D. H. Ward. 1989. Autumn use of Izembek Lagoon, Alaska, by brant from different breeding areas. Journal of Wildlife Management 53:720–725.

Smith, R. H. and G. H. Jensen. 1970. Black brant on the mainland coast of Mexico. Transactions of the North American Wildlife and Natural Resources Conference 35:227–241.

Spencer, D. L., U. C. Nelson, and W. A. Elkins. 1951. America's greatest goose-brant nesting area. Transactions of the North American Wildlife Conference 16:290–295.

Ward, D. H., and R. A. Stehn. 1989. Response of brant and other geese to aircraft disturbance at Izembek Lagoon, Alaska. U.S. Fish and Wildlife Service Report, Anchorage, Alaska. 193 pp.

Appendix. Common and Scientific Names of the Plants and Animals Named in the Text.

Plants	
Hoppner sedge	*Carex subspathacea*
Sedges	*Carex* spp.
Tufted hairgrass	*Deschampsia caespitosa*
Creeping alkali grass	*Puccinellia phraganodes*
Widgeongrass	*Ruppia maritima*
Sea lettuce	*Ulva lactuca*
Eelgrass	*Zostera marina*
Birds	
Black brant	*Branta bernicla nigricans*
Bald eagle	*Haliaeetus leucocephalus*
Glaucous gull	*Larus hyperboreus*
Parasitic jaeger	*Stercorarius parasiticus*
Mammals	
Arctic fox	*Alopex lagopus*
Fish	
Pacific herring	*Clupea harengus*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

13.2.1. Waterfowl Use of Wetland Complexes

Leigh H. Fredrickson and Frederic A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri–Columbia
Puxico, MO 63960

Waterfowl are a diverse group of birds that have widely divergent requirements for survival and recruitment. Whistling-ducks, geese, and swans (Anserinae) and ducks (Anatinae) have contrasting life history requirements.

Several goose populations have expanded greatly despite extensive continental wetland losses and degradation. Most expanding populations nest in arctic areas where modifications or disturbance of nesting habitats have been minimal. These grazers often find suitable migratory and wintering habitats in terrestrial or agricultural environments. In contrast, ducks are less terrestrial and populations are influenced more by wetland characteristics, such as quality, total area of wetland basins, and size and configuration of these basins. Because many dabbling ducks nest in upland habitats surrounding wetlands, recruitment of waterfowl is closely tied to both terrestrial and wetland communities. Their primary upland and wetland nesting habitats, as well as migratory and wintering habitats, have been severely degraded or lost to agriculture.

Management for waterfowl in North America is complicated further because each of over 40 species has unique requirements that are associated with different wetland types. Likewise, the requirements for a single species are best supplied from a variety of wetland types.

In recent years, the relations between migrating and wintering habitats have been identified for mallards and arctic-nesting geese. These cross-seasonal effects emphasize the importance of habitats at different latitudes and locations. Thus, effective management requires an appreciation of the general patterns of resource requirements in the annual cycle. Recognition of the adaptations of waterfowl to changing wetland systems provides opportunities for managers to meet the diverse needs of waterfowl.

The Annual Cycle

Waterfowl experience events during a year that necessitate energy and other nutritional requirements above the maintenance level (Fig. 1). These additional requirements, associated with processes such as migration, molt, and reproduction, are obtained from a variety of habitats. Other factors that influence wetland use include sex, dominance, pairing status, flocking, and stage in the life cycle. All these processes influence the resources needed as well as access to habitats where required resources are available.

The large body sizes and high mobility of waterfowl allow them to transfer the required nutrients or energy among widely separated wetlands. The general pattern of reproduction in waterfowl is unusually costly for females at the time of egg laying because eggs (and often clutches) are large. The large egg size of waterfowl requires rapid transfer of protein and lipid stores from the female to the developing egg. In the wood duck, daily costs of egg

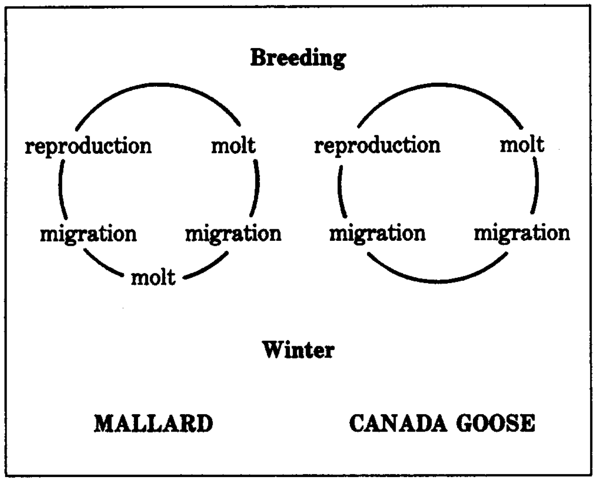


Figure 1. Major annual events in the life cycle of a mallard and a Canada goose.

production are high and can exceed 210% of the basal metabolic rate (BMR) during peak demand. The daily protein requirements for egg laying are smaller than lipid requirements, but the females must meet these requirements by consuming invertebrates where they may be limiting. Parental investment after the time of hatch is small, however, compared to bird species that must brood and feed their offspring.

Flight is energetically expensive and is usually estimated at 12–15 × BMR (Table 1). For example, a mallard weighing 2.5 lb would require 3 days of foraging to replenish fat reserves following an 8-hour flight if caloric intake were 480 kcal/day (Fig. 2). However, if food availability were only equivalent to 390 kcal/day, then the mallard would need 5 days to replenish these reserves. If mallards must fly to reach food, the time required to replenish lost reserves is even longer (Fig.2). These time differences indicate the importance of well-managed areas and the need to protect waterfowl from disturbances.

The requirements for molt are poorly known or little studied, but recent information suggests the total cost of winter molt in female mallards is nearly equivalent to the energetic cost of egg laying and incubation. Not only is the loss of feathers involved, but there are thermoregulatory and foraging constraints during molt that are difficult to monitor in the field.

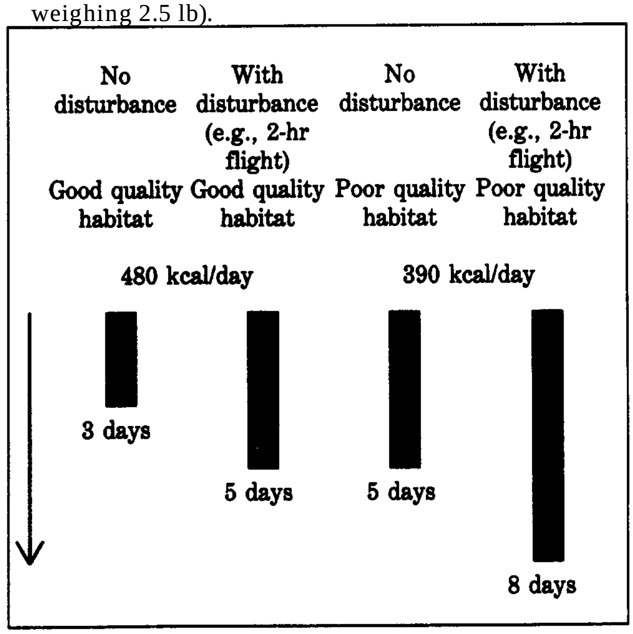
Waterfowl Reproductive Strategies

Each waterfowl species has a unique reproductive strategy. These strategies range from those of arctic-nesting geese, which transport large fat reserves to breeding habitats, to those of common eiders, which acquire all necessary reserves for reproduction on the breeding grounds (Fig. 3). The locations from which arctic-nesting geese acquire the different components for breeding have not been completely identified, but evidence indicates that most, if not all, of the lipid and protein resources are transported from migratory and wintering habi-

Table 1. *Estimated energetic costs of some common waterfowl activities in relation to basal metabolic rate (BMR). Values represent averages from the literature.*

Activity	Estimated cost × BMR
Resting	1.3
Alert	1.5
Comfort movements	1.5
Oiling/preening	2.0
Courtship	2.0
Social interactions	3.2
Swimming	3.2
Diving	5.0
Flying	12.0–15.0
Egg laying	
Early follicular growth	16.7
Maximum during egg-laying	20+
Last egg	10.2

Figure 2. Time required to replenish endogenous fat reserves following and 8-hr migratory move (for a duck weighing 2.5 lb).



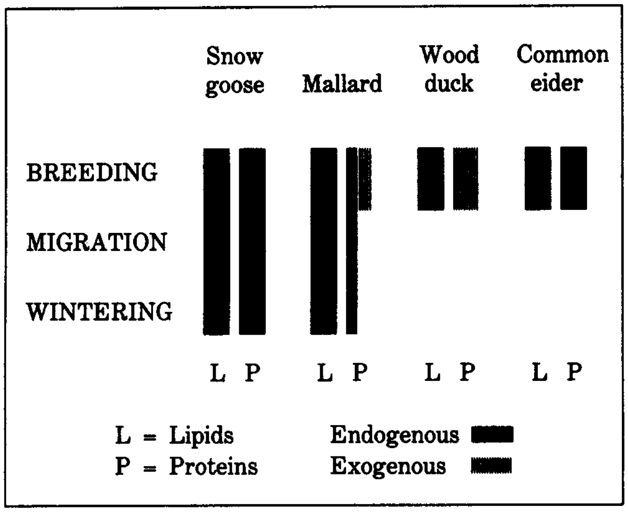


Figure 3. Reproductive strategies of four waterfowl species in relation to time in the annual cycle when the lipids and proteins for breeding are required.

Table 2. *Water depths and vegetative characteristics at foraging sites of some North American waterfowl.*

Species	Water depth	Vegetative structure
Small Canada geese	dry, mudflat	Short herbaceous
Large Canada geese	dry, mudflat <10 inches	Short herbaceous, rank seed-producing annuals
Northern pintail	<10 inches	Open water with short, sparse vegetation
Mallard	<10 inches	Small openings, tolerate robust vegetation
Ring-necked duck	>10 inches	Scattered, robust emergents
Lesser scaup	>10 inches	Open water, scattered submergents

tats as body reserves. Environmental conditions in different seasons and on widely separated habitats may have an important influence on the success of sequential activities in the annual cycle of these arctic-nesting geese.

Mallard breeding strategies are differ from strategies of snow geese. Most of the lipid reserves and as much as half of the protein required for reproduction in mallards are transported to the breeding grounds as body reserves. Wood ducks differ from mallards and geese because they acquire lipid and protein reserves for reproduction primarily from breeding habitats. Lipid reserves are acquired from breeding habitats before laying begins, but protein requirements are obtained solely from daily foraging. Common eiders are like wood ducks in that they acquire reserves for egg laying on the breeding grounds. But, unlike wood ducks, they acquire protein and lipid reserves for breeding and store them as reserves before laying begins.

An understanding of the range of strategies and the timing of these needs enables wetland managers at different latitudes to produce the desired resources in a timely manner.

Relation Among Habitat Variables and Waterfowl Use

Waterfowl managers have long recognized the relation among habitat structure, water depth, and water use by waterfowl. The stage in the annual cycle and the associated behavioral adaptations of waterfowl determine which resources managers must provide.

Appropriate water depths should be available for effective waterfowl management. Shallow water is essential for dabblers because the optimum foraging depth is 2–10 in. (Table 2). Although diving ducks can exploit deeper water, there is little justification to provide deep waters when they can reach food resources in shallow water. Such strategies decrease costs associated with pumping or supplying water for waterfowl.

Waterfowl have various tolerances for the height and density of vegetation. Sea ducks and divers are adapted to large bodies of open water. Mallards, wood ducks, and blue-winged teal readily use habitats with dense vegetation; northern pintails prefer shallow, open habitats where visibility is good and vegetation sparse.

Little information is available on how waterfowl make decisions relating to where they feed and which foods they select. Nevertheless, geese are known for their ability to select forage of high nutritional content. Complex habitat and nutritional requirements, in conjunction with recent losses and degradations of wetland habitats, require managers to consider a wide array of factors when attempting to optimize use by waterfowl (Table 3).

When conflicting factors are apparent, advanced planning is essential to optimize and maintain desired use of habitats. Such conflicts are apparent to managers facing difficult decisions because the site may provide habitats for breeding, migratory, and wintering waterfowl. Determining a

Table 3. *Important considerations to ensure optimum use of wetland complexes by waterfowl.*

1) **Life cycle event**
   - Molt
   - Reproduction
   - Migration
2) **Behavioral activities**
   - Roosting
   - Social behavior
   - Foraging
3) **Habitat structure**
4) **Water depth/regimes**
5) **Food quality/type**
6) **Wetland complex**
7) **Disease**
8) **Habitat degradations**
   - Habitat losses
   - Habitat perturbations
     - Toxicants
     - Turbidity
     - Modified hydrology
     - Modified structure
9) **Disturbance**
   - Hunting
   - Other recreation
     - Fishing
     - Water skiing
     - Bird watching
   - Aircraft—military and commercial
   - Research/management
   - Industrial/commercial

reasonable balance of the resources required to meet seasonal requirements of all populations of waterfowl using a specific refuge undoubtedly is more challenging than determining the species of plants needed to provide food and cover.

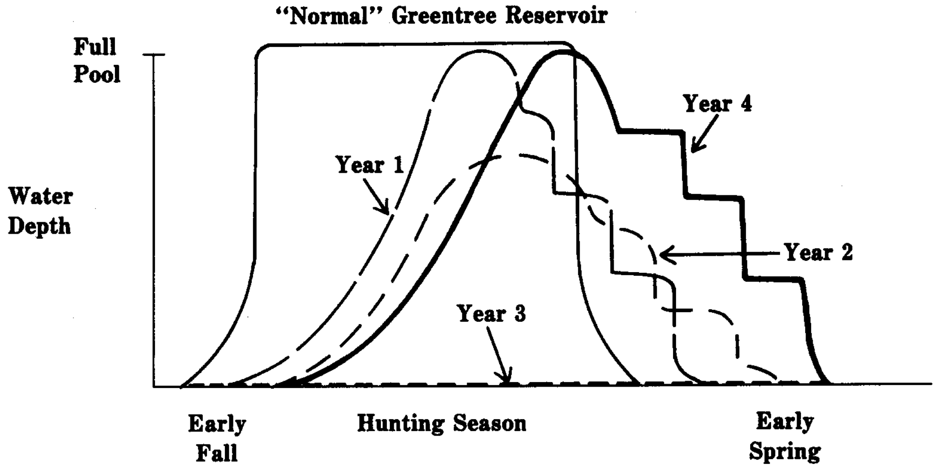
Resource Availability and Exploitation by Waterfowl

By understanding how waterfowl use resources managers are able to attract and hold waterfowl on managed habitats. Monocultures should be avoided, whether natural plant communities (such as large expanses of dense cattail) or agricultural crops. Manipulation of soil and water to produce habitat structure or foods essential as life requisites may be a necessary part of refuge management. Production of these requisites does not assure that waterfowl will use the resources.

Foods are only accessible if (1) appropriate water depths are maintained during critical time periods, (2) habitats are protected from disturbance, and (3) habitats that provide protein and energy are close to one another. Disturbance is particularly damaging, because it affects access to and acquisition of requirements throughout the annual cycle (Table 2, Fig. 2). The subtle effects of bird watchers, researchers, and refuge activities during critical biological events may be as detrimental to waterfowl populations as hunting or other water-related recreational activities (boating, etc.). At certain locations, predators or activities associated with barge traffic, oil exploration, or other industrial or military operations are detrimental.

Identification of the proportions of each wetland type within refuge boundaries, and the potential for management within each wetland type, is essential. Wetlands on private or other public property within 10 miles of the refuge boundary should also be used to estimate resources within the foraging range of most waterfowl. As wetlands are lost on areas surrounding refuges, managers will be able to identify special values or needs for certain habitat types on refuges. For example, producing only row crops on refuge lands in extensive areas of agriculture may be less valuable than supplying natural vegetation and associated invertebrates to complement these high-energy agricultural foods. Furthermore, the presence of toxicants or disease may preclude use of some wetlands.

An important part of management is identification of wetlands that are productive and unmodified. These wetlands should be protected in their natural state rather than changed by development. Where man-made or modified wetlands are managed, manipulations that emulate natural wetland complexes and water regimes provide diverse habitats for a variety of waterbirds. Well-timed, gradual changes in water level are effective approaches that provide good conditions for producing foods and desirable foraging depths for game and nongame birds. In fall, many southern habitats are dry, but having pools full before waterfowl arrive and maintaining pools at capacity until after their departure may reduce access to many resources by waterfowl. By providing changing water depths in greentree reservoirs or elsewhere, managers can enhance cost-effectiveness by assuring that resources produced are also used effectively. For example, a management scenario for modifying the time and pattern of fall flooding in a greentree reservoir or a moist-soil impoundment might include four or more approaches to flooding (Figs. 4 and 5).



Rationale

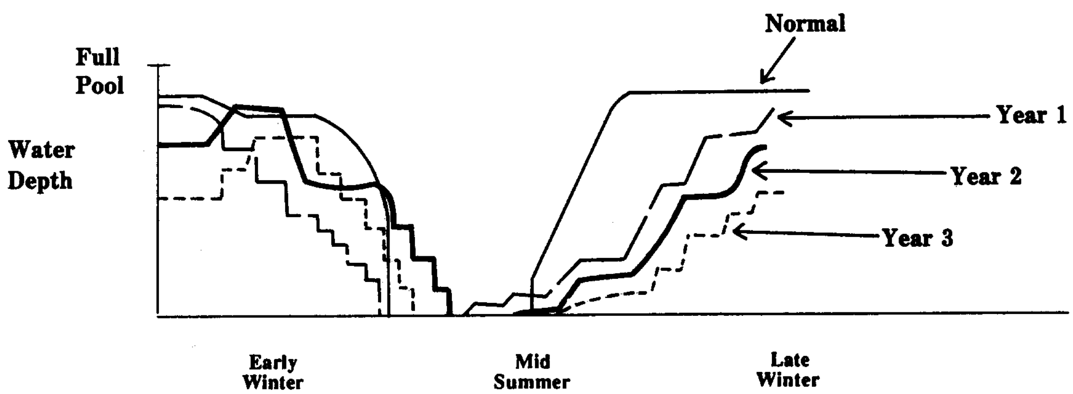
Year 1 - Gradual flooding to provide access to food resources on a continuing basis throughout the hunting season. Gradual drawdowns commence before the end of the waterfowl season.

Year 2 - Gradual flooding but water levels never reach full pool. Gradual drawdown extending into spring.

Year 3 - No flooding.

Year 4 - Similar to Year 1, but full pool not reached until end of hunting season. Gradual drawdown extending well into spring.

Figure 4. Suggested flooding regimes for southern greentree reservoirs.



Rationale

Normal - Typical midsummer drawdown to establish moist-soil vegetation. Fall and winter flooding for waterfowl.

Year 1 - Gradual drawdown to optimize use by late spring migrants. Gradual reflooding for rails and waders.

Year 2 - Gradual drawdown lasting into midsummer to optimize use by late spring, migrant waterfowl, shorebirds, and waders. Gradual reflooding in fall to optimize use of seed resources.

Year 3 - Increasing water depths in spring to make food resources available. Gradual drawdown by late spring, followed by gradual reflooding in fall to shallow depths.

Figure 5. Suggested flooding regimes for seasonally flooded wetlands of the Midwest.

By recognizing the importance of natural wetland complexes throughout the annual cycles of waterfowl, managers can provide waterfowl with required resources.

Suggested Reading

Ankney, C.D., and C.D. MacInnes. 1978. Nutrient reserves and reproductive performance of female lesser snow geese. Auk 95:459–471.

Drobney, R.D. 1980. Reproductive bioenergetics of wood ducks. Auk 97:480–490.

Drobney, R.D., and L.H. Fredrickson. 1985. Protein acquisition: a possible proximate factor limiting clutch size in wood ducks. Wildfowl 36:122–128.

Fredrickson, L.H. and R.D. Drobney. 1979. Habitat utilization by postbreeding waterfowl. Pages 119–129 *in* T.A. Bookhout, ed. Waterfowl and wetlands: an integrated review. Proc. 1977 Symp., North Cent. Sect., The Wildl. Soc., Madison, Wis. 147 pp.

Fredrickson, L.H. and M.E. Heitmeyer. 1988. Waterfowl use of forested wetlands in the southeastern United States—an overview. Pages 307–323 *in* M.W. Weller, ed. Waterfowl in winter—a symposium and workshop. University of Minnesota Press, Minneapolis.

Fredrickson, L.H., and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildl. Serv., Resour. Publ. 148. 29 pp.

Heitmeyer, M.E., and L.H. Fredrickson. 1981. Do wetland conditions in the Mississippi Delta hardwoods influence mallard recruitment? Trans. N. Am. Wildl. and Nat. Resour. Conf. 46:44–57.

Krapu, G.L. 1979. Nutrition of female dabbling ducks during reproduction. Pages 59–70 *in* T.A. Bookhout, ed. Waterfowl and wetlands: an integrated review. Proc. 1977 Symp., North Cent. Sect., The Wildl. Soc., Madison, Wis. 147 pp.

Owen, R.B., Jr., and K.J. Reinecke. 1979. Bioenergetics of breeding dabbling ducks. Pages 71–99 *in* T.A. Bookhout, ed., Waterfowl and wetlands: an integrated review. Proc. 1977 Symp., North Cent. Sect., The Wildl. Soc., Madison, Wis. 147 pp.

Weller, M.W. 1975. Migratory waterfowl: a hemispheric perspective. Publicaciones Biologicas Instituto de Investigaciones Cientificas U.A.N.L. 1:89–130.

White, D.H., and D. James. 1978. Differential use of freshwater environments by wintering waterfowl of coastal Texas. Wilson Bull. 90:99–111.

Appendix. Common and Scientific Names of Animals Named in Text.

Wood duck	*Aix sponsa*
Northern pintail	*Anas acuta*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Lesser scaup	*Aythya affinis*
Ring-necked duck	*Aythya collaris*
Canada goose	*Branta canadensis*
Snow goose	*Chen caerulescens*
Common eider	*Somateria mollissima*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.2.2. The North American Waterfowl Management Plan: A New Approach to Wetland Conservation

Angela V. Graziano
U.S. Fish and Wildlife Service
North American Waterfowl and Wetlands Office
Room 340, Arlington Square
Washington, D.C. 20240

Diana H. Cross
U.S. Fish and Wildlife Service
Office of Information Transfer
1201 Oak Ridge Drive, Suite 200
Fort Collins, Colorado 80525

The decline of waterfowl populations and the loss of wetlands are high-ranking environmental concerns in North America. The importance of these issues is reflected in an ambitious wetland recovery plan, the North American Waterfowl Management Plan. Signed in 1986 by the U.S. and Canadian federal governments, the plan features specific strategies to reverse the declines in waterfowl numbers and wetland acreage. The goal is to restore waterfowl populations to a level common to the 1970's by improving and securing long-term protection of 6 million acres (2.4 million ha) of habitat in 34 areas of major concern.

The key to achieving this goal is partnerships: federal, state, provincial, territorial, and tribal governments joining forces with private conservation organizations and individuals. Early on, it was clear to authors of the plan that securing habitat for waterfowl would also yield benefits for a wealth of other wildlife and plants. Partners in the plan looked beyond the protection of individual wetlands and single-species management to integrated management of ecosystems on public and private land.

More recently, national programs such as the North American Wetlands Conservation Act, major agricultural legislation, and agreements with Mexico stimulated new ways of approaching the challenge. Recognizing that objectives have increased since 1986 and that benefits to species other than waterfowl could be more explicitly addressed, the North American Waterfowl Management Plan Committee in 1992 initiated a process to update the plan. The update will reflect a thorough evaluation of the implemented plan. In this paper, we describe the current status of the plan, including accomplishments, benefited species, and plans for future projects.

North American Wetlands Conservation Act

The North American Wetlands Conservation Act, passed in 1989, provides matching grants to public-private partnerships for protecting and managing wetland habitats in North America. A key component of the legislation is "... to sustain an abundance of waterfowl and other migratory birds consistent with the goals of the North American Waterfowl Management Plan ...." Proposed projects by partners in Canada, Mexico, and the United States are ranked for their potential benefits to wetland functions and for their ability to further the national and international goals of the plan. All projects must have at least a one-to-one match of non-federal U.S. dollars. Ducks Unlimited, Inc., the National Fish and Wildlife Foundation, and The Nature Conservancy have been primary sources of these matching dollars. A nine-member council appointed by the Secretary of the Interior recommends projects for approval of funding to the Migratory Bird Conservation Commission. The North American Waterfowl and Wetlands Office of the U.S. Fish and Wildlife Service then administers the projects.

Wetland creation, restoration, and acquisition are in all stages of implementation in the United States and Canada. Money appropriated under this act is also supporting conservation education in Mexico, designed to teach people in local communities the importance of wetlands to migratory birds and to other wetland-dependent wildlife and fishes.

Habitat Joint Ventures

The joint venture concept is based on the development of partnerships to meld resources for maximizing financial, organizational, and other in-kind support toward a common objective in a geographic region. A separate management board establishes priorities and direction for each joint venture, while participating federal, provincial, state, and private partners work through state steering committees to carry out projects at the local level. Although each joint venture has different strategies for accomplishing its stated objectives, all depend on multiple partnerships to protect, restore, and enhance targeted habitats.

Atlantic Coast Joint Venture

Scope: Extends from Maine to South Carolina; habitats range from freshwater inland and coastal marshes to estuaries and adjacent upland ecosystems.

Purpose: To provide habitat protection for fishes, shellfishes, mammals, waterfowl, shorebirds, songbirds, and raptors; initially focused on the American black duck. Coastal habitats were destroyed or degraded by commercial and agricultural industrialization.

Progress: Partners in New Jersey are building a bioreserve to connect protected public and private lands into an unfragmented tract for the survival of a unique diversity of animals and plants, including the largest known concentration of the sensitive joint vetch. The bioreserve will also provide protection for migrating neotropical birds and nesting bald eagles.

Major Partners: Natural Lands Trust; New Jersey Division of Fish, Game, and Wildlife; New Jersey Green Acres Program; New Jersey Waterfowl Stamp Committee; The Nature Conservancy; and U.S. Fish and Wildlife Service.

Central Valley Joint Venture

Scope: The Central Valley of California where about 60% of the waterfowl in the Pacific Flyway spend the winter. The area is also the sole wintering ground for the endangered Aleutian Canada goose.

Purpose: To protect upland and wetland habitat for 55% of the species listed as threatened or endangered in California. Nearly 95% of the original wetlands in this part of California have been lost, primarily to agricultural drainage. This joint venture will provide additional winter habitat for northern pintails and other waterfowl to help disperse the birds and reduce potential threats from disease.

Progress: Secured 14,000 acres (5,666 ha) at Llano Seco Rancho, one of the largest unprotected parcels of riparian forest and wetland remaining in California’s Central Valley.

Major Partners: California Department of Fish and Game; Dow Chemical Company; Ducks Unlimited, Inc.; National Fish and Wildlife Foundation; Parrott Investment Company; The Nature Conservancy; and U.S. Fish and Wildlife Service.

Eastern Habitat Joint Venture

Scope: Encompasses portions of Ontario, Quebec, New Brunswick, Nova Scotia, Newfoundland, and Prince Edward Island. Its focus is on coastal marshes, interior wetlands, and farmland wetlands.

Purpose: To protect 617,000 acres (249,700 ha) of habitat for breeding, staging, and migrating American black ducks, mallards, ring-necked ducks, wood ducks, green-winged teals, and sea ducks as well as Canada geese, snow geese, and shorebirds.

Progress: Improving the quality of wetlands through vegetation management and installation of water-control structures. Partners are seeking agreements with landowners to leave green belts and trees with cavities and to manage beaver impoundments. Special private land programs will affect the management of another 3.9 million acres (1.6 million ha).

Major Partners: Agriculture Canada; Canadian Wildlife Service; Ducks Unlimited, Canada; Ducks Unlimited, Inc.; the provinces of Ontario, Quebec, New Brunswick, Nova Scotia, Newfoundland, and Prince Edward Island; U.S. Fish and Wildlife Service; and Wildlife Habitat Canada.

Gulf Coast Joint Venture

Scope: The coastal area bordering the Gulf of Mexico from Texas to Alabama, one of the most important sites for wintering waterfowl in North America.

Purpose: To protect coastal marshes and wetlands and associated uplands that are habitat for wintering waterfowl, endangered whooping cranes, peregrine falcons, and five species of sea turtles; to protect additional habitat for wintering mallards and northern pintails and to increase the carrying capacity for birds on already acquired lands and water. Implementation of this joint venture will also benefit numerous species of fishes, shellfishes, migrating shorebirds, and other wildlife.

Progress: Enhancing and restoring 23,000 acres (9,308 ha) of permanent and seasonal wetlands under 10-year agreements with private landowners on more than 600 sites in Texas, Louisiana, and Mississippi. Much of the habitat gains will be on actually farmed lands. The remaining acreage will be restored palustrine emergent and forested wetlands.

Partners: More than 100 landowners; state agencies; and U.S. Fish and Wildlife Service.

Lower Great Lakes/St. Lawrence Basin Joint Venture

Scope: Wetlands along the Lower Great Lakes and the St. Lawrence Basin in Vermont, New York, Pennsylvania, Ohio, and Michigan.

Purpose: To protect habitat of breeding and migrating birds by restoring privately owned wetlands and enhancing federal- and state-owned areas.

Progress: The Ohio Division of Wildlife is leading the restoration of 5,200 acres (2,104 ha) of freshwater coastal marshes and estuaries along the Lake Erie shores. The division also plans to create 1,300 acres (526 ha) of wetlands and enhance 2,600 acres (1,052 ha) of state-owned waterfowl habitat.

Major Partners: Ducks Unlimited, Inc.; Ohio Division of Wildlife; Pennsylvania Game Commission and other state agencies; The Nature Conservancy; and U.S. Fish and Wildlife Service.

Lower Mississippi Valley Joint Venture

Scope: Encompasses sections of 10 states: Oklahoma, Texas, Missouri, Arkansas, Louisiana, Illinois, Indiana, Kentucky, Tennessee, and Mississippi. Most mid-continent waterfowl, especially mallards, winter in this area, which is also habitat for songbirds, shorebirds, wading birds, furbearers, reptiles, and invertebrates.

Purpose: To protect 300,000 acres (12,141 ha) of habitat in the Lower Mississippi River Valley and enhance 1.6 million acres (0.6 million ha) of additional habitat for wintering mallards and northern pintails, to increase the carrying capacity for wintering birds on land and water already acquired for waterfowl, and to provide higher quality habitat for other wetland wildlife.

Progress: Partners are compensating farmers for adopting conservation-farming practices and are sharing costs of water-control structures that benefit wildlife while improving soil and water conservation.

Major Partners: Ducks Unlimited, Inc.; state conservation agencies; private landowners; National Fish and Wildlife Foundation; The Nature Conservancy; and U.S. Fish and Wildlife Service.

Pacific Coast Joint Venture

Scope: Stretches from northern California to the Skeena River in British Columbia. This is the first joint venture with habitat in both the United States and Canada; the targeted area consists largely of islands, estuaries, freshwater wetlands, and agricultural lands on the floodplains of the creeks and rivers.

Purpose: Habitat protection sought by the United States for three birds of concern to both countries—the lesser snow goose, the black brant, and the trumpeter swan. Emphasis in Canada will also be placed on these birds as well as on the large wintering and migrating populations of mallards and northern pintails. Shorebird habitats will be protected in the process.

Progress: Since inception of this joint venture in 1991, 20,000 acres (8,094 ha) of habitat affected at a cost of more than $42 million.

Major Partners: Ducks Unlimited, Inc.; The Nature Conservancy; states.

Playa Lakes Joint Venture

Scope: More than 25,000 shallow basins known as playas scattered over the southern high plains in Colorado, Kansas, Oklahoma, Texas, and New Mexico. Playa lakes provide important habitat for migrating and wintering waterfowl and other migratory birds in the Central Flyway.

Purpose: To ensure adequate habitat (land and water) for breeding, migrating, and wintering waterfowl and other migratory birds through land acquisition and management.

Progress: Oklahoma Department of Wildlife Conservation received deed on a playa in Texas County in December 1991; will manage area for waterfowl and other migratory birds. In Kansas, easements to flood playas are in effect with five landowners. The Playa Lakes Joint Venture received recognition by President Bush in the first annual President's Environmental and Conservation Awards in October 1991.

Major Partners: Landowners joined in partnership with the National Fish and Wildlife Foundation, Phillips Petroleum, all five state wildlife agencies, The Nature Conservancy, and U.S. Fish and Wildlife Service. Because more than 99% of the playa lakes are privately owned, partnerships are critical to management of these unique wetlands.

Prairie Habitat Joint Venture

Scope: Prairie and parkland regions of Manitoba, Saskatchewan, and Alberta, which provide the continent's most important breeding areas for the mallard, the northern pintail, the blue-winged teal, other prairie ducks, and shorebirds and wading birds.

Purpose: To protect and enhance about 3.6 million acres (1.5 million ha) of habitat for breeding waterfowl and to preserve wetlands and improve the surrounding upland acres by planting nesting cover.

Progress: Prairie CARE (Conservation of Agriculture, Resources, and the Environment) programs used in the three provinces. Prairie CARE pays farmers to set aside parcels of land as natural habitat or to change management practices. The program also provides financial and technical assistance to farm and conservation associations for field demonstrations, allowing farmers to experiment with new farming methods, such as stubble mulching, fall seeding, direct seeding, and rotational grazing, without financial risk.

Major Partners: Canadian Wildlife Service; Ducks Unlimited Canada; provinces of Alberta, Manitoba, and Saskatchewan; and U.S. Fish and Wildlife Service.

Prairie Pothole Joint Venture

Scope: The prairie pothole region, including some 300,000 square miles from south-central Canada to the north-central United States. Although widely known for its excellent habitat for breeding ducks, the region also supports about 225 other species of birds, including endangered species, and small mammals, fishes, and reptiles.

Purpose: To protect and improve breeding habitat in the mid-continent at a ratio of 3 acres of upland nesting cover/acre of water. During the last 50 years, much of this vital habitat has been lost to increased agricultural production and drainage.

Progress: Partners are developing incentives for landowners who restore wetlands, alter grazing systems, delay hay-cutting to spare nests, cooperate on predator control, and practice no-till or minimum-till cultivation. The joint venture is accomplishing its goals through existing agricultural programs and education.

Major Partners: Ducks Unlimited, Inc.; National Audubon Society; National Wildlife Federation; five state fish and game departments; The Nature Conservancy; U.S. Fish and Wildlife Service; and Wildlife Management Institute.

Rainwater Basin Joint Venture

Scope: The Rainwater Basin of south-central Nebraska, which includes parts of 17 counties in the state that are critical habitat during spring and fall migration for millions of geese and ducks.

Purpose: To protect 9,000 acres (3,642 ha) of existing wetlands, restore or create an additional 15,000 acres (6,070 ha), and provide reliable water sources for at least one-third of protected wetlands. These areas have been severely degraded by agricultural operations over the years.

Progress: Recently formed joint venture in process of identifying restoration projects and forging partnerships. So far, the U.S. Fish and Wildlife Service has improved 560 acres (227 ha) of managed wetlands and indirectly benefited the entire 1,163 acres (471 ha) of wetlands on its Funk Lagoon Waterfowl Production Area in Phelps County, Nebraska.

Upper Mississippi River/Great Lakes Region Joint Venture

Scope: Boundaries stretch over Minnesota, Iowa, Missouri, Wisconsin, Illinois, Indiana, and Michigan; include important migration and staging areas that were converted to agriculture.

Purpose: To increase populations of waterfowl and other wetland wildlife by protecting, restoring, creating, and enhancing wetlands and associated upland habitats.

Progress: Partners are striving to increase public awareness through information and education and are providing incentives to private landowners.

Partners: Private landowners; National Fish and Wildlife Foundation; state agencies; and U.S. Fish and Wildlife Service.

Species Joint Ventures

In contrast with habitat joint ventures, which direct efforts to projects on the ground, species joint ventures were established to address critical information gaps for several species. This information is used to identify necessary research and monitoring, to assign priorities from a continental perspective, to promote and encourage funding and participation in priority research, and to facilitate timely dissemination of information.

Arctic Goose Joint Venture

Several species of geese nest primarily in arctic North America where research and monitoring are difficult and costly. As a result, knowledge of the distribution, productivity, and other life-history factors of geese that nest in the arctic is limited. The goal of this international joint venture is to facilitate research and monitoring of these geese throughout their range and to improve communication among all partners. Attention is focused on subspecies of the brant, the greater white-fronted goose, the Canada goose, and the snow goose.

Black Duck Joint Venture

The American black duck, once the most abundant freshwater duck in eastern North America, reached a population low in the 1980's after a 30-year decline. Habitat loss, competition with mallards, hunting mortality, and a myriad of other problems contributed to this decline.

The charge of the Black Duck Joint Venture is to coordinate and promote data gathering—surveys, banding, and research—among flyway councils, universities, and federal, provincial, and state conservation agencies to improve population and habitat management. The gathered information will assist the existing habitat-based joint ventures that are central to the historic habitat of the American black duck.

What is in Store for the North American Plan

In January 1992, the North American Waterfowl Management Plan Committee endorsed a comprehensive evaluation to ensure that the habitat management programs are achieving the goals and objectives of the plan. The evaluation will include tracking of accomplishments, monitoring of habitat and population responses, assessing whether ventures are sufficiently extensive and appropriate, and providing information to guide further implementation. Research scientists have a major role in the evaluation.

To meet the challenges of wetland loss requires a shared vision and commitment among a multitude of partners for protecting, restoring, and enhancing critical habitat that supports wetland wildlife. These collective commitments will ensure that the natural areas needed by a diversity of wildlife will be preserved.

Appendix. Common and Scientific Names of the Birds and Plant Named in the Text.

Birds	
Wood duck	*Aix sponsa*
Northern pintail	*Anas acuta*
Green-winged teal	*Anas crecca*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
American black duck	*Anas rubripes*
Greater white-fronted goose	*Anser albifrons*
Ring-necked duck	*Aythya collaris*
Brant	*Branta bernicla*
Black brant	*B. b. nigricans*
Canada goose	*Branta canadensis*
Aleutian Canada goose	*B. c. leucopareia*
Snow goose	*Chen caerulescens*
Lesser snow goose	*C. c. caerulescens*
Trumpeter swan	*Cygnus buccinator*
Peregrine falcon	*Falco peregrinus*
Whooping crane	*Grus canadensis*
Bald eagle	*Haliaeetus leucocephalus*
Plant	
Sensitive joint vetch	*Aeschynomene virginia*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

13.2.4. Avian Botulism: Geographic Expansion of a Historic Disease

Louis N. Locke and Milton Friend
U.S. Fish and Wildlife Service
National Wildlife Health Research Center
6006 Schroeder Road
Madison, WI 53711

Synonyms

Limberneck, western duck sickness, duck disease, alkali poisoning

Cause

Avian botulism is a paralytic, often fatal disease of birds resulting from ingestion of toxin produced by the bacterium *Clostridium botulinum*. Waterfowl die-offs from the botulism are usually caused by type C toxin; sporadic die-offs among fish-eating birds, such as common loons (*Gavia immer*) and gulls, have been caused by type E toxin.

Not enough is known about avian botulism to precisely identify the factors leading to an outbreak. When an outbreak does occur, it is usually perpetuated by a well-understood bird-maggot cycle (Figure 1).

Clostridium botulinum persists in wetlands in a spore form that is resistant to heat and drying and in some instances remains viable for years. Toxin production occurs during multiplication of the vegetative form of the bacteria following spore germination. The vegetative form requires dead organic matter and a complete absence of oxygen to grow and produce toxin. Optimum growth of the bacteria occurs at about 25° C (77° F). Toxin production is optimized within a pH range of 5.7 to 6.2 and depends on the protein content of the medium in which the bacteria are growing. All kinds of animal protein are suitable for toxin production. Especially potent toxin is produced in bird, mammal, and a variety of invertebrate carcasses. This entire process is further complicated by a poorly understood but important role of bacteriophages—viruses that infect bacteria. Recent findings show that bacteriophages determine if toxin will be produced during *C. botulinum* growth and multiplication stages.

Important environmental factors that contribute to initiation of avian botulism outbreaks include water depth, water level fluctuations, and water quality; the presence of vertebrate and invertebrate carcasses; rotting vegetation; and high ambient temperatures.

Shallow water permits rapid warming of the submerged marsh soil during periods of high ambient temperatures. Toxin is produced when these soils contain both the spores of *C. botulinum* and suitable organic nutrients for spore germination and reproduction of bacterial cells. Fluctuating water levels that produce “feather edge” shorelines contribute to avian botulism outbreaks when terrestrial and aquatic invertebrates die as land areas are flooded and the underwater areas subsequently become dry when the water recedes. Fertilization of a marsh with sewage or run-off from agricultural activities can stimulate plant or invertebrate animal population growth for short periods, but results in plant and vertebrate die-offs once this stimulus subsides. The resulting mass of nutrients is then

Adapted from: Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., *Resour. Publ.* 167. 225 pp.

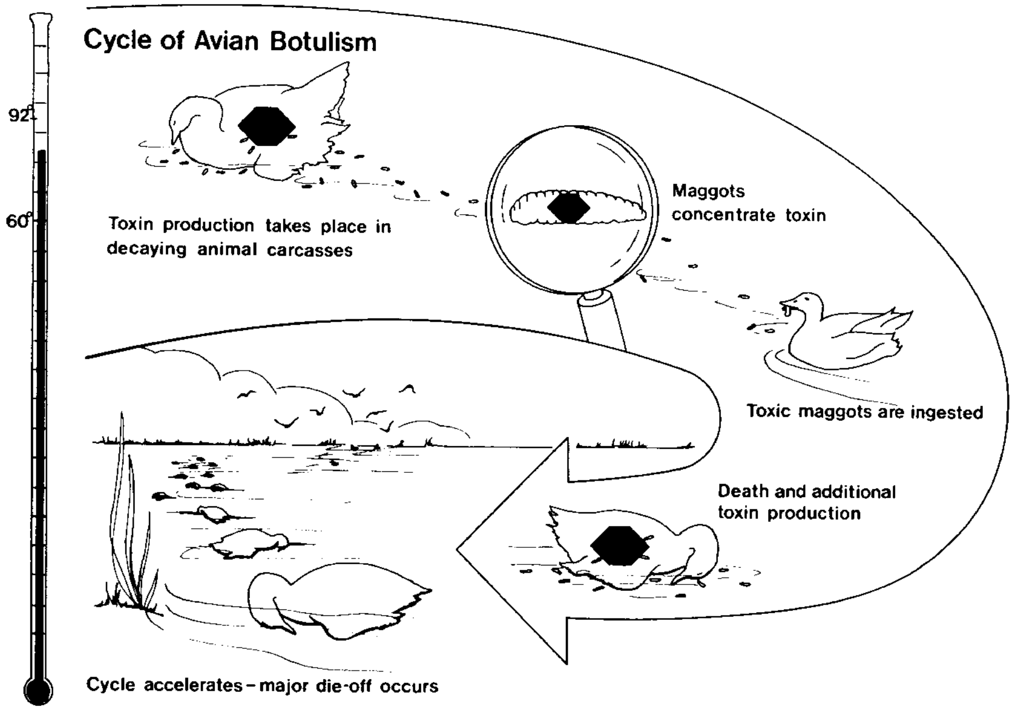


Figure 1. Avian botulism cycle.

available for growth of *C. botulinum* and toxin production. Dense vegetation can entrap and thus kill fish, amphibians, or invertebrates, and masses of rotting marsh plants can reduce oxygen levels to the point that aquatic animal life is killed. Both of these conditions provide large amounts of growth material for toxin production. The presence of vertebrate carcasses and high ambient temperatures are also conducive to the buildup of fly populations involved in the bird-maggot cycle for avian botulism transmission.

Species Affected

Many species of birds and some mammals are affected by type C botulism. In the wild, waterfowl and shorebirds are most often affected (Figure 2). Vultures are known to be highly resistant to type C toxin.

Losses vary a great deal from year to year at site-specific locations and from species to species. A few hundred birds may die in 1 year and tens of thousands or more the following year. More than a million deaths from avian botulism have been reported in relatively localized outbreaks in a single year, and outbreaks with losses of 50,000 birds or more have been relatively common (Table 1).

Figure 2. Frequency of botulism in major groups of wild birds.

Type of bird	Type C	Type E
Waterfowl	●●●●	●
Loons	○	●●●
Herons	●●	○
Shorebirds	●●●●	○
Gulls	●●●	●●●
Raptors	●	○
Upland game birds	●	○
Songbirds	●	○

●●●● Common; die-offs occur almost yearly
●●● Frequent
●● Occasional
● Infrequent
○ Not reported

Table 1. *Major waterfowl botulism outbreaks.*

Location	Year	Estimated loss
Utah and California	1910	millions
Lake Malheur, Oregon	1925	100,000
Great Salt Lake, Utah	1929	100,000–300,000
Tulare Basin, California	1941	250,000
Western United States	1952	4–5 million
Montana (near Billings)	1978	50,000
Montana (near Billings)	1979	100,000
Great Salt Lake, Utah	1980	110,000

Table 2. *Initial outbreaks by location of type C avian botulism in wild waterfowl.*

Location	Year	Location	Year
The Americas		Europe	
United States	1910	Sweden	1963
Canada	1913	Denmark	1967
Uruguay	1921	England	1969
Mexico	1976	Netherlands	1970
Argentina	1979	East Germany	1971
Brazil	1982	West Germany	1971
Australia-Asia		Italy	1973
Australia	1934	Spain	1973
New Zealand	1972	Norway	1975
Japan	1973	Scotland	1977
Africa		Czechoslovakia	1981
Union of South Africa	1956	Wales	1983

Distribution

Outbreaks of avian botulism have occurred in the United States and Canada since the beginning of the century, if not earlier. Outbreaks have also been reported to occur in many other countries. Most of these reports are recent, usually within the past 20 years (Table 2). Most type C outbreaks within the United States occur west of the Mississippi River; however, outbreaks have occurred from coast-to-coast and border-to-border (Figure 3). Type E outbreaks in birds are much less frequent and within the conterminous United States have been confined to the Great Lakes region.

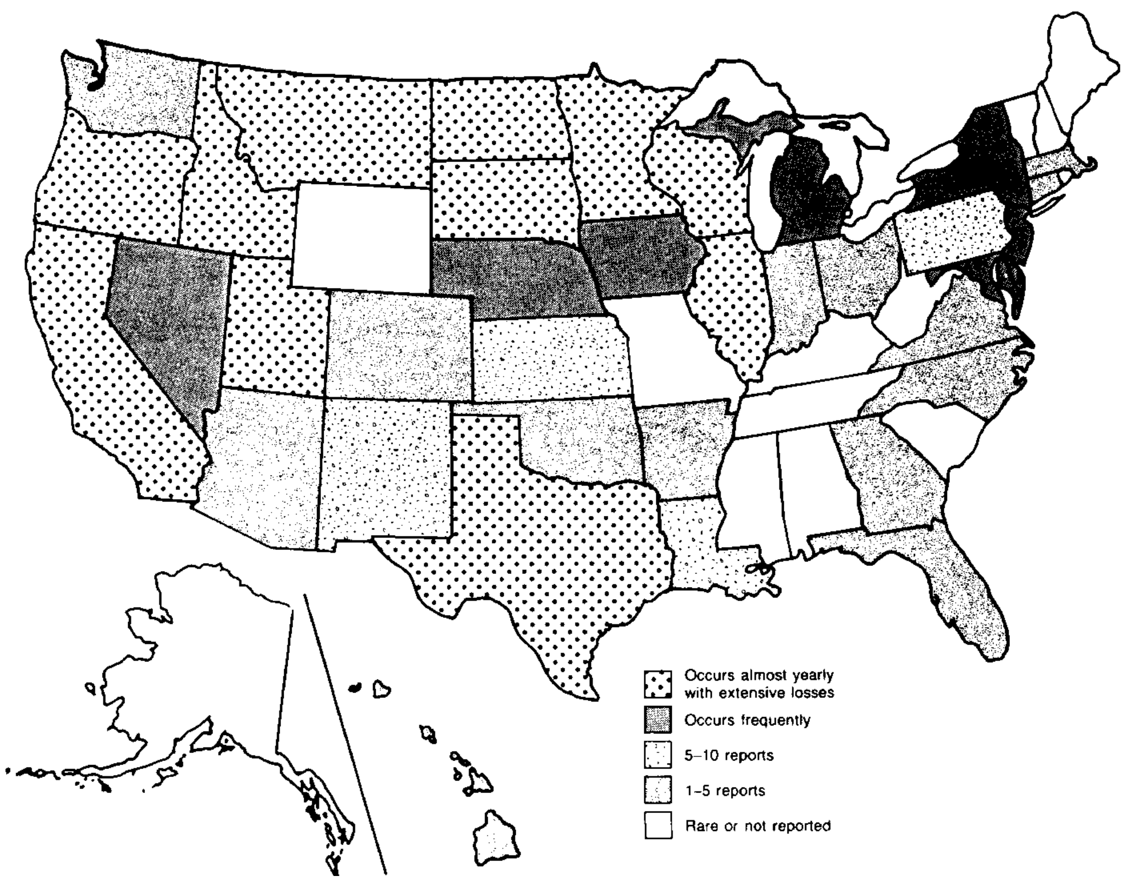


Figure 3. Frequency of type C botulism in waterfowl.

Seasonality

July through September are the primary months for type C avian botulism outbreaks in the United States and Canada. However, outbreaks occur as late as December and January and occasionally during early spring in southern portions of the United States and in California. Type E outbreaks have occurred during late fall and spring.

Field Signs

Lines of carcasses coinciding with receding water levels generally typify the appearance of major die-offs, although outbreaks have also occurred in impoundments containing several feet of water, lakes with stable water levels, and in large rivers. When receding water conditions are involved, botulism is typically a disease of the water's edge, and seldom are sick or dead birds found very far from the vegetation bordering the water or the original water's edge. In impoundments where water levels are relatively stable, affected birds are likely to be found in areas of flooded vegetation. Botulism-affected birds also tend to congregate along vegetated peninsulas and islands.

Healthy birds, sick birds, and recently dead birds will commonly be found together during a botulism outbreak, along with carcasses in various stages of postmortem decay. Often, a variety of species representing two or three or even more orders of birds suffer losses simultaneously.

Avian botulism affects the peripheral nerves and results in paralysis of voluntary muscles. Inability to sustain flight is seen early in botulism. Once the power of flight is lost and paralysis of leg muscles has occurred, ducks suffering from botulism often propel themselves across the water and mud flats with their wings. This sequence of signs contrasts with that of lead-poisoned birds, which retain their ability to walk and run even though flight becomes difficult.

Paralysis of the inner eyelid or nictitating membrane (Figure 4) and neck muscles follows, resulting in inability to hold the head erect (Figure 5). These are the two most easily recognizable signs of avian botulism. Once birds reach this stage, death from drowning often occurs before the bird might otherwise die from the respiratory failure caused by botulinum toxin.

Avian botulism often occurs in the seasons when waterfowl are flightless because of wing molt. Care then must be taken to separate birds in molt

Figure 4. Paralysis of the inner eyelid is a common sign in botulinum-intoxicated birds.

Figure 5. Paralysis of the neck muscles in bitulinum-intoxicated birds results in inability to hold the head erect (limberneck). Death by drowning often results.

from those with early stages of intoxication because the behavior of these birds may be similar. Molting birds are difficult to catch and birds that cannot be captured with a reasonable effort should not be pursued further. If these birds are suffering from botulism, they can be easily captured when they become unable to dive to escape pursuit. Birds at this level of intoxication still have a high probability for survival if proper treatment is administered.

Gross Lesions

There are no characteristic or diagnostic gross lesions in waterfowl dying of type C or type E botulism.

Diagnosis

The most reliable test for avian botulism is the mouse protection test. Blood is collected from a sick or freshly dead bird and the serum fraction is then inoculated into two groups of laboratory mice, one group of which has been given type-specific antitoxin. The mice receiving antitoxin will survive and those that receive no antitoxin will become sick or die with characteristic signs if botulinum toxin is present in the serum sample.

Control

Management of Environment

Control efforts need to focus on three important factors that contribute to the development and maintenance of avian botulism outbreaks: fluctuating water levels during hot summer months, an abundance of flies, and animal carcasses for toxin production. On areas managed primarily for migratory waterfowl (ducks, geese, swans), reflooding of land that has been dry for a long time is not recommended during summer. Similarly, sharp drawdowns of water should be avoided since they could result in fish-kills and die-offs of aquatic invertebrates whose carcasses could then become centers for the growth of *C. botulinum*. On those areas managed primarily for shorebirds, water drawdowns are essential, and botulism control must focus on a cleanup of any carcasses that may result.

Prompt removal and proper disposal of vertebrate carcasses by burial or burning are highly effective mechanisms for removing the major sources of toxin production and maggot development. The importance of prompt and thorough carcass removal and proper disposal cannot be overemphasized. Several thousand toxic maggots can be produced from a single waterfowl carcass. Consumption of as few as two to four of these toxic maggots can result in intoxication of a duck, thereby perpetuating the botulism cycle. It is not uncommon to find three or four freshly dead birds within a few feet of a maggot-laden carcass. Failure to carry out adequate carcass removal and disposal programs can result in a rapid buildup of highly toxic materials, and can accelerate losses as well as seed the environment with *C. botulinum* toxin and spores as the carcasses decompose. Toxin formed in these carcasses is quite stable. This preformed toxin can be taken in by invertebrates, remain free in bottom sediments, or become suspended in the water column where it can serve as the source of winter and spring botulism outbreaks when ingested by feeding birds.

Many botulism outbreaks occur on the same wetlands year after year, and within a wetland there may be localized “hot spots.” Also, outbreaks often follow a fairly consistent and predictable time sequence. These conditions have direct management implications that should be applied toward minimizing losses. Specific actions that should be taken include accurately documenting conditions and dates of outbreaks in problem areas, planning for and implementing intensified surveillance and carcass pickup and disposal, and modifying habitats to reduce the potential for botulism losses and deny bird use on major problem areas during the botulism “season.” Surveillance and carcass disposal activities should start 10 to 15 days before the earliest documented cases and continue 10 to 15 days after the end of the botulism “season.” Habitat modifications will primarily involve control of water quality and water levels.

Because fish carcasses can also serve as sites for *C. botulinum* growth, they should be promptly removed during fish control programs in marsh environments, or fish control programs should be restricted to the cooler months (non-fly season). Power lines that cross marsh environments have been associated with major botulism outbreaks. Bird carcasses from collisions with power lines have served as initial points for toxin production within the marsh environment. Therefore, if possible, power lines should not be placed across marsh environments used by large concentrations of water birds.

Numerous outbreaks of avian botulism have been associated with sewage and other wastewater discharge into marsh environments. This relation is not presently understood, but has occurred often enough that wetland managers should discourage the discharges of these effluents when substantial waterfowl or shorebird use occurs or is likely to occur on an area during the ensuing 30 days.

Treatment of Sick Birds

Studies at Bear River Refuge, Utah, have clearly demonstrated that a high percentage of botulinum-intoxicated waterfowl can be saved. If the birds are provided with fresh water and shade, or injected with antitoxin, recovery rates of 75–90% and higher can result. In contrast with waterfowl, very few American coots (*Fulica americana*), shorebirds, gulls, and grebes have survived treatment for botulism. Experience to date with these species indicates that rehabilitation efforts are not worthwhile.

When botulinum-intoxicated birds are treated, the birds should be maintained under conditions that provide unrestricted access to fresh water, maximum provision for shade, an opportunity for birds that recover to fly out of the enclosure when they choose to, and minimum disturbance (including presence of humans). It is also important to remove carcasses daily from enclosures to prevent the buildup of toxic maggots within the treatment area, and to monitor the cause of mortality since one cannot assume botulism is the cause. The weakened condition of botulinum-intoxicated birds can result in the eruption of infectious disease such as avian cholera. Should this occur, it is essential to immediately address the infectious disease problem.

Costs associated with capturing and treating sick birds are high. Therefore, the emphasis for dealing with avian botulism should be on prevention and control of this disease rather than on treatment of intoxicated birds. However, antitoxin should be available for use in case endangered species are affected. The National Wildlife Health Research Center has produced and maintains antitoxin for this purpose. Contact the center's Resource Health Team for assistance.

Human Health Considerations

Botulism in humans is usually the result of eating improperly home-canned foods and is most often caused by type A or type B botulinum toxin. There have been a few human cases of type E botulism in North America as the result of eating improperly smoked or cooked fish or marine products. Although humans are regarded as being fairly resistant to type C botulinum toxin, at least two cases of type C botulism have been reported, although the origins were unidentified. Thorough cooking destroys botulinum toxin in food.

Suggested Reading

Eklund, M. W., and V. R. Dowell, Jr., editors. 1987. Avian botulism: an international perspective. Charles C. Thomas, Springfield, Ill. xxi + 405 pp.

Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., Resour. Publ. 167. 225 pp.

Rosen, M. N. 1971. Botulism. Pages 100–117 *in* J. W. Davis, R. C. Anderson, L. Karstad, and D. 0. Trainer, eds. Infectious and parasitic diseases of wild birds. Iowa State University Press, Ames.

Wobeser, G. A. 1981. Diseases of wild waterfowl. Plenum Press, New York. xii + 300 pp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1989

13.2.5. Avian Cholera: A Major New Cause of Waterfowl Mortality

Milton Friend
U.S. Fish and Wildlife Service
National Wildlife Health Research Center
6006 Schroeder Road
Madison, WI 53711

Synonyms

Fowl cholera, avian pasteurellosis

Cause

Avian cholera is a highly infectious disease caused by the bacterium, *Pasteurella multocida.* Acute infections are common and can result in death 6 to 12 hours after exposure. Under these circumstances “explosive” die-offs involving more than 1,000 birds per day have occurred in wild waterfowl. More chronic infections with longer incubation times and less dramatic losses also occur. Transmission can occur by bird-to-bird contact, ingestion of contaminated food or water, and perhaps in aerosol form.

Species Affected

It is likely that most species of birds and mammals can become infected with *P. multocida.* Most (if not all) bird species are susceptible to clinical disease following exposure to virulent strains of *P. multocida* commonly found in waterfowl. Specific relations between bird and mammal strains of this bacterium are not well understood. Strains isolated from cattle have not been shown to readily cause clinical disease in birds.

Scavenger species such as crows and gulls are commonly diagnosed as having died from this disease, but deaths of raptors such as hawks and eagles from avian cholera are far less frequent (Figure 1). Species losses for most major outbreaks are closely related to species composition and abundance during the period of the die-off.

Distribution

Avian cholera was unreported in free-living migratory birds in the United States before 1944. Losses have now been reported coast-to-coast and border-to-border. The occurrence of this disease within the United States has increased dramatically since 1970, and avian cholera now ranks with avian botulism and lead poisoning as major causes of waterfowl mortality. The frequency and severity of avian cholera outbreaks vary greatly among areas (Figure 2). This disease has also been diagnosed in waterfowl in many countries, including Canada, but not Mexico. This is probably due to the lack of surveillance and reporting rather than to absence of this disease in Mexico.

In the United States there are four major focal points for avian cholera in waterfowl: the Central Valley of California; the Tulare Lake and Klamath Basins of northern California and southern Oregon; the Texas Panhandle; and Nebraska’s Rainwater Basin. The movement of avian cholera from these areas follows the well-defined pathways of waterfowl movement. Spread of this disease along the Missouri and Mississippi river drainages is also

Adapted from: Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., *Resour. Publ.* 167. 225 pp.

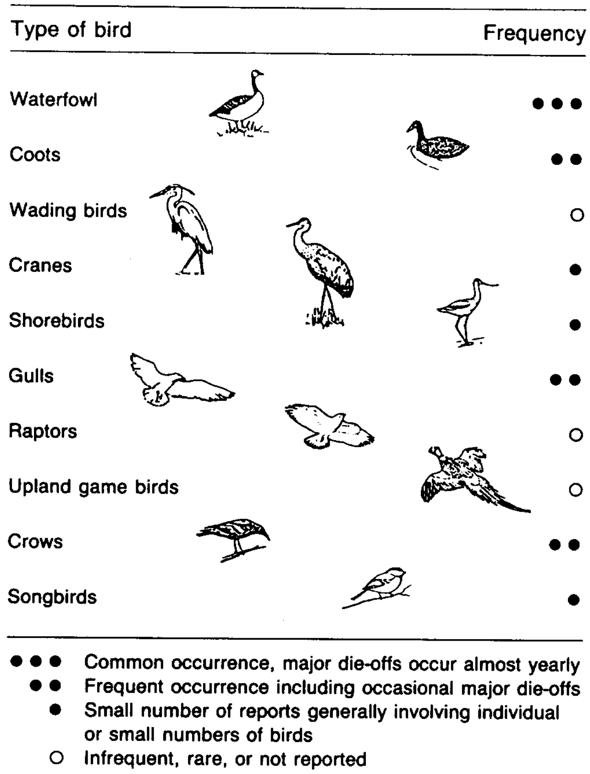


Figure 1. Relative occurrence of avian cholera in wild birds.

consistent with waterfowl movement. No consistent patterns of avian cholera outbreaks exist within the Atlantic Flyway except for periodic occurrences in eiders nesting off the coast of Maine (Figure 3).

Seasonality

Losses can occur at any time of the year. A major loss of snow geese occurred in spring on Canadian breeding grounds, in addition to losses of breeding eiders in Maine and Quebec. Outbreaks in California normally start during fall and continue into spring. Late winter is the peak time for avian cholera in the Texas Panhandle, and spring migration has resulted in annual losses from this disease in Nebraska's Rainwater Basin since 1975 and in western Saskatchewan, Canada, since 1977.

Field Signs

Few sick birds are seen during avian cholera outbreaks because of the acute nature of this disease. However, the number of sick birds increases when a die-off is prolonged over several weeks. Sick birds often appear lethargic or drowsy and can be approached quite closely before attempting escape. When captured, these birds often die quickly, sometimes within a few seconds or minutes after being handled. Other birds have convulsions, swim in circles, or throw their heads back between their wings and die. These signs are similar to those seen in duck plague and in some types of pesticide poisoning. Other signs include erratic flight, such as flying upside down before plunging into the water or onto the ground and attempting to land a foot or more above the surface of the water.

Always suspect avian cholera when large numbers of dead waterfowl are found in a short time, few sick birds are seen, and the dead birds appear to be in good flesh. When sick birds are captured and die within a few minutes, avian cholera should also be suspected. None of the signs described above are unique to this disease; their occurrence should be recorded as part of any history being submitted with specimens and must be considered along with lesions seen at necropsy.

Gross Lesions

Under most conditions, birds that have died of avian cholera have substantial amounts of subcutaneous and visceral fat (except for seasonal losses of fat). The most prominent lesions seen at necropsy involve the heart and liver and sometimes the gizzard. Hemorrhages of various sizes are frequently found on the surface of the heart muscle or the coronary band. Hemorrhages are also sometimes visible on the surface of the gizzard. Areas of tissue death that appear as small white to yellow spots are commonly seen within the liver. Where the area of tissue death is greater, the spots are larger and in some instances the area of tissue death is quite extensive.

The lower portions of the digestive tract (below the gizzard) commonly contain thickened yellowish fluid that is heavily laden with *P. multocida*.

Diagnosis

As with all diseases, isolation of the causative agent is required for a definitive diagnosis. Submitting a whole carcass provides the diagnostician with the opportunity to evaluate gross lesions seen at necropsy and also provides all appropriate tissues for isolation of *P. multocida*.

When it is not possible to send whole carcasses, tissues should be sent that can be collected in as

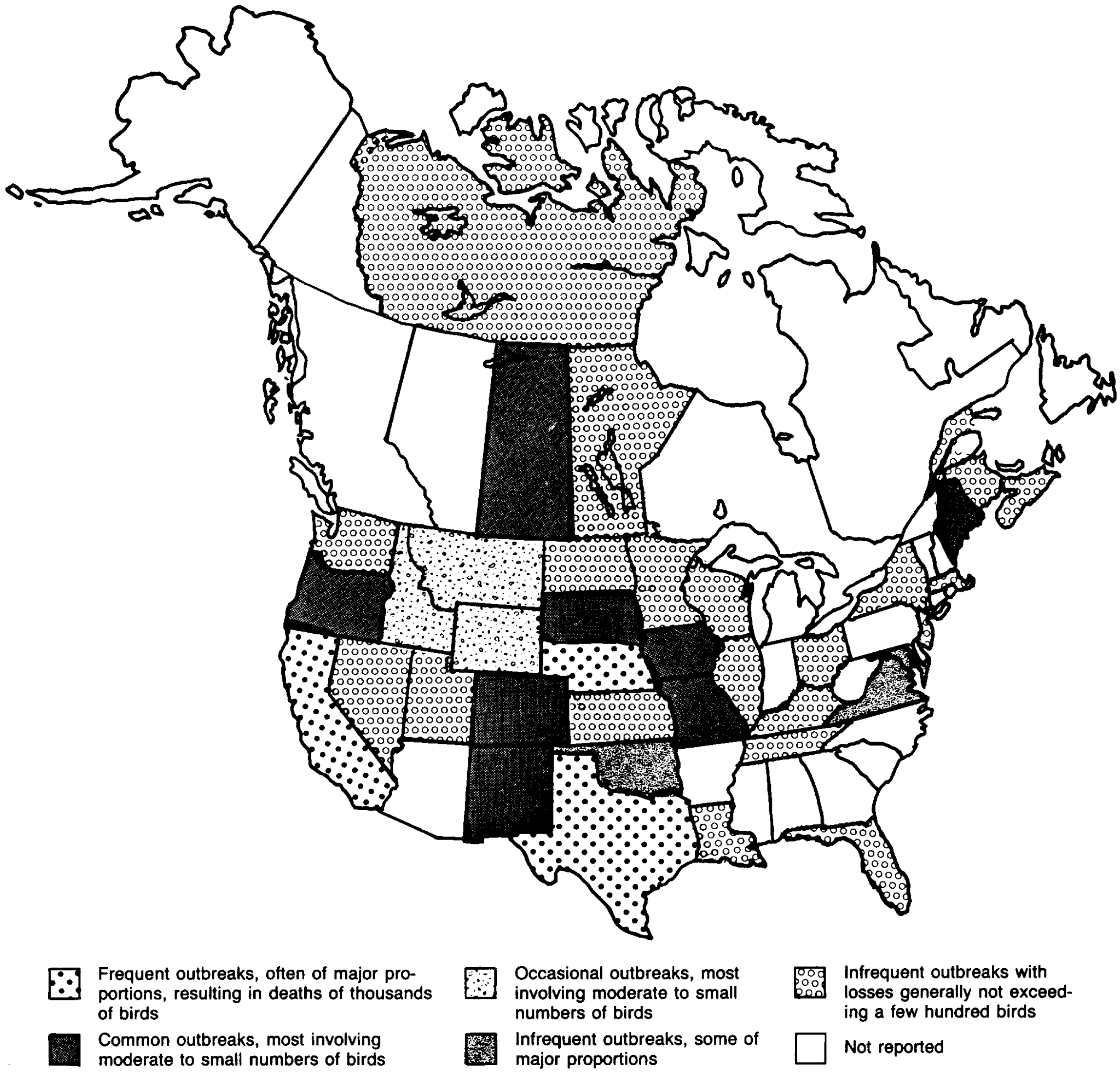


Figure 2. Reported distribution of avian cholera in wild birds.

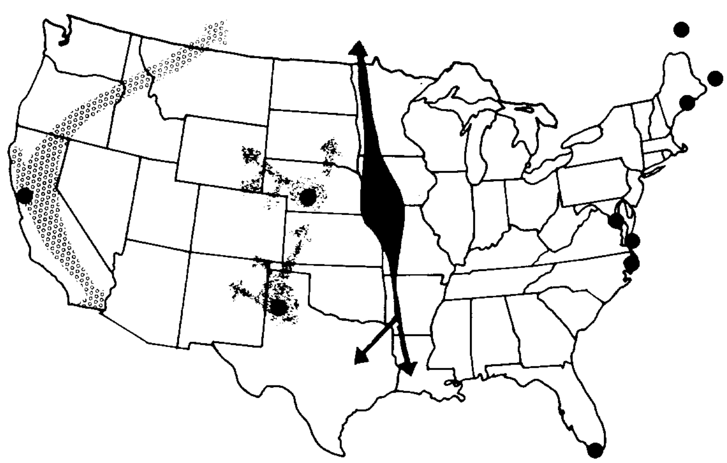


Figure 3. The occurrence of avian cholera in waterfowl seems to be closely related to bird movements west of the Mississippi River. There is no apparent pattern for outbreaks along the Atlantic seaboard.

sterile a manner as possible in the field. The most suitable tissues for culturing are heart blood, liver, and bone marrow. Remove the entire heart and place in a Whirl-Pak bag for shipment as identified in the "Field Guide to Wildlife Diseases"; do not attempt to remove the blood from the heart. The liver should also be removed and placed in a separate bag; if it cannot be removed intact, submit a major portion of this organ (at least half). Refrigerate these samples as soon as possible after collection and insure that they are kept cool during shipment. When shipment is to be delayed for more than a day or transit time is expected to exceed 24 hours, freeze these specimens.

Pasteurella multocida persists for several weeks to several months in bone marrow. The wings of badly scavenged or decomposed carcasses should be submitted whenever avian cholera is suspected as the cause of death and more suitable tissue samples are not available.

Control

Spread of avian cholera through waterfowl and other migratory bird populations is enhanced by the gregarious nature of most waterfowl species and by dense concentrations of birds that result from habitat limitations. Prolonged environmental persistence of this bacteria further promotes new outbreaks. Pond water remained infective for 3 weeks after dead birds were removed from one area in California; survival in soil for up to 4 months was reported in another study; persistence of this organism in decaying bird carcasses occurred for at least 3 months.

Early detection of avian cholera outbreaks should include frequent surveillance of areas where migratory birds are concentrated, as a first line of defense in controlling this disease. The opportunity to prevent substantial losses is greatest during the early stages of outbreaks. Control actions need to be focused on minimizing exposure of migratory and scavenger bird species to *P. multocida* and minimizing environmental contamination by this organism.

We recommend rigorous collection and incineration of carcasses as standard procedures. Carcass collection contributes to avian cholera control in several ways. Several milliliters of fluids containing large concentrations of *P. multocida* are often discharged from the mouths of birds dying from this disease, resulting in heavy contamination of the surrounding area. Carcass decomposition results in additional contamination. These carcasses serve to attract (decoy) other birds, thereby increasing the probability for infection. Scavenging of carcasses also results in disease transmission through the direct consumption of diseased tissue (oral exposure).

Care must be exercised during carcass collection to minimize the amount of fluid discharged into the environment from the mouths of birds. Pick birds up head first, preferably by the bill, and immediately place in plastic bags. Double-bagging is recommended to prevent fluids leaking from punctures that may occur in the inner bag. Bags of carcasses should always be securely closed before being removed from the area.

Prompt carcass removal also prevents scavenging by birds that can mechanically transport infected material to other sites or by feeding or drinking at other locations following consumption of infected tissue. This situation is aggravated by apparent longer disease incubation times in gulls, crows, and some other avian scavengers. Instead of dying within hours or 1 to 2 days after exposure to virulent strains of *P. multocida*, death more typically occurs after several days to 1 to 2 weeks. Death may occur at locations far from the site where the bird was exposed. When these birds die, they serve as new potential focal points for contamination.

Population reduction of infected American coots, crows, eiders, gulls, and terns has been used to combat avian cholera. Destruction of migratory birds infected with this disease can be justified only under special circumstances and conditions: (1) the outbreak must be discrete and localized rather than generalized and widespread; (2) techniques must be available that will allow complete eradication without causing widespread dispersal of potentially infected birds; (3) methods used must be specific for target species and pose no significant risk for nontarget species; (4) eradication must be justified on the basis of risk to other populations if the outbreak is allowed to continue; and (5) the outbreak represents a new geographic extension of avian cholera into an important migratory bird population.

Habitat management is another useful tool in combating avian cholera outbreaks. In some instances it may be necessary to prevent further use of a specific wetland or impoundment because it is a focal point for infection of waterfowl migrating into the area. Drainage, in conjunction with creating or enhancing other habitat within the area through water diversion (from other sources), or pumping operations serves to deny bird use of the problem area and redistributes waterfowl into more desirable habitat. Ability to add a large volume of water to a problem area can also help dilute concentrations of *P. multocida* to less dangerous levels. These actions require careful evaluation of bird movement patterns and the avian cholera disease cycle. Moving birds infected with avian cholera from one geographic location to another site is seldom desirable.

Under extreme conditions, disinfection procedures to kill *P. multocida* may be warranted in wetlands where large numbers of birds have died during a short time. The environmental effect of such measures needs to be evaluated and appropriate approvals obtained before these actions are undertaken.

Hazing with aircraft has been successfully used to move whooping cranes away from a major outbreak of avian cholera. Eagles can be attracted to other feeding sites using road-killed deer as a food source. During an avian cholera outbreak in South Dakota, a large refuge area was temporarily created to hold infected snow geese in an area by closing hunting. At the same time, a much larger population of snow geese about 10 miles away was moved out of the area to prevent transmission of the disease into that population. The area closed to hunting was reopened once the desired bird movement had occurred.

Vaccination and postexposure treatment of waterfowl have both been successfully used in combatting avian cholera in Canada goose propagation flocks. The National Wildlife Health Research Center has developed and tested a bacterin (a killed vaccine) that totally protected Canada geese from avian cholera for the entire 12 months of a laboratory study. This product has been used for several years with good results in a Canada goose propagation flock that has much contact with free-flying wild waterfowl and field outbreaks of avian cholera. Before use of the bacterin, this same flock of Canada geese suffered an outbreak of avian cholera and was successfully treated with intramuscular injections of 50 mg of oxytetracycline followed by a 30-day regimen of 500 g of tetracycline per ton of feed.

As yet, there is no practical method of immunizing large numbers of free-living migratory birds against avian cholera. However, captive propagation flocks can be protected by this method. Endangered species can be trapped and immunized if the degree of risk warrants this action. Live vaccines should not be used for migratory birds without adequate safety testing.

Human Health Considerations

Avian cholera is not considered a high risk disease for man because of differences in species susceptibility to different strains of *P. multocida*. However, *P. multocida* infections in humans are not uncommon. Most of these infections result from an animal bite or scratch, primarily from dogs and cats. The use of dogs is not recommended for picking up carcasses during avian cholera outbreaks because of potential contamination of their mouths with *P. multocida* and later exposure of people as a result of licking hands or faces. Regardless, the wisdom of wearing gloves and thoroughly washing skin surfaces is obvious when handling birds that have died from avian cholera.

Infections unrelated to wounds are also common, and in the majority of human cases these involve respiratory tract exposure. This is most apt to occur in confined areas with restricted air movement where a large amount of infected material is present. Processing of carcasses associated with avian cholera die-offs should be done outdoors or in other areas with adequate ventilation. When disposing of carcasses by open burning, avoid direct exposure to smoke from the fire.

Suggested Reading

Brand, C. J. 1984. Avian cholera in the Central and Mississippi Flyways during 1979–80. J. Wildl. Manage. 48:399–406.

Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., Resour. Publ. 167. 225 pp.

Rhoades, K. R., and R. B. Rimler. 1984. Avian pasteurellosis. Pages 141–156 *in* M. S. Hofstad, H. J. Baarnes, B. W. Calnek, W. M. Reid, and H. W. Yoder, Jr., eds. Diseases of poultry. 8th ed. Iowa State University Press, Ames.

Rosen, M. N. 1971. Avian cholera. Pages 59–74 *in* J. W. Davis, R. C. Anderson, L. Karstad, and D. 0. Trainer, eds. Infectious and parasitic diseases of wild birds. Iowa State University Press, Ames.

Wobeser, G. A. 1981. Diseases of wild waterfowl. Plenum Press, New York. xxi + 300 pp.

Appendix. Common and Scientific Names of Animals Named in Text.

Canada goose	*Branta canadensis*
Snow goose	*Chen caerulescens*
Crows	*Corvus* sp.
American coot	*Fulica americana*
Whooping crane	*Grus americana*
Gulls	Larinae
Eiders	*Somateria* sp.
Terns	*Sterna* sp.
Deer	*Odocoileus* sp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1989

13.2.6. Lead Poisoning: The Invisible Disease

Milton Friend
U.S. Fish and Wildlife Service
National Wildlife Health Research Center
6006 Schroeder Road
Madison, WI 53711

Synonym

Plumbism

Cause

Lead poisoning is an intoxication resulting from absorption of hazardous levels of lead into body tissues. Lead pellets from shot shells, when ingested, are the most common source of lead poisoning in migratory birds. Other far less common sources include lead fishing sinkers, mine wastes, paint pigments, bullets, and other lead objects that are swallowed.

Species Affected

Lead poisoning has affected every major species of waterfowl in North America and has also been reported in a wide variety of other birds. The annual magnitude of lead poisoning losses for individual species cannot be precisely determined. However, reasonable estimates of lead-poisoning losses in different species can be made on the basis of waterfowl mortality reports and gizzard analyses. Within the United States, annual losses from lead poisoning have been estimated at between 1.6 and 2.4 million waterfowl, based on a fall flight of 100 million birds. Proportional adjustments that reflect current waterfowl populations and increasing use of nontoxic shot should be made when estimating current lead-poisoning losses.

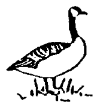
Lead poisoning is common in mallards, northern pintails, redheads, scaup, Canada and snow geese, and tundra swans. The frequency of this disease decreases with increasing specialization of food habits and higher percentages of fish in the diet. Therefore, goldeneyes are seldom affected and mergansers rarely affected (Figure 1). Among land birds, eagles are most frequently reported dying from lead poisoning. Lead poisoning in eagles generally is a result of swallowing lead shot embedded in the flesh of their prey.

Distribution

Losses occur coast-to-coast and border-to-border within the United States. Documented occurrences of lead poisoning in migratory birds vary widely between States and do not necessarily reflect true geographic differences in the frequency of occurrence of this condition. For example, although the geographic distribution of lead poisoning in bald eagles is closely associated with their wintering areas, the number of lead poisoning cases from Wisconsin and Minnesota is disproportionately high. The reported distribution of lead poisoning is more a function of recognition than of frequency of occurrence. The general distribution of this disease in waterfowl on the basis of lead shot ingestion surveys and documented mortality is reflected in Figure 2.

Adapted from: Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., *Resour. Publ.* 167. 225 pp.

Type of bird	Relative occurrence
Whistling-ducks	○
Swans	
Tundra swans	●●●
Mute swans	●●
Other swans	●
Geese	
Canada geese	●●●
Snow and Ross' geese	●●●
Brant and other geese	○
Ducks	
Puddle ducks	●●●
Bay diving ducks	●●●
Teal, shoveler, wood duck	●
Sea ducks	○
Mergansers	○


●●● Frequent reports of mortality including individual die-offs involving hundreds to thousands of birds
●● Often reported mortality
● Occasionally reported mortality; lead shot ingestion studies generally indicate low levels of exposure to lead shot
○ Rare reports of mortality; lead shot ingestion studies generally indicate little or no lead shot ingestion

Figure 1. Relative occurrence of reported lead poisoning in North American waterfowl.

Lead poisoning has also been reported as a cause of migratory bird mortality in other countries, including Australia, Canada, Denmark, Germany, Great Britain, Italy, Japan, New Zealand, and Sweden.

Seasonality

Losses can occur at any time of the year, although most cases of lead poisoning occur after the waterfowl hunting season has been completed in northern areas and during the later part of the season in southern areas of the United States. January and February are peak months for cases in tundra swans, Canada geese, and puddle ducks. Spring losses are more commonly reported for diving ducks. Tundra swans are also frequently lead poisoned during spring migration.

Field Signs

Lead-poisoned waterfowl are often mistaken for hunting season cripples. Special attention should be given to waterfowl that do not take flight when the flock is disturbed and to small aggregations of waterfowl that remain after most other birds of that species have migrated from the area. Lead-poisoned birds become reluctant to fly when approached; those that can still fly are often noticeably weak flyers, unable to sustain flight for any distance, flying erratically and landing poorly. Birds that attempt to escape pursuit by running may exhibit an unsteady gait. In lead-poisoned Canada geese, the head and neck position may appear "crooked" or bent in flight; a marked change in the tone of call is also sometimes evident in this species. As the disease progresses and waterfowl become flightless, the wings are held in a characteristic "roof-shaped" position (Figure 3), followed by wing droop as the birds become increasingly moribund. There may be a fluid discharge from the bill, and often there is an absence of escape response.

Lead-poisoned waterfowl are easily captured during advanced stages of intoxication. Because severely affected birds generally seek isolation and protective cover, well-trained retrieving dogs can help greatly to locate and collect these birds. An abundance of bile-stained feces on an area used by waterfowl is suggestive of lead poisoning and warrants ground searches even if other field signs have not been observed. Green-colored feces can also result from feeding on green wheat and other plants, but the coloration is somewhat different.

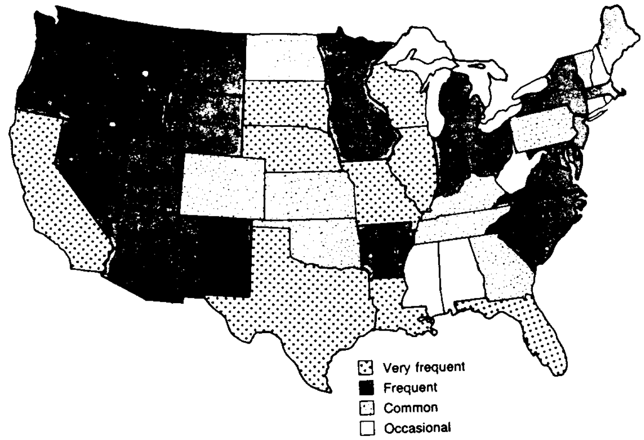


Figure 2. Relative occurrence of lead exposure in waterfowl based on gizzard analyses and reported mortality.

Gross Lesions

Lead-poisoned waterfowl are often emaciated because of the prolonged course of the illness and its effect on essential body processes. Therefore,

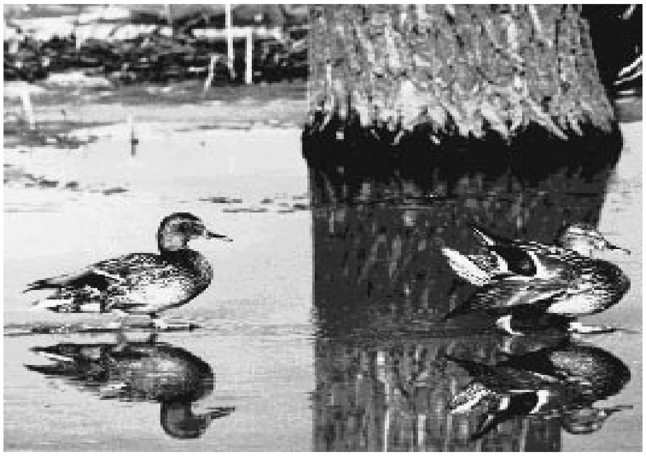


Figure 3. Characteristic "roof-shaped" position of the wings in a lead-poisoned mallard (*leading bird*).

Figure 4. "Hatchet-breast" appearance of a lead-poisoned mallard (*top bird*) and northern pintail. The skin has been removed from the breast of the pintail to further illustrate the severe loss of muscle tissue.

many affected birds appear to be starving; they are light in weight, have a "hatchet-breast" appearance, (Figure 4), and the undersurface of their skin is devoid of fat. The vent area of these birds is often stained with a bright green diarrhea. The heads of Canada geese may appear puffy or swollen because serumlike fluids accumulate in the tissues of the face.

Lesions observed at necropsy of lead-poisoned birds that have died after a prolonged illness generally consist of the following:

- Severe wasting of the breast muscles.
- Absent or reduced amounts of visceral fat.
- Impactions of the esophagus or proventriculus in about 20–30% of affected waterfowl. These impactions may contain food items, or combinations of food, sand, and mud. The extent of impaction may be restricted to the gizzard and proventriculus, extend to the mouth, or lie somewhere between.
- A prominent gallbladder that is distended, filled with bile, and dark or bright green.
- Normally yellow gizzard lining discolored a dark or bright green. Gizzard contents are also often bile-stained.
- Lead pellets or small particles of lead often present among gizzard and proventricular contents. Pellets that have been present for a long time are well worn, reduced in size, and disklike rather than spherical (Figure 5). Careful washing of contents is required to find smaller lead fragments. X-ray examination is often used to detect radiopaque objects in gizzards, but recovery of the objects is necessary to separate lead from other metals. Flushing contents through a series of progressively smaller sieves is one method for pellet recovery.

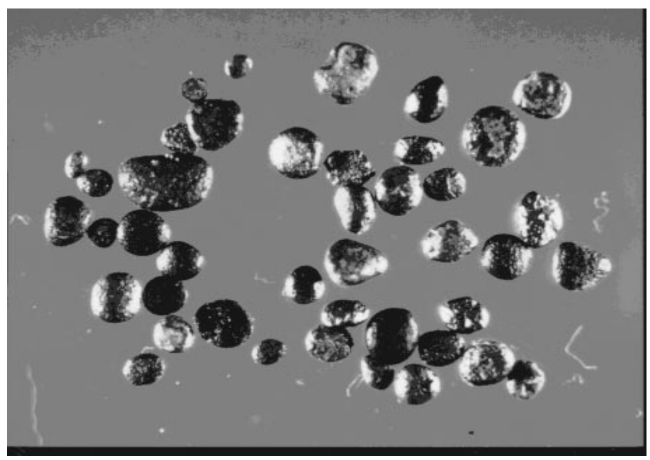


Figure 5. Lead shot, originally round, have been worn down in a waterfowl gizzard. Note the flattened, disklike shape of many of these pellets.

The above field signs and gross lesions provide a basis for a presumptive diagnosis of lead poisoning. However, none of these signs and lesions is diagnostic by itself and all can result from other causes. Also, many of the above signs and lesions are absent in birds that die acutely following an overwhelming lead exposure.

Control

Two actions can often be taken to reduce the magnitude of mortality from lead poisoning when die-offs occur: denying bird use in problem areas, and rigorous pickup and proper disposal of dead and moribund birds.

Denying birds use of problem areas requires knowing where the birds are picking up the lead. This is complicated by the fact that signs of intoxication may not appear until a week after lead ingestion, and birds may not start dying until 2 to 3 weeks after lead ingestion. Habitat modification is also useful in some instances, but differences in feeding habits must be considered. For example, placing additional water on an area may protect puddle ducks from reaching lead shot on the bottom of wetlands, but this creates attractive feeding areas for diving ducks. Similarly, draining an area may prevent ingestion of lead shot by waterfowl, but creates an attractive feeding area for shorebirds or ring-necked pheasants. Therefore, control actions must consider the broad spectrum of wildlife likely to use the area at the time action is taken. Rigorous pickup and proper disposal of lead-contaminated waterfowl carcasses is required to prevent raptors and other scavenger species from ingesting them. The high percentage of waterfowl with embedded body shot provides a continual opportunity for lead exposure in raptors that far exceeds the opportunity for ingestion of shot present in waterfowl gizzards.

Other management practices that have been used to reduce losses from lead poisoning on site-specific areas include: (1) tillage programs to turn lead shot below the surface of soil so that shot is not readily available to birds; (2) planting food crops other than corn and other grains that aggravate the effects of lead ingestion; and (3) requiring the use of nontoxic shot on hunting areas. The potential contributions of the first two practices toward reducing lead-poisoning losses among migratory birds are, at best, limited and temporary. The use of nontoxic shot is the only long-term solution for significantly reducing migratory bird losses from lead poisoning.

Medical treatment of lead-poisoned birds is generally not a reasonable approach. However, endangered species or other birds of high individual value that are lead poisoned may warrant medical treatment. In those instances, treatment should be done only by qualified persons familiar with and skilled in the proper use of lead-chelating chemicals. Under the best of circumstances, results of treatment are unpredictable and the success rate low.

Human Health Considerations

People do inadvertently consume lead-poisoned waterfowl. Although this is not desirable, no appreciable risks to human health exist. Most lead present in the body of a lead-poisoned bird is in soft tissues such as liver and kidneys rather than in the flesh. The dose relation (mg of lead per kg of body weight) and lead excretion processes are such that a great number of lead-poisoned birds would need to be consumed in a relatively short time before toxic levels could build up in the human body. Persons who eat liver, kidney, and other soft tissues from lead-poisoned birds would consume more lead than those who eat only muscle tissue of these birds. Persons who consume waterfowl bone marrow would be additionally exposed to lead, since lead is stored long-term in bone.

There are a few documented eases of humans developing lead poisoning after having accidentally ingested lead shot embedded in the meat they ate. This type of lead poisoning is rare, perhaps due to caution exercised when eating hunter-killed wildlife so as to avoid potential damage to teeth from biting into shot. Lead shot that is ingested can also become lodged in the appendix, resulting in appendicitis. Although this does not happen often, it happens most in people who hunt waterfowl for subsistence.

Suggested Reading

Friend, M., editor. 1987. Field guide to wildlife diseases. U.S. Fish Wildl. Serv., Resour. Publ. 167. 225 pp.

Kraft, M. 1984. Lead poisoning. Are we wasting our waterfowl? Kans. Wildl. 41:13–20.

Sanderson, G. C., and F. C. Bellrose. 1986. A review of the problem of lead poisoning in waterfowl. Illinois National History Survey 172. Spec. Publ. 4.

Trainer, D. 0. 1982. Lead poisoning of waterfowl. Pages 24–30 *in* G. L. Hoff and J. W. Davis, eds. Noninfectious diseases of wildlife. Iowa State University Press, Ames.

Wobeser, G. A. 1981. Diseases of wild waterfowl. Plenum Press, New York. xii + 300 pp.

Appendix. Common and Scientific Names of Animals Named in Text.

Wood duck	*Aix sponsa*
Northern pintail	*Anas acuta*
Shoveler	*Anas clypeata*
Mallard	*Anas platyrhynchos*
Teal	*Anas* spp.
Redhead	*Aythya americana*
Scaup	*Aythya* spp.
Brant	*Branta bernicla*
Canada goose	*Branta canadensis*
Goldeneye	*Bucephala* spp.
Snow goose	*Chen caerulescens*
Ross' goose	*Chen rossii*
Tundra swan	*Cygnus columbianus*
Mute swan	*Cygnus olor*
Whistling ducks	*Dendrocygna* spp.
Bald eagle	*Haliaeetus leucocephalus*
Mergansers	*Lophodytes cucullatus, Mergus* spp.
Ring-necked pheasant	*Phasianus colchicus*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1989

13.2.7. Identifying the Factors That Limit Duck Production

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Road
Fort Collins, CO 80526

Low duck populations in the late 1980's and early 1990's prompted unprecedented action from the natural resources community. Agencies and private organizations that were traditionally involved with waterfowl management redoubled their efforts, in the process forming partnerships with groups that were relatively new to the waterfowl management arena. Many resource managers who have had relatively little experience with waterfowl habitat management now find themselves expected to manage duck populations for increased production. Decades of waterfowl research and management experience have provided them with many potential management tools. Unfortunately, the absence of general guidelines for directing waterfowl management actions has put these newcomers to the field at a decided disadvantage. This is particularly true for managers who reside outside of the northern Great Plains, a region that has been the focus of most research on breeding ducks.

This leaflet is intended to orient managers to approaches for identifying the factors that limit duck production. The concepts presented here will assist in making logical management choices in regions where little is known about breeding ducks and their habitat. Although it may serve as interim guidance, this leaflet is not intended to substitute for rigorous, scientific research on waterfowl biology. Readers are urged to use this leaflet as a starting point from which to gather additional knowledge using companion leaflets and technical publications.

The Reproductive Cycle

Although ducks are a diverse group of birds, many dabbling and diving ducks in North America show similarities in general facets of their breeding biology. A basic understanding of the important events and forces that drive reproductive behavior is essential to interpreting premanagement information. The following sections provide a summary of duck breeding biology that, although not strictly accurate for any particular species, is generally representative of the most common North American ducks.

Resource Needs

Most ducks arrive on their breeding grounds from late March to early May. Shortly thereafter they begin to make regular use of wetlands that vary in size, water permanency, and vegetative composition. These wetlands, together with surrounding uplands, constitute the home range of individual pairs. Usually, males become aggressive toward other birds of the same species, defending either wetlands within the home range or space around their mates. These aggressive interactions cause birds to distribute themselves throughout the breeding habitat.

The need for dietary protein during the prenesting and egg-laying periods causes ducks to seek aquatic invertebrate foods, which may compose 75 to 100% of the hen's diet. Many species maximize food acquisition during this period by capitalizing on the seasonal peaks in aquatic food abundance that differ among wetland types. For example, shallow, temporary wetlands may exist only a few weeks, but during that time they warm quickly and develop invertebrate populations long before permanent ponds. By moving among wetlands and selecting those with the richest invertebrate fauna, ducks are able to quickly acquire the protein necessary for egg production. Thus, small, shallow wetlands contribute as much to ducks during the breeding period as large, permanent cattail marshes. A diverse wetland community is critical to this food acquisition strategy.

Territorial aggression is often initiated when males sight other birds of the same species. This visual spacing limits the number of pairs that an area can support. Habitats with many small ponds on which ducks may isolate themselves, or those with heavy vegetation, bays, or inlets where pairs are visually separated, can reduce encounters between birds and increase pair densities. Wetlands most attractive to dabbling ducks contain about a 50:50 ratio of open water to emergent vegetation. Patches of emergent plants, sparse enough to allow a duck to swim through, are more attractive than large blocks of thick, unbroken vegetation.

Nest Sites

Most diving ducks and some dabbling ducks construct nests over water amid emergent vegetation. In contrast, most dabbling duck nests are made in dead vegetation remaining from the previous growing season. Often, this residual vegetation is found in grassland and shrub habitat located up to a mile from water. Tall, dense grasses or shrubs with low growth forms are usually preferred by dabbling ducks. Islands also provide attractive nesting habitat if adequate vegetative cover is present. Hens explore many potential sites, but select only one to construct a nest. Most ducks lay a single egg each day until a clutch of 9 to 11 eggs is complete.

Incubation

As the clutch nears completion, hens begin an incubation period that ranges from 23 to 30 days for most species, with shorter periods typical of species that lay smaller eggs. Duck nests are often destroyed by mammalian, avian, or reptilian predators. At present, throughout much of the northern Great Plains, predators are abundant, and duck nests are concentrated because nesting cover is limited. Consequently, the percentage of nests that hatch at least one egg (nest success) is often less than 15%. In habitats where nests are dispersed and predators are less common, much higher (40 to 70%) success rates are typical. Most ducks will renest if their initial clutch is destroyed during laying or early in incubation and a sufficient number and diversity of wetlands remain available. In some species, hens that successfully hatch a clutch often return to the vicinity of the successful nest site in subsequent years, and sometimes to the same nest bowl. During incubation, hens leave the nest for a recess three to five times per day. They continue to meet their mates during these recesses until the male leaves his territory and joins groups of other males in preparation for molt. This usually occurs about 1 to 2 weeks into incubation.

Broods

Newly hatched ducklings leave the nest soon after hatching, and may walk through uplands or follow streams to brood-rearing wetlands up to a mile away. Even after reaching a wetland, broods may move among ponds. Ducklings of most species feed almost entirely on aquatic invertebrates until about a month old. Thereafter, ducklings of dabbling duck species gradually increase their consumption of seeds and other vegetation. Because ducklings cannot thermoregulate until they are about 2 weeks old, they are periodically brooded by the hen. Predation and exposure can cause high mortality among ducklings. Contaminants can also cause mortality, either by direct toxicity or, more often, by reducing the abundance of essential invertebrate foods. In many habitats, 20 to 50% of all duck broods are entirely destroyed, and typically only about half of the ducklings in the remaining broods survive. Habitat use by broods differs among species, but is generally related to the need for areas secure from predators and severe weather. Diving duck broods seek security in open water, where they dive to escape predators. Dabbling duck broods usually prefer dense emergent vegetation.

The Limiting Factor

Contemporary waterfowl management generally uses three approaches for guiding management actions. Actions initiated on an international scale, such as in the North American Waterfowl Management Plan, often originate from broad policy directives such as the need to preserve wetlands or increase nesting success. Other initiatives are guided by computer simulations, such as the Mallard Management Model, that recommend actions based on knowledge of waterfowl biology and factors that suppress reproduction. However, similar guidelines are generally unavailable for managing the scattered, diverse duck breeding habitats of North America. In such habitats, management actions are often guided by the manager's experience and intuition.

Predation, resource limitations, and environmental conditions are factors that may suppress waterfowl populations below their biological potential. However, only one factor is most limiting to populations at any time. Aldo Leopold described the limiting factor as "the one that has to be removed first, and usually the one to which the application of a given amount of effort will pay the highest returns, under conditions as they stand." The effort required to remedy a limiting factor may vary, but until it is removed, activities directed at other, nonlimiting factors will offer relatively little improvement in duck production.

Although many contemporary ecologists view the limiting factor concept as an oversimplification of complex interrelationships, it is nonetheless a useful starting point for considering factors that suppress waterfowl recruitment. Sometimes, a factor that limits duck production can result from deficiencies independent of the breeding habitat, for example, food shortages on wintering areas that prevent the acquisition of fat reserves necessary for successful breeding. Such limitations are usually beyond the control of individual managers. Most factors that are potentially limiting to duck production, however, can be traced to four important requirements of breeding habitat: the ability to attract and retain spring migrants, provide for the resource and social needs of breeding pairs, secure adequate nesting habitat, and provide suitable brood-rearing habitat. Unfortunately, drought, localized agricultural effects, and other dynamic events may cause deficiencies in these requirements to vary annually. Thus, management to correct long-term habitat deficiencies should be based on average habitat conditions. These average conditions should be determined by evaluating premanagement information collected during more than one breeding season.

Because wetland communities are the basic unit in which ducks live and acquire resources during breeding, premanagement information should be gathered independently for each discrete community, not averaged across several isolated wetland complexes. Although waterfowl researchers are beginning to understand the implications of habitat fragmentation for breeding ducks, it is well established that the benefits of small tracts of waterfowl habitat are often swamped by the effects of habitat degradation on adjacent lands. The protocol described here may still be useful for identifying factors limiting duck production, but management to overcome these deficiencies on small tracts of land may be futile in the face of overwhelming external forces.

Obtaining Premanagement Information

Spring Migrants and Breeding Pairs

Information on the number of spring migrants and resident breeding pairs can be obtained through a series of ground counts beginning with the first influx of spring migrants and continuing through the early incubation period. Spring migrant and pair counts, as well as brood counts, should be conducted on a large block of contiguous habitat that is representative of the management area. Ideally, surveys should be conducted two or three times per week, but in no case less than once a week. Because females typically take incubation recesses early and late in the day, nesting chronology and indices to nest success are most readily interpreted if observers restrict their counts to the period between 1 hour after sunrise to 1 hour before sunset. Observers should quietly walk near wetlands but avoid flushing ducks. If birds flush to nearby areas, observers should avoid duplicate counts on these individuals. During the time when spring migrants move through the region, simply tally the numbers of individuals by species and sex. When the number of ducks and the species composition stabilizes, one may assume that many birds now in the area are beginning to establish home ranges in preparation for breeding. At this time, begin counting male-female pairs and single males, tallying these males as "indicated pairs." These single or "lone" males are usually mates of females who are searching for nest sites, laying eggs, or incubating. For each species, the highest number of pairs plus indicated pairs counted in any census represents the total estimated pairs resident in the wetland community.

Nesting Habitat and Success

The quantity of available nesting habitat is often easy to judge in relation to species requirements. Most diving ducks construct nests over water in robust emergent plants. Map the distribution and vegetative composition of these emergent beds, and note if such areas remain inundated during the incubation period. Cavity-nesting duck species use holes excavated by woodpeckers or created by internal rot in old trees. Note the number and distribution of potential nest trees or actual nest sites and their distances from the wetland. Dabbling ducks and some diving ducks nest in grasses or shrubs adjacent to wetlands. Map the area and distribution of these habitats.

The quality of nesting habitat is difficult to judge for overwater- and cavity-nesting species. However, the height and density of upland sites can be measured using a Robel pole or similar device. Readings obtained at a standardized viewing height and distance can then be compared with minimum standards required by different species. Whenever possible, managers should determine the relative quality of potential nesting habitat.

Duck nesting success is a more indirect index of nesting habitat conditions because it is dependent on the quality and quantity of habitat as well as the density and composition of the local predator community. In grassland habitats, large numbers of nests can often be located using cable-chain drags. In shrubland or wooded areas, hand drags, dogs, or observations of hens returning to nest sites may be necessary to locate nests. When nests are found, note the size of the completed clutch, candle the eggs to determine the stage of incubation, then flag the site by placing a marker at some set distance and direction away from the nest. Excessive disturbance to the nest site must be avoided. Later, revisit the site to determine the fate of the nest. Nests that were abandoned or destroyed by predators will contain whole eggs and pieces of eggshell with membranes firmly attached. Note the condition of the eggs and look for tracks, scats, or other evidence that may suggest the cause of nest failure. Successful nests are typified by shell membranes that are easily separated from shell fragments.

Brood-rearing Period

Begin duck brood surveys when broods of early-nesting species first appear. Surveys should be conducted in early morning (30 minutes before to 1 hour after sunrise) and in late evening (2 hours before until 30 minutes after sunset). Counts conducted at times other than early and late in the day will census only a fraction of the broods present and will be biased towards diving duck species that use open water areas during brood-rearing. Viewers should quietly observe broods, from elevated vantage points if necessary, and note the species, size of the brood (number of ducklings), and age of the ducklings. Be aware that duck broods may move among wetlands, and try to avoid duplicate counts. If movements between wetlands are uncommon and the number of broods per wetland is low, it is often possible to distinguish individual broods based on a combination of species, size, and age. In such cases, note the number of ducklings in a brood on subsequent observations. If a brood is not observed on subsequent surveys and the likelihood of secondary movements to another rearing wetland is remote, record the possibility that the entire brood perished. To obtain data on duckling attrition, individual broods should be observed every 3 to 5 days, particularly when ducklings are young and mortality rates are highest. The most important index to obtain during the brood-rearing period is the number of young remaining in old (prefledging, or class III) broods.

Identifying the Limiting Factor

Attracting and retaining spring migrants, providing resources for breeding pairs, securing adequate nesting habitat, and providing suitable brood-rearing areas are all interdependent activities, wherein each event is dependent on the success of previous events. The following sections provide a basis for identifying deficiencies in this reproductive chain of events by interpreting the

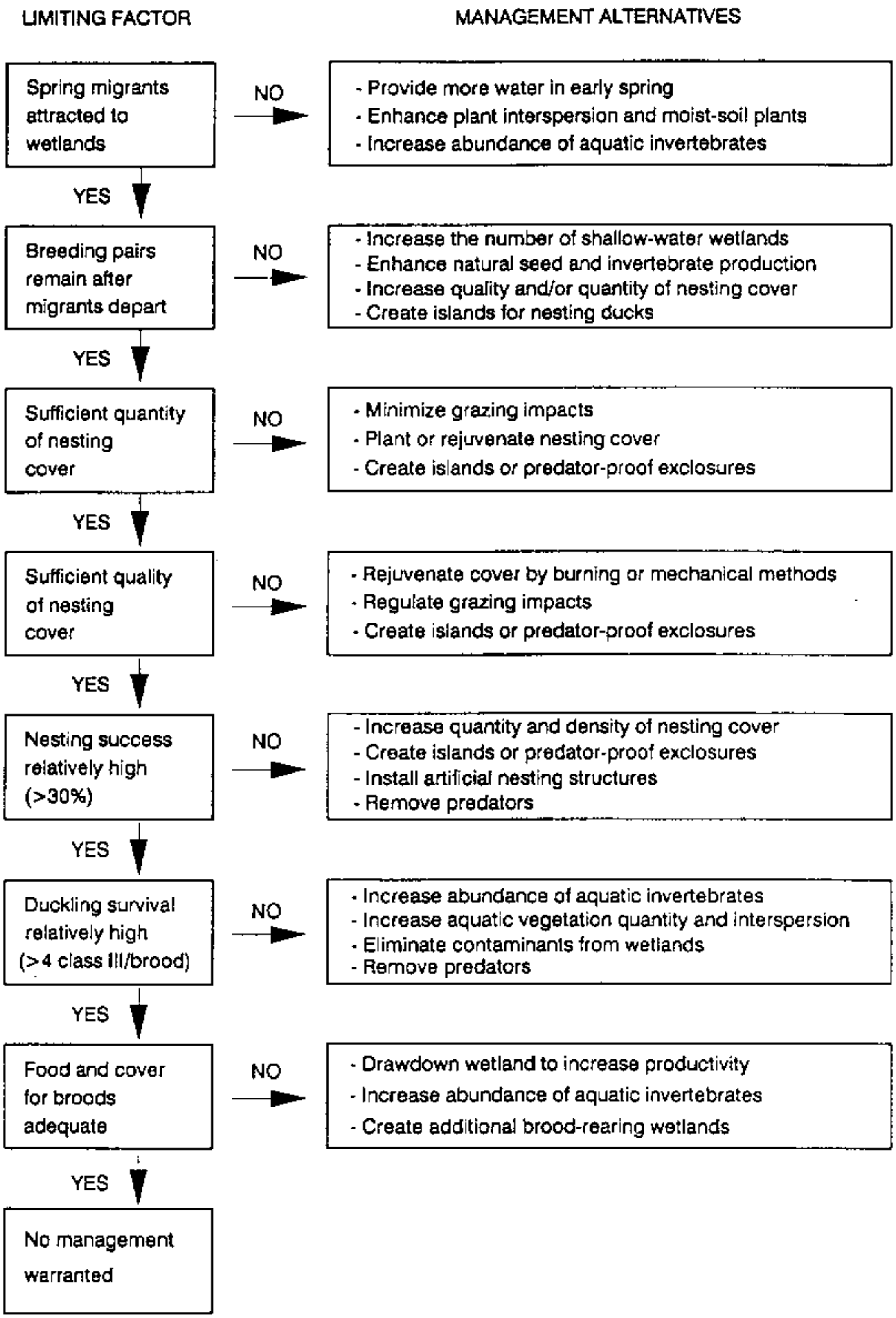


Fig. 1. General management alternatives for addressing factors that limit duck recruitment. Readers should consult technical publications for detailed information on specific alternatives.

premanagement data described above. Once a limiting factor has been identified, general management actions for correcting these deficiencies can be considered (Fig. 1). Readers should consult technical publications for information on which management action is most appropriate and how to implement an action.

Attracting and Holding Spring Migrants and Breeding Pairs

Summarize data on the numbers of ducks present in early spring, looking for evidence of a sharp decline indicative of migrants departing the area and resident pairs remaining behind. If large numbers of migrants were present, but later departed, and those migrants were species that normally breed in the area, consider actions to attract and hold spring migrants.

Examine the number of indicated breeding pairs that remain after migrants leave the area, then determine if the habitat is supporting breeding pairs up to its potential. The key to assessing this potential is knowing how many pairs are attracted to good wetland communities in your geographic area. Comparing pair densities on nearby, high quality breeding habitat provides the best basis for contrast. Historical data also can be consulted. Lacking these data, managers should consult state or federal agencies for area-specific data. For example, curves depicting average breeding pair densities as a function of wetland size and type have been developed for the northern Great Plains (e.g., Cowardin et al. 1988). Wetland complexes that fail to attract adequate numbers of breeding pairs can be managed to increase pair numbers.

Enhancing Nesting Habitat and Nest Success

Emergent vegetation suitable for overwater nesters should be dense, have a height of at least 3 feet above water, and remain flooded during the period of nesting. Suitable emergents should occur in wide bands around the periphery of the wetland or as large islands within the wetland basin. Most cavity-nesting species select nest sites within 200 yards (183 m) of a wetland, although wood ducks (*Aix sponsa*) will use cavities up to 1 mile (1.6 km) from water. If suitable cavities are few or absent within this area, artificial nesting structures can help correct the deficiency. Ducks that nest in upland sites require grasses, legumes, shrubs, or combinations of the above plants within 1 mile of wetlands. Suitable nesting areas should occur in large (more than 40 acres or, 16 ha), unbroken blocks of habitat.

Nesting cover should meet minimal Robel pole indices for height and density (typically, dense at heights of 18 inches—0.5 m—above the ground), and should be secure from grazing and agricultural manipulations until after the incubation period. If density or height is insufficient, several management actions can be used to enhance the quality of nesting cover.

Data on the fate of marked nests should be corrected for exposure, according to the Mayfield correction technique, then average nest success rates should be calculated for the management area. Generally, nest success rates greater than 40% are acceptable in most habitats, whereas rates lower than 15% are usually insufficient to maintain a stable duck population. Lacking direct measures of nest success, managers may obtain qualitative indices of nest loss through "social indices" that rely on the tendencies of many duck species to renest if their initial nests are destroyed. The simplest of these indices is an analysis of the weekly ratios of indicated pairs (lone males) to actual (male–female) pairs during the egg-laying and incubation period for each species. Local populations experiencing low rates of nest loss often exhibit ratios that increase sharply in the first few weeks, then gradually decline from a high level (e.g., 0.2:1, 1.3:1, 3.4:1, 3.0:1, and 2.8:1). Populations experiencing high nest loss may exhibit an increase, followed by a sharp decrease, then a subsequent increase in these ratios (e.g., 0.2:1, 1.3:1, 3.4:1, 1.8:1, and 2.7:1), indicative of unsuccessful hens rejoining their mates in preparation for a second nesting attempt.

Additional evidence of nest destruction may be derived by examining the hatching chronology of duck broods for each species. This is accomplished by back-dating broods to the date of hatch, using information on duckling ages. A frequency distribution of number of broods hatched within 5-day intervals typically depicts a peak of hatch followed by a much smaller, well-defined, second peak from renesting attempts (Fig. 2). Hatching curves that exhibit pronounced renesting peaks or are relatively flat suggest excessive rates of nest loss.

If the quantity and quality of nesting cover are adequate but nesting success is low, try to determine the cause of nest failure. Predation is

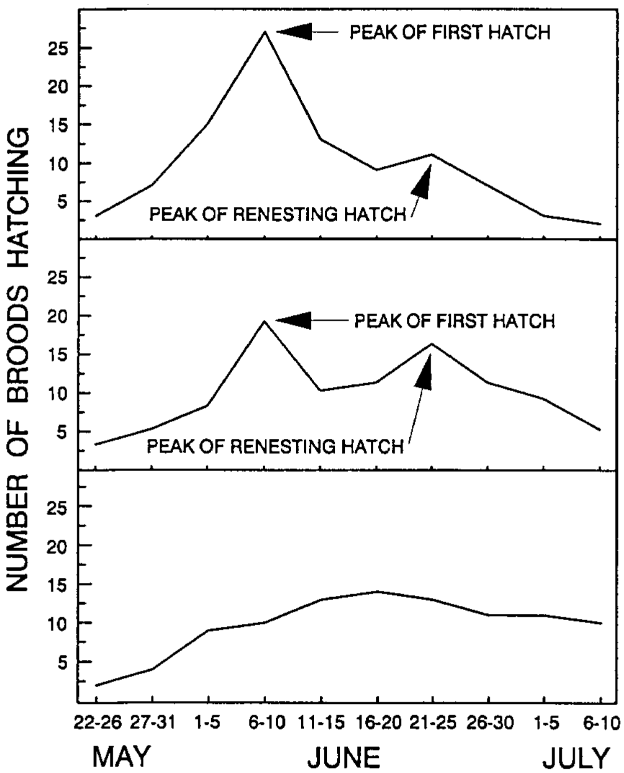


Fig. 2. Hypothetical hatching curves for local duck populations experiencing relatively high (*top*) and low (*middle and bottom*) nesting success during early incubation.

one common reason for nest failure in many habitats, and may be indicated by evidence left at the nest. However, do not discount the possibilities of flooding, destruction from agricultural operations, or exposure to weather. A wide array of corrective actions are available to enhance nesting success, depending on the cause of nest failure.

Improving Brood-rearing Habitat and Duckling Survival

Duckling mortality is indicated either by loss of complete broods or by brood attrition, wherein the number of ducklings in a brood is reduced over time. Mortality caused by exposure, starvation, or death from pesticides or other contaminants often results in the catastrophic loss of entire broods. In contrast, mortality caused by predation may result in a more gradual decrease in brood size. Generally, an average of five ducklings per prefledging (class III) brood is considered acceptable attrition. Supplemental information, such as, from bait stations to identify the presence of predators, invertebrate sampling to gauge the abundance of food, and water quality measures to detect contaminants, may be needed to isolate the causes of duckling mortality. Such supplemental data are usually vital for selecting an appropriate management strategy to enhance brood survival.

Rather than remain in undesirable habitat, broods may move to other wetlands. The quality of brood-rearing habitat may therefore be reflected by the number of resident broods, compared with the number of resident breeding pairs that were in the area, after taking into account nest success rates and renesting activity. If the estimated number of broods occupying a wetland complex is far less than the estimated number believed to have hatched, management may be necessary to enhance the quality of brood-rearing habitat. Often, the root causes of low brood usage and poor brood survival are the same, and a single management action may be used to address both problems.

Other Considerations

Before initiating any management measure, consider whether human disturbance or natural forces have sufficiently altered the ecosystem to warrant intervention. Do not use management tools as "weapons" against a healthy landscape. The waterfowl response to management of such areas will be relatively slight when compared with results of the same effort applied to dysfunctional ecosystems. Unfortunately, however, some of the most important waterfowl breeding habitats in North America have been severely degraded. When managing these habitats, overall objectives should be consistent with the natural values of the ecosystem. Not all wetlands are meant to be breeding habitats. Migratory stopover and wintering areas provide essential resources for ducks, and managers should avoid modifying such areas to create breeding habitat if doing so would impair these other seasonal uses. Although management actions can temporarily alter waterfowl habitats for other than natural uses, they do so only with high cost, intensive labor, and possibly detrimental effects to the ecosystem.

Once a limiting factor has been identified and an appropriate management response is devised, managers should resist the temptation to simultaneously initiate more than one action on a single area. Imposing more than one management treatment complicates evaluations of the effectiveness of the actions, and often results in no more success than a single treatment that is selected with reasonable forethought.

Lastly, management actions should be evaluated to determine whether the objectives of the project were attained. The same techniques and data analyses used when collecting premanagement information should be employed during this follow-up evaluation.

Suggested Reading

Bellrose, F. C. 1980. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, Penn. 543 pp.

Cowardin, L. M., D. H. Johnson, T. L. Shaffer, and D. W. Sparling. 1988. Applications of a simulation model to decisions in mallard management. U.S. Fish and Wildlife Service Technical Report 17. 28 pp.

Higgins, K. F., L. M. Kirsch, H. F. Duebbert, A. T. Klett, J. T. Lokemoen, H. W. Miller, and A. D. Kruse. 1977. Construction and operation of cable–chain drag for nest searches. U.S. Fish and Wildlife Service Wildlife Leaflet 512. 14 pp.

Johnson, D. H. 1979. Estimating nest success: the Mayfield method and an alternative. Auk 96:651–661.

Kirby, R. E. 1988. American black duck breeding habitat enhancement in the northeastern United States: a review and synthesis. U.S. Fish and Wildlife Service Biological Report 88(4). 50 pp.

Lokemoen, J. T. 1984. Examining economic efficiency of management practices that enhance waterfowl production. Transactions of the North American Wildlife Natural Resources Conference 49:584–607.

Ringelman, J. K. 1991. Evaluating and managing waterfowl habitat. Colorado Division of Wildlife Division Report 16. 48 pp.

Robel, R. J., J. M. Briggs, A. D. Dayton, and L. C. Hulbert. 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. Journal of Range Management 23:295–297.

Weller, M. W. 1956. A simple field candler for waterfowl eggs. Journal of Range Management 20:111–113.

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

13.2.8. Rescue and Rehabilitation of Oiled Birds

Sallie Welte and Lynne Frink
Tri-State Bird Rescue and Research, Inc.
P.O. Box 289
Wilmington, DE 19899

Oil contamination of waterfowl and seabirds has been documented as a significant cause of morbidity and mortality in birds for more than 50 years. Each year more than one million birds may die from oil contamination in North Atlantic waters alone; worldwide mortality is unknown.

Of special concern is that many of the seabirds commonly affected are not prolific breeders, and assessment of each species' status is handicapped by the difficulty of accurately monitoring trends in marine bird populations.

Oiled bird rehabilitation is an intensive, crisis-oriented response, requiring an experienced management agency, specialized medical expertise, stockpiles of specially designed equipment, and a tremendous investment of human resources.

Nevertheless, after a major oil spill, the public demands that the affected wildlife species be treated, and the Fish and Wildlife Service, as the mandated response agency for the United States, will be called in to respond to the situation.

Unfortunately, very few organizations have the expertise required to rehabilitate oiled birds. Public interest and involvement in the plight of oiled wildlife have resulted in some disastrous rehabilitation efforts. Oiled birds have been rolled in kitty litter, dipped in melted butter, covered with cornmeal, and plucked, all with tragic consequences. When overseen by an experienced agency, however, successful oiled bird rehabilitation has occurred. Particular rehabilitation success is seen in swans, geese, and ducks, with average release rates exceeding 90%.

In this chapter we attempt to provide the wildlife professional with a basic understanding of the internal and external effects of oil on birds, and the key components of an effective oil spill response. We emphasize the handling of waterfowl and seabirds. This chapter does not provide the detailed information needed to manage a major oil spill response.

Effects of Oil Contamination

Once a bird is contaminated by oil, a sequence of physiologic and metabolic changes begins which contributes to its decreased chance of survival and reproductive success. Oil exposure, unless excessive, is not immediately incapacitating; most birds remain vigorous enough to avoid capture for one or more days. This delay contributes to avian mortality by complicating rehabilitation efforts and increasing the secondary exposure of eggs, nestlings, scavengers, and predators to oil.

External Effects

An immediate effect of oil exposure on birds is the disruption of their feather structure. The resulting decreases in flight ability and water repellency limit the animal's ability to forage for

Double-crested cormorant contaminated with North Sea crude oil.

food and to escape predation. Contamination and disruption of a bird's plumage also reduce the insulating properties of its feathers, increasing the bird's vulnerability to temperature extremes. In addition, a bird's direct contact with oil components can result in chemical burns and the absorption of toxic chemicals through its skin.

Internal Effects

Internal effects of oil result from the ingestion, aspiration, or absorption of oil components. Although visually less apparent than external oil effects, the internal effects of oil are equally life-threatening and often more difficult to treat. While some damage is specific to the oil fractions and contaminants involved, a general pattern of pathological changes characterizes oil toxicosis. These changes include kidney damage, altered liver function, aspiration pneumonia, and irritation of the intestines.

Birds ingest oil when they preen in an attempt to clean their feathers. The resulting intestinal irritation can exacerbate dehydration and metabolic imbalances caused by decreased food intake. The bird can no longer absorb nutrients or regulate body fluids and electrolytes adequately, and may even hemorrhage into its intestinal tract. Anemia due to oil toxicosis has been documented. In addition, birds become less tolerant of stress and more susceptible to disease and to the effects of previously accumulated toxins.

Whereas all types of birds can be affected by a spill, some species are more vulnerable than others. Particularly susceptible are the diving birds, such as loons, cormorants, and diving ducks. Entire populations can be at risk when species that have delayed maturity and low reproductive potentials are contaminated. Birds that live in harsh environments may not survive the added stress of oil exposure and reduced food supplies.

Long-term and Secondary Effects

Oiled adults frequently contaminate nests, eggs, and young. Likewise, secondary oiling of other flock members and predators can occur.

Decreased reproductive success has been seen in birds experimentally oiled or force-fed oil. Delayed onset of laying, decreased fertility of eggs, abnormal yolk composition, and altered shell thickness have all been documented. Secondarily exposed embryos may die from suffocation or hatch with gross skeletal and bill abnormalities. Decreased growth rates and body weights of experimentally exposed juveniles may result from the ingestion of contaminated foods or the impaired parenting ability of affected adults.

In major oil spills, habitats are altered, food resources changed, and resident animals subjected to chronic oil exposure through contaminated substrates. The potential for bioaccumulation of toxic substances in invertebrates and lower vertebrates warrants further study.

Rehabilitation of Contaminated Birds

Successful oiled bird rehabilitation involves six basic procedures:

- prompt intervention and retrieval of contaminated birds;
- stabilizing the bird;
- removing oil from the bird's feathers;
- removing the cleaning agent from the feathers;

- restoring waterproofing; and
- acclimating the bird for release.

Effective rehabilitation efforts require coordination of State, Federal, and private agencies. The importance of establishing contingency plans in high-risk areas before oil spills occur cannot be overemphasized.

All field agents should be trained in handling techniques that are nonstressful to birds. A facility having adequate space, ventilation, and a regulated temperature should be identified. Hot-water sources and an approved wastewater disposal system must be located. Basic rehabilitation equipment can be stockpiled in advance, so that medical care, nutritional support, and cleaning efforts can begin without delay. Licensed rehabilitators trained in oil spill response protocols should be contacted as soon as a spill occurs.

Field Assessment, Intervention, and Retrieval

Mechanisms should be in place for all aspects of bird retrieval and management, including:

- field strategies for aerial overflights, and ground teams to identify birds at risk;
- procedures for preventing exposure of unaffected animals;
- protocols for field retrieval, emergency stabilization, and transport of contaminated birds; and
- risk assessment and safety protocols for field personnel.

Preventing Exposure

Various techniques can be used to disperse uncontaminated animals from a problem area or to concentrate and hold them in clean areas. Efforts to discourage unoiled birds from contaminated areas must be done early in the spill; these can include scare devices such as propane exploders and cracker shells, hazing with motorized equipment, or relocation through baiting at an alternative feeding area. No attempt should be made to disperse oiled birds since this can lead to introduction of oiled animals into uncontaminated populations.

For priority species, unoiled animals can be relocated through capture in cannon nets, drop nets, rocket nets, and swim-in or walk-in traps, and rapidly transported to "safe" areas. The effort and expense required to trap, examine, and relocate unoiled birds is significantly less than that required to retrieve and rehabilitate oiled animals. Appropriate hazing and trapping techniques differ in each spill situation.

Capture and Transport of Oiled Waterfowl

Human safety should be considered before any retrieval effort is made; hazardous weather conditions, unsafe footing, icy rivers, or dangerous seas may preclude a rescue attempt.

Teamwork is essential to minimize stressing these already compromised animals. As oiled birds lose their waterproofing, they move to shore, first preening on the open beaches and later hiding effectively under tussocks of grass or next to boulders. Birds in this condition should be retrievable by teams on foot; every day's delay in retrieval significantly increases mortality.

Beached birds should be approached quietly and smoothly from the water's edge; this technique can be extremely effective if the retrieval crews are in place shortly before dawn. If the capture attempts fail, birds should not be chased. In marine situations, boats and long-handled dip nets can be used for an approach at low tide to birds that have come ashore.

Immobilization is accomplished by placing towels, sheets, or nets over the entire bird, including the head. Heavy gloves, which reduce human dexterity and can thus cause injury to the animal, are not recommended. Birds are carefully handled through light coverings that minimize damage to the birds' feathers and human exposure to the oil.

Netted birds are gently removed from the netting and completely covered with cloth. Care must be taken to fold the bird's wings in a normal position against its body. A small bird can be secured against the field agent's abdomen, at waist level; the bird is cradled in one hand with the other hand placed lightly on the back. Larger waterfowl and some species with sharp bills can be carried in a reverse body hold: the towel-covered bird is placed, facing backward, against the side of the handler's body, under the arm. Support for the bird's legs is provided by the hand and forearm, with the bird's head facing backward between the the handler's upper arm and side of the body.

Aggressive birds such as raptors, cormorants, and herons can seriously injure even experienced handlers. While head restraint is important for all species, it is critical when handling these birds;

raptors should have their legs secured as well. We recommend that field personnel be trained in handling techniques for these more aggressive species.

Suspension of any bird through “wing holds” at its humerus is strongly discouraged because of the high incidence of shoulder injuries associated with this form of immobilization.

After capture, birds should be immediately placed in ventilated, solid-sided carriers—such as cardboard boxes or shipping kennels—for transport. Burlap bags and wire cages can contribute to eye injuries and feather damage, respectively, and should not be used. Social, nonaggressive birds may be placed with one or two conspecifics, but aggressive species such as loons and cormorants should be individually housed.

Crated birds should not be placed in direct sunlight or transported in open vehicles (such as pickup trucks). Birds must be evaluated frequently for overheating when the ambient temperature is greater than 70° F and for possible chilling in cooler weather. If the birds demonstrate open-mouthed breathing or other signs of heat stress, additional ventilation holes can be made and the number of birds per carrier can be decreased. Draping a portion of the container with a towel or blanket provides some protection from cold. Captured birds should receive medical evaluation and preliminary treatment within 1 to 2 hours. This can be done by trained personnel in the field or at a treatment center.

Field agents should be instructed to record all bird sightings, whether a capture effort is successful or not, so that an accurate assessment of spill impact can be made. Dead birds are retrieved and placed in plastic bags, which are then labeled with pickup location and date.

Stabilizing the Bird

Immediate treatment reduces the toxic effects of ingested oils and stabilizes the bird before cleaning. The following procedures can be done in the field; otherwise they are part of the entry treatment at a rehabilitation center.

First, oil is removed from the bird’s nares and oral cavity with clean gauze or cotton swabs. Contaminants are flushed from the eyes by irrigation with a warm, sterile, 0.9% (physiologic) saline solution.

Next, a clear electrolyte solution (e.g., Pedialyte, lactated Ringer’s solution) is administered by stomach tube (15–20 cc/kg) to rehydrate the bird while flushing oil from its gut; this is followed by a small volume (2–4 cc/kg) of the enteric protectant Pepto-Bismol. Only birds that can maintain normal head carriage are given oral fluids; extremely depressed animals should receive immediate emergency treatment, including intravenous fluids for rehydration.

On admittance to the rehabilitation center, each bird is identified with a temporary leg band and given a complete physical examination; the bird’s temperature and weight should also be recorded. The bird’s vent is checked for possible impaction by oil or matted feathers. Feather and blood samples can be collected for diagnostic, documentation, or research purposes. Debilitated animals require more extensive medical care.

Birds that have been examined are kept warm and quiet, away from people and other stressors until judged stable enough to withstand the cleaning procedure. Once cleaned, a bird is fed a nutrient-rich tubing solution at 4–6 hour intervals until it can be given free access to food and water.

When large numbers of birds have been contaminated, it may be necessary to first treat the animals that have the best probability of survival or the greatest “value” as a species. Euthanasia may be considered for common birds that exhibit acute signs of disease or that have injuries that would require extended treatment.

Birds brought in dead, or dying at the center should be necropsied to aid in determining treatment protocols for the survivors.

Removing Oil From Feathers

Oil must be removed without damaging feather structure. A safe and effective method uses successive detergent baths in warm (103–104°F) water. Oil will not lift off the feathers in cooler water. In addition to being able to remove the oil, the cleaning agent must not irritate the skin or damage feather structure; it must be easily rinsed without leaving a residue that might interfere with waterproofing.

Extensive research indicates that Dawn dishwashing detergent (Proctor & Gamble) best meets these criteria. Many “miracle cleansers” are promoted during major oil spills; every effort should be made to avoid experimentation with these products.

Effective detergent concentrations vary from 2–15%, depending upon oil characteristics. Large quantities of detergent solution are mandatory. Ten-gallon tubs should be used to wash birds the

Cleaning a Canada goose contaminated by #6 fuel oil.

size of ducks or geese; larger birds require children's wading pools or human bathtubs.

Two handlers should restrain the bird in the tub while the detergent solution is ladled over its body and wings and the feathers gently stroked in the direction of growth. During the washing, the bird's eyes should be frequently flushed with a sterile saline solution to prevent irritation. The bird's head should be secured at all times to prevent injury to workers or its possible immersion in the detergent solution. If raptors are being cleaned, additional immobilization of the feet is necessary. Washing is successively repeated in three or more tubs, depending upon the extent and nature of the oil. Special procedures are required when tarry oils or adhesives are involved.

Removing the Cleaning Agent From Feathers

Rinsing is carried out with a combination of spray rinses and tub baths in 104°F water, until beads of water roll freely from the feathers, and the bird begins to look "dry." Special attention should be given to the undertail coverts, under the wings, and the neck of the bird. Incomplete rinsing prevents adequate waterproofing of the feathers and is a primary cause of bird's failure to rehabilitate. Feathers should be blotted with a clean towel; the bird should then be placed to dry with free access to heat lamps.

With appropriate organization, the entire cleaning effort should take about 60 minutes; a bird that becomes stressed (rapid heart rate, open-mouthed breathing, drooping head) during cleaning should be quickly rinsed and placed in a clean, quiet area. Once stablized, it should be washed again.

Restoring Feather Structure

Newly washed birds are placed in clean holding pens and given access to food and water.

Sterile saline is used to flush the eyes of a great blue heron to remove contaminants.

Cushioning is necessary for diving ducks and other species that are not mobile on land (e.g., loons), and appropriately sized branches should be provided for raptors and other perching birds. The birds are monitored for abnormal droppings, loss of appetite, depression, or signs of disease, and appropriate treatment is given. After 24 hours, the birds should be given access to pools of water in which they can swim and preen. Required pool size depends on the species, but the pool may need to be as large as 10 feet × 10 feet × 30 inches deep. Misting may be used to stimulate preening in those species that normally do not swim. Diving, swimming, and preening enables the bird to realign its feathers and restore feather structure. Natural oils distributed from the uropygial gland enhance feather restoration, but are not required for it. Waterproofed birds will demonstrate diamondlike beading of water on their feathers and will be able to remain in water (the time varies with species) or be misted without getting wet.

For properly washed birds not suffering from complicating factors, the entire cleaning and restoration process can occur in 48–96 hours.

Acclimating and Evaluation for Release

Waterproofed birds are gradually exposed to outside weather conditions. Seabirds are preconditioned by being fed successive tubing solutions of 2.0% saline for 24–48 hours before release to stimulate and evaluate salt gland function.

Candidates for release must be waterproof, active and alert, of average weight for species and sex, have adequate musculature, and exhibit no discernible signs of disease.

Birds should be banded with U.S. Fish and Wildlife Service bands (State and Federal banding permits required) and released early in the day in an appropriate, oil-free habitat.

Management of Major Oil Spill Crises

Rehabilitating a single oiled bird is difficult; an oil spill involving 50, 100, or 1,000 contaminated animals introduces crisis-management concerns, including media relations, volunteer and staff training, human health hazards and liability, interagency communication and coordination, disposal of environmental wastewater, and stress management.

Delineation of Responsibility

Federal field response coordinators should focus on supervision of the overall response, including the private and State agencies and cleanup contractors responsible for retrieval, rehabilitation, and release of wildlife. All costs should be documented and recovered from the spiller or from specially designated Federal accounts.

To ensure a safe, efficient response, no agency or organization should be contracted to rehabilitate oiled birds unless it possesses proper Federal permits, has adequate liability insurance for staff and volunteer workers, and is experienced in wildlife oil spill responses. The organization should be able to obtain independent analysis of the oil and assessment of potential hazards to human workers. All treatment protocols should be clearly presented, and, if necessary, justified for the designated Service field response coordinator.

Worker safety and agency liability are areas of growing concern. Occupational Safety and Health Administration (OSHA) standards concerning hazardous wastes and emergency responses also apply to some aspects of oil spill responses. Application of these rulings is not uniform; we recommend that regional OSHA offices be contacted for current information. Disposal of wastewater from a cleaning center must be in compliance with State and Federal regulations; current techniques include reclaiming oil fractions and treating wastewater or disposing of it in an approved landfill. Disposal contracts should be made with reputable and licensed haulers. County health departments, local hospitals, and area veterinarians can offer assistance for proper disposal of medical wastes. Nonperishable supplies can be stockpiled for use in future spills.

Controlled Access and Public Relations

Access to the rehabilitation center must be strictly controlled. Only trained volunteers and those directly participating in the response should be admitted. All workers should wear name tags identifying their assigned responsibilities.

Members of the general public attempting to visit the center should be thanked for their concern and given a brochure describing the center's procedures and offering them an opportunity to sign up for future training sessions or to donate needed materials (sheeting, towels, pie plates, etc.).

Center policies should be established and posted to aid in effective and accurate media communication. Comments to the media should be restricted to those taken directly from the daily news release, which should be typed every morning and be available to the press.

Interviews and video opportunities should be limited to one or two 15-minute sessions daily, with the times clearly posted at the entrance to the center.

Rehabilitation Center Operations

During the first days of an oil spill response, the center is open almost 24 hours a day, with staff and volunteers working rotating shifts. Certain policies are followed to provide continuity and consistency of operation.

Each area of the facility should be clearly identified and posters describing the treatment protocol for that area should be prominently displayed. An end-of-day report summarizing all pertinent operational and caseload information should be completed each day by the appropriate staff.

At least one person should be on duty during each shift to handle all telephone calls; a second worker should be responsible for weekly scheduling of staff and volunteers. A supplies team should obtain all items necessary for smooth operation of the center.

Even in a small oil spill response, resource needs are tremendous. If the rehabilitation center admitted and treated 30 birds a day, three wash lines would be needed, necessitating 10 bird-cleaning volunteers for each 8-hour shift. As much as 4,500 gallons of clean water would be required, half of which would become oil-contaminated, requiring special disposal. Workers would also be needed for each shift for operations control, medical, and rehabilitation areas, swelling the number of people needed for one 24-hour day to 54.

Conclusion

Bird rehabilitation after a major oil spill is an emergency operation requiring immediate action by prepared, experienced personnel. The key components of an effective response are:

- contingency planning to identify key agencies, people, and material needs;
- rapid response;
- enlisting an experienced response agency to direct wildlife care; and
- adherence to proven protocols.

Suggested Resources

Bayer, R. D. Oiled birds: How to search for and capture oiled birds at Oregon intertidal areas. Gahmken Press, Newport, Oreg. 30 pp.

Burridge, J., and M. Kane, editors. 1985. Rehabilitating oiled seabirds: a field manual. American Petroleum Institute, Publication 4407. Washington, D.C. 79 pp.

Environment Canada. How to rescue oiled birds. (For information on this 20-minute video, contact Environment Canada, 351 St. Joseph Boulevard, Ottawa, K1A OH3.)

Friend, M. 1987. Field guide to wildlife diseases. Vol 1: General field procedures and diseases of migratory birds. U.S. Fish Wildl. Serv., Resour. Publ. 167. 225 pp.

Frink, L. F., and S. Welte. 1990. Oiled bird rehabilitation: a guide for establishing and operating a treatment facility for oiled birds. Unpublished manual. Tri-State Bird Rescue and Research, Inc., Wilmington, Del. 65 pp.

Leighton, F. 1983. The pathophysiology of petroleum oil toxicity in birds: a review. *In* D. G. Rosie and S. N. Barnes, eds. The effects of oil on birds: physiological research, clinical applications and rehabilitation. Proceedings of a 17–19 September 1982 conference at the Wetlands Institute, Stone Harbor, N.J.

Experienced Response Agencies

International Bird Rescue Research Center, 699 Potter Street, Berkeley, Calif. 94710. (415)841-9086.

Tri-State Bird Rescue and Research, Inc., P.O. Box 289, Wilmington, Del. 19899. (302)737-7241.

Environment Canada has trained response agencies in Newfoundland, Nova Scotia, and Quebec. Contact: Gilles Lauzon, Contingency Planning Officer, Environmental Emergencies, Environment Canada, PVM, 15th Floor, 351 St. Joseph Blvd., Ottawa, Canada, K1A OH3.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1991

13.2.10. Decoy Traps for Ducks

James K. Ringelman
Colorado Division of Wildlife
317 Prospect Street
Fort Collins, CO 80526

Waterfowl managers and researchers must often capture ducks to band, mark, or measure. During fall and winter, cannon nets, walk-in bait traps, or swim-in traps with funnel entrances are commonly used to capture ducks. However, all of these use bait, usually grain, to lure birds. During the breeding and post-breeding periods, when the diet of many dabbling duck species is dominated by aquatic invertebrates, birds often respond poorly to bait traps. Many diving ducks do not respond to bait traps at any time of the year. Decoy traps are an effective alternative to bait traps in spring and early summer because they rely on behavioral responses, not food, to attract and capture birds.

Portable decoy traps employ one or more live "decoy" ducks confined at a highly visible, over-water site. Wild ducks are captured when they attempt to approach these decoy birds. This behavioral reaction seems to be based largely on either a territorial response (territorial individuals approach a conspecific with the intent of ejecting it from a territory) or a mate-seeking response (birds approach a prospective mate). However, since species different from that of a decoy bird are also captured, ducks probably also approach while seeking a place to loaf, preen, or feed.

Trap Design and Construction

Although decoy traps have been designed specifically for both dabbling and diving ducks, differences in design are more reflective of an evolution in door and trigger mechanisms than a need to tailor traps to a particular species. For example, spring-loaded doors were originally devised because funnel entrances used in early traps were not effective for capturing canvasbacks (*Aytha valisineria*); later researchers found spring-loaded doors increased capture rates for other species as well. Consequently, managers are advised to construct and deploy traps with the most recent innovations in door and trigger mechanisms. Although these traps are more expensive and complex to assemble, enhanced capture rates and reliability more than offset these disadvantages.

The key design considerations for decoy traps are (1) a central decoy compartment that forces wild birds to enter the trap to get next to the decoy bird, (2) large entrance holes that allow wild birds to view the decoy bird through a single layer of wire mesh, (3) a reliable, yet stable trigger mechanism, and (4) multiple compartments large enough to allow simultaneous capture of pairs.

The most effective decoy trap for both dabbling and diving ducks is constructed from 14-gauge, 1- × 1-in. or 1- × 2-in. mesh, galvanized, welded wire (Figs. 1 and 2). About 29 ft of welded wire, 5 ft wide, is needed for each trap (Fig. 1). Round traps are preferable to square designs because they provide a greater opportunity for multiple catches and are easily transported (rolled) by one person. Hog rings or other wraparound metal fasteners (Valentine Equipment Company, 7510 South Madison St., P.O. Box 53, Hinsdale, Ill. 60521)[1] should be used to tightly join seams and hinge doors and treadles. A pair of

[1] **NOTE:** Use of trade names does not imply U.S. Government endorsement of commercial products.

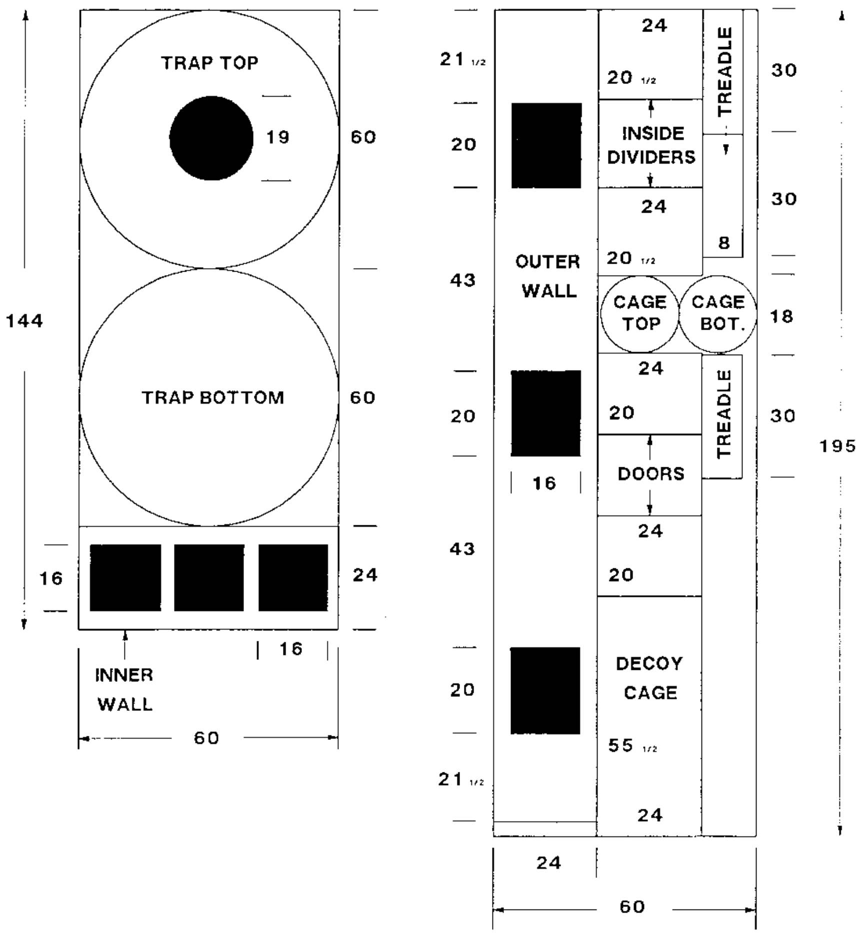


Fig. 1. Layout of decoy trap components cut from 5-ft-wide welded wire with a 1- × 2-in. mesh. *Blackened* areas denote cutouts. All dimensions are in inches.

utility springs, 8 to 12 in. long and covered with flexible tubing to prevent binding with the wire mesh, are used to close each door. Doors operate independently and, when closed, are designed to overlap entrance holes by 2 in. on all sides. Heavy (6-gauge) wire should be used to reinforce door edges. Treadles are hinged to the bottom of the trap parallel to the doors and 18 to 20 in. from the opening. Monofilament fishing line (20-lb test) connects the trigger to the top end of the treadle, which is positioned just below the water surface.

For the welfare of the decoy bird, the decoy compartment should be constructed of the same gauge welded wire with a top that can be tightly secured with wire or latches to guard against predators. The decoy compartment must be equipped with a loafing platform fastened about 6 in. from the bottom of the compartment. Decoy birds should be provided with a covered food tray. Aluminum window screen fastened to the bottom of the compartment will prevent spilled food from sinking out of reach of the decoy bird. The trap diagramed here (Fig. 1) includes a removable decoy cage, which is enclosed within the inner wall of the trap. This feature will aid in replacing the decoy duck without handling birds at the trap site, thus reducing stress on the decoy bird and speeding the process of exchanging decoys.

Trigger mechanisms have been made with either 6-gauge wire, coiled to pivot at about one-third of its length, then bent to form a door release, or with a modified pan and dog from a #1 long-spring, steel leg-hold trap. The former trigger is simple, but difficult to adjust so that it is sensitive enough to release when a bird touches the treadle, yet is insensitive to wind, wave action, and the movements of birds captured in adjoining compartments. The latter design (pictured in Sharp and Lokemoen 1987), although more difficult and expensive to build, is more sensitive and reliable.

Upon completion of the trap, any projecting wire ends should be trimmed back as close as possi-

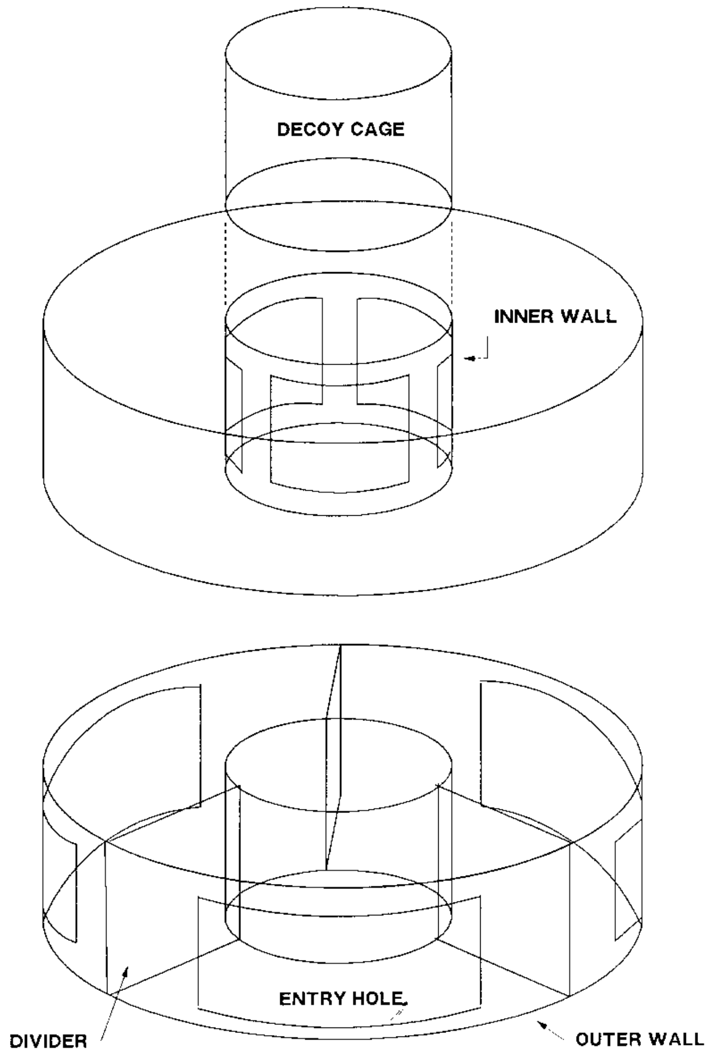


Fig. 2. Assembly view of the portable decoy traps. Doors (not shown) hinge along the top of entry hole.

ble to the trap to minimize cuts to ducks and duck trappers. Depending on trigger mechanisms and local prices, this trap costs from $150 to $200 in materials and takes from 10 to 14 h to assemble.

Selecting Decoy Birds

Capture rates are dependent on breeding stock of the decoy birds as well as the performance of individual decoy ducks. Choosing the appropriate decoy bird is a trade off between selecting birds that will adapt to the decoy compartment and maintain adequate body weight (game-farm stock), and using birds that perform appropriate behavioral displays necessary to attract wild birds (wild-captured ducks). The best compromise to these criteria, and thus the birds most desirable as decoy ducks, are either wild stock ducks raised from eggs hatched in captivity or first generation offspring of wild-stock birds. A single female of the species targeted for capture should be selected as the decoy bird. Such females outperform males and generally have capture rates similar to pairs. Several decoy birds should be maintained at an upland pen site and rotated into traps every 2 or 3 days, or more frequently if the birds are exposed to severe weather or other stresses. Decoy ducks should be provided food on a daily basis. Humane treatment of all birds must be an important concern of managers using decoy traps.

Trap Deployment

Decoy traps are usually deployed in water 1 to 4 ft deep, and held in place by 3 or more metal conduit pipes driven into the substrate, then fastened to the trap with hose clamps. For deeper water sites, floats with anchors can be used in place of conduit. Traps should be set in wetlands frequented by the target species, and set so that the bottom of the entrance holes are 2 in. below the water surface, thereby allowing ducks to swim into the trap. The loafing platform for the decoy bird should be high enough above the water to remain dry even with wind-driven waves. Decoy traps are most successful if placed out in open water where they are visible to large numbers of ducks. Check traps a minimum of three times per day, usually in early morning, at midday, and at dusk.

Decoy traps are most effective during the pre- and early-nesting periods when pair bonds are strong. As incubation proceeds and males congregate in groups, the effectiveness of these traps usually declines. Even so, decoy traps have been used successfully to capture fully feathered ducklings and postbreeding, flightless ducks in late summer. Although portable decoy traps have not been used during fall and winter, it is doubtful that they would be effective during these seasons.

Capture Rates and Age-Sex Composition

Compared with bait traps used during fall and winter, capture rates of decoy traps are low. However, decoy traps will often capture birds when other techniques will not, and operation of decoy traps is not as labor intensive as techniques such as cannon nets. In the high-density duck breeding habitats of the north-central United States and south-central Canada, capture rates for adult mallards (*Anas platyrynchos*) average 0.32 males per trap-day and 0.09 females per trap-day. During the postbreeding period, immature mallards have been captured at a rate of 0.06 immatures per trap-day, while adult capture rates approximated those of adult females during breeding. Capture rates for lesser scaup (*Aythya affinis*), canvasbacks, and redheads (*A. americana*) average 0.56, 0.84, and 1.10 ducks per trap-day, respectively.

Among mallards, males typically make up the bulk of the catch. However, in Manitoba, redhead females were captured 1.8 times more often than males in relation to their abundance. Early morning and late evening are usually the most productive periods for trapping. The age ratio of breeding, female canvasbacks captured in decoy traps has been shown not to differ from that of the breeding population, suggesting that at least for this species, decoy traps are not age-biased. An added benefit of decoy traps is that once placed in the breeding territory of a pair, they may recapture the same individuals several times.

Suggested Reading

Anderson, M. G., R. D. Sayler, and A. D. Afton. 1980. A decoy trap for diving ducks. J. Wildl. Manage. 44:217–219.

Blohm, R. J., and P. Ward. 1979. Experience with a decoy trap for male gadwalls. Bird-Banding 50:45–48.

Blums, P. N., V. K. Reders, A. A. Mednis, and J. A. Baumanis. 1983. Automatic drop-door traps for ducks. J. Wildl. Manage. 47:199–203.

Rogers, J. P. 1964. A decoy trap for male lesser scaups. J. Wildl. Manage. 28:408–410.

Sharp, D. E., and J. T. Lokemoen. 1987. A decoy trap for breeding-season mallards in North Dakota. J. Wildl. Manage. 51:711–715.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.2.11. Increasing Waterfowl Nesting Success on Islands and Peninsulas

John T. Lokemoen
U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
Rural Route 1, Box 96C
Jamestown, North Dakota 58401-9736

Waterfowl that nest in uplands in the prairie pothole region have had low recruitment rates in recent decades, primarily because of predation. The loss of breeding waterfowl and their progeny has generated interest in management techniques that safeguard incubating hens and their eggs. Developing islands and peninsulas for nesting waterfowl has potential because these sites are naturally attractive to breeding ducks and geese. In fact, dense nesting colonies of ducks developed on some islands when successful females and a portion of their female progeny returned in subsequent years.

Managers have successfully duplicated the beneficial attributes of islands by developing various nesting habitats that are protected by water barriers. This chapter addresses the management of existing islands, the creation of new islands, and the modification of peninsulas into islands to increase nesting success in waterfowl.

Locating Manageable Islands and Peninsulas

Hundreds of natural islands and peninsulas occur in the prairies and plains of the United States and Canada. Management of islands and peninsulas is most successful here, where waterfowl populations are high and terrestrial mammals are the primary nest predators.

Many existing islands and peninsulas can be located with aerial photographs or with maps of the National Wetlands Inventory. The location of each potentially manageable island and peninsula and pertinent management information should be recorded in a permanent ledger. At each site, factors such as ownership, number of wetlands within 1 mile (1.6 km), type and area of existing nesting cover, and the classification of the present wetland should be recorded (Table).

Management of Islands

A variety of waterfowl, most notably gadwalls, mallards, lesser scaups, and Canada geese, nest on islands (Table). In addition, islands are favored as breeding habitats by some shorebird species, such as American avocets and piping plovers, and by colonial nesters, namely American white pelicans, common terns, and several species of gulls.

Site Selection Factors

The safest nesting islands are usually far from shore in large saline lakes or in open freshwater wetlands. Islands should be at least 425 feet (130 m) from shore and 300 feet (91 m) apart. This distance and separation impede travel of predators

Table. Percent species composition of waterfowl that nested on islands and peninsulas in North and South Dakota and of breeding waterfowl in the prairie pothole region, 1985–1989.

Species	Dakota breeding population	Peninsula nesting population	Island nesting population
American wigeon	6	tr	tr
Blue-winged teal	28	18	6
Canada goose	tr	tr	5
Gadwall	10	42	42
Green-winged teal	2	tr	tr
Lesser scaup	3	9	7
Mallard	17	15	32
Northern pintail	8	9	4
Northern shoveler	11	6	1
Redhead	6	tr	2
Ruddy duck	6	0	tr

between islands and reduce territorial strife between nesting pairs of Canada geese. Although wide expanses of open water deter moves of mammalian predators, large lakes may harbor gulls, which can kill small ducklings.

Saline, subsaline, or brackish wetlands provide the most suitable sites for islands with nesting habitat for ducks. For most aquatic and mammalian predators of waterfowl, saline lakes are a poor source of food and lack adequate cover. A description of saline wetlands can be found in Stewart and Kantrud (1971).

More duck nests are on islands in a wetland complex than on other islands. The most suitable island sites have 40 or more wetlands within 1 mile. Wetland complexes are best if they include seasonally flooded ponds for breeding pair habitat and semipermanently flooded ponds for broods. Nearby wetlands are particularly important to breeding birds that use islands in very saline lakes or in deep freshwater lakes, which may provide little food and cover to waterfowl.

The presence of adequate nesting cover is important. Most breeding ducks on islands nest in low shrubs (≤4 feet [about 1 m]) or in tall grasses and forbs. Densities of nesting ducks are lower on islands with tall shrubs (>4 feet [> 1 m]) and trees, such as fireberry hawthorn and American plum. Tall shrubs reduce the amount of low nesting cover that ducks seek and provide perching and nesting sites for avian predators.

Construction of Islands

Construct islands with a packed soil base for stability and a covering of ≥4 inches (10 cm) of topsoil to support vegetation for nesting cover. Put the top of the island 3 or 4 feet (about 1 m) above the average wetland level. Create a natural appearance to the island by rounding corners. Orient the long axis of the island with the direction of the prevailing storm winds to reduce erosion. Obtain details for the construction of islands from Ducks Unlimited or from Ecological Services offices of the U.S. Fish and Wildlife Service.

Spacing and size of natural islands have not been reliable biological predictors of their use by ducks, possibly because island location and the quality of nesting cover are more important factors. However, the spacing and size of islands are important economic considerations in construction because of the high costs of equipment and labor. Management is cost effective of natural islands that are larger than 0.1 acre (>0.04 ha) or of many islands at a single location. However, no more than 1 acre (0.4 ha) of islands should be built for each square mile (2.6 square km) of suitable habitat. Construction of less than 0.25 acre (<0.1 ha) islands is not advised. Small islands probably attract fewer nesting hens, their construction requires proportionately more earth than a 1-acre (0.4 ha) island, yet their annual management costs are similar. Conversely, larger than 1 acre (0.4 ha) islands are not particularly cost-effective in increasing the number of waterfowl nests.

Waterfowl in central North Dakota have successfully used small rock islands (averaging 0.006 acre [0.002 ha]). These islands are built mainly of rocks that were obtained from cultivated fields, piled in the wetland basin, and covered with soil from the wetland bottom. These islands are constructed in open water or in emergent vegetation in small prairie wetlands. Rock islands usually do not have to be seeded other than having a handful of grass–legume seeds raked into the soil.

Management of Peninsulas

The mallard, gadwall, and blue-winged teal are the predominant nesting species on peninsulas in the prairie pothole region (Table). The northern pintail and lesser scaup are secondary in importance as nesting species on peninsulas; nesting of Canada geese, colonial waterbirds, and shorebirds is negligible.

Site Selection Factors

Like islands, peninsulas for intensive management of waterfowl production should be in saline or open freshwater lakes. Such wetlands are usually free of emergent vegetation and therefore provide good loafing sites for breeding pairs of ducks but little food and cover for aquatic mammalian predators. Peninsulas should be managed in ≥2 feet (0.6 m) deep wetlands because the water barrier is present during most years and fences and moats do not have to extend far to reach >1 foot (0.3 m) deep water. Lakes for the management of peninsulas should be within 1 mile (1.6 km) of suitable wetland habitat for pairs and broods. Duck species that usually nest on peninsulas prefer moderate to tall cover, including low shrubs (<4 feet [1 m]) and grass–forb mixtures. Remove tall shrubs and trees from managed peninsulas and control all subsequent regrowth.

Because managed peninsulas attract breeding pairs from a large surrounding area, the effectiveness of management increases when sites are 1 mile (1.6 km) or farther apart. Management of peninsulas that are smaller than 2 acres (0.8 ha) is probably not cost-effective. The number of expected ducklings on these small peninsulas is too modest to justify the cost of management.

Construction of Fences

The most common barriers to predators at peninsulas are electric fences. Electric fences should extend across the base of the peninsula and into the water on each side (Fig. 1). Normally, fences have to project only 50 feet (15 m) into open water but must extend into at least 1 foot (0.3 m) deep water.

Most fences have a permanent portion on upland and an attached but removable segment in wetlands. The portion on upland is a wire barrier of 2 pieces of 1-inch (2.5 cm) mesh, 18-gauge (1.2 mm diameter of wire) poultry netting. The netting extends from 1 foot (0.3 m)

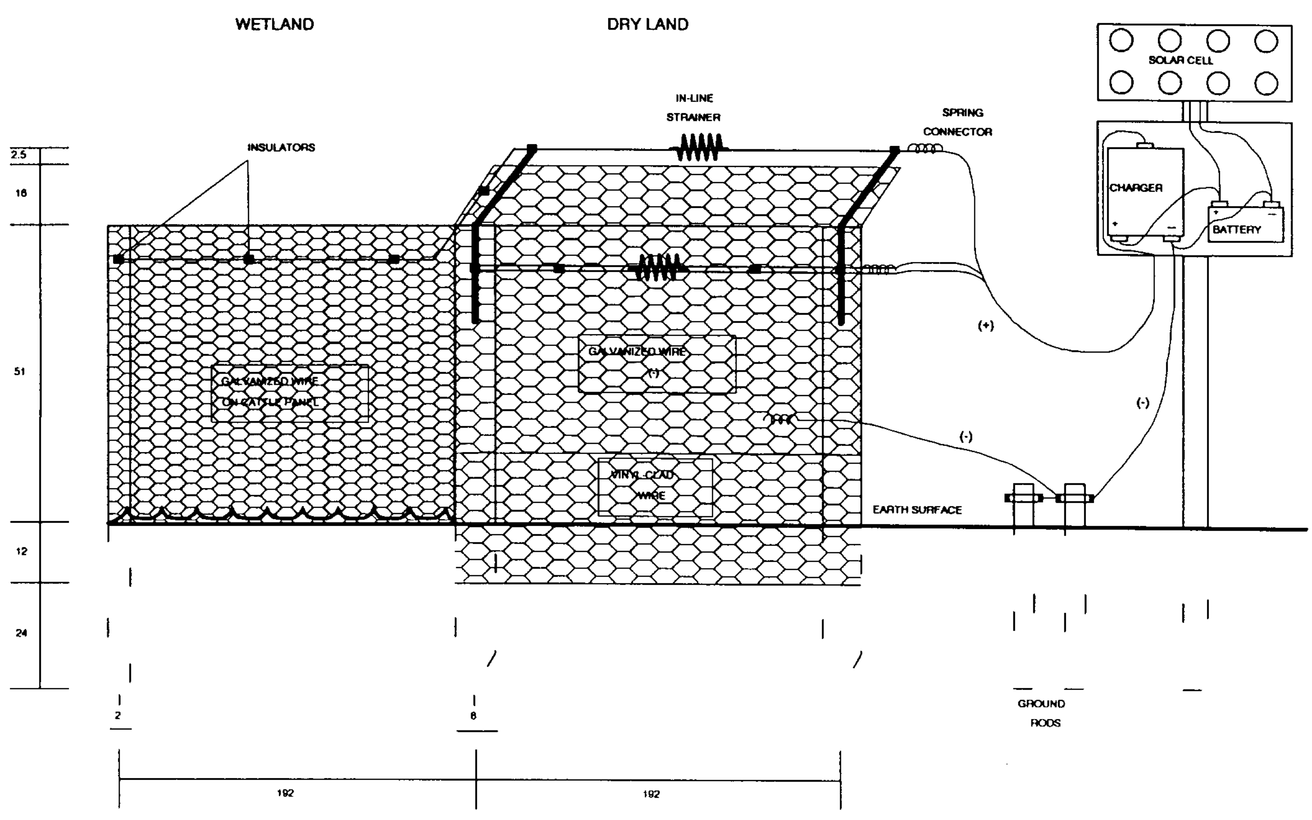


Fig. 1. A dry land section and an adjoining wetland section of an electrified barrier fence to bar access of predators to peninsulas. All measurements are in inches.

below ground to 5.5 feet (1.7 m) above ground. Use galvanized wire (which also serves as a ground) for the energized wires on the upper part of the fence. Vinyl-clad netting for the lower 2–3 feet (0.6–0.9 m) of the fence, including the 1 foot (0.3 m) below ground, retards rusting. The two wire meshes are woven together with stainless steel wire or fastened together with hog rings. In some situations a zinc-coated knotted fence or "horse fence" is used for the wire barrier. The knotted fence is more flexible for use on uneven ground and more resistant to fire. Where fire is a serious problem, a 3 foot (about 1 m) area on either side of the fence should be cleared of vegetation to prevent flames from scorching the wires.

Two 12.5-gauge (wire diameter = 2.7 mm) energized wires are attached to the side of the wire barrier facing the base of the peninsula. These wires are 4 feet (1.2 m) above ground and 2.5 inches (6.3 cm) and 5.0 inches (12.7 cm) from the poultry netting. The wires are held in place by fiberglass rods that are driven into the wooden posts and by insulators that are attached to the poultry netting. Place another energized wire 5 inches (12.7 cm) above the top of the poultry netting. To deter predators from jumping over the fence, the top 1 foot (0.3 m) should lean toward the base of the peninsula at a 45° angle. Areas without coyotes may not need the 45° overhang. Electrify wires with small high-voltage units such as the E-12 energizer made by Gallagher Power Fence, Inc., San Antonio, Texas. Power the energizer with a solar-charged battery. The poultry netting and the electric wires must be stretched tightly.

To reduce damage to the fences from water and ice, commercially available "cattle panels" (16 feet long by 4.25 feet high [about 5.0 m by 1.3 m]) of heavy steel rod can be used for the removable segment of the fence. Cover each panel with 1-inch (2.5 cm) poultry netting, and place an energized wire 5 inches (12.7 cm) above the top of the panel. The energized wire can be attached to the top of the panels by welding 1 rod to each panel, placing an insulator on the rod, and connecting the wire to the insulator. The panels can be held together by hog-rings or wire, and they can be held upright with fence posts that are driven into the wetland bottom. Extend the panels into the wetland each spring after the ice melts and remove them each fall prior to freezing. Check fences at regular intervals to repair electrical malfunctions and structural damage.

Construction of Moats

Open water moats can also be used to bar access of predators to peninsulas. Moats should have a 3:1 side slope, a ≥200 foot (61 m) width, and a ≥3 foot (≥1 m) water depth at the average wetland level. Because their construction is expensive, moats are most suitably employed at peninsulas with narrow necks because less soil needs to be moved during construction. Soil removed from the excavation is usually used to increase the size of the protected nesting habitat.

Management of Nesting Cover

On islands and peninsulas with poor nesting habitat, establish plant cover that ducks prefer for nesting. Canada geese have no specific requirements for nesting cover but prefer open sites. For nesting cover for ducks on newly constructed sites, immediately establish vegetation, which also prevents soil erosion. Grass-legume cover can be established by seeding with small grain drills after construction is completed in winter. Preferred plant species for nesting cover include intermediate wheatgrass, tall wheatgrass, and smooth brome mixed with alfalfa and small amounts of sweetclover. Grass and legume seed is available at many grain elevators and in seed houses in western states and provinces. Information on seeding rates and seeding techniques can be found in Duebbert et al. (1981).

The vigor and attractiveness of grass–legume plantings decline over time. Plant vigor can be restored by moderate cultivation. Alternatively, existing vegetation can be eliminated by spraying or plowing, and the area can be reseeded. Burning vegetation on islands is usually not recommended because fire eliminates all suitable nesting cover such as tall weeds, grasses, or low shrubs. Burning is advised only for complete restoration of cover.

Another option of establishing low–shrub nesting cover on a portion of the island is the planting of western snowberry or Wood's rose. The planting and weeding of seedling shrubs require hand labor for the first growing season. However, once established, low shrubs provide excellent nesting cover for many years. Plant low shrubs at a 2.5-foot (0.8 m) spacing during April or May after the last hard frost. Put grass–legume seedings and low shrub plantings into soil where existing plants have been controlled by tillage or chemicals. Shrub seedlings of the described species are usually available at nurseries in most western states and provinces.

Nesting cover that has been reduced by grazing can be restored by excluding livestock with fences. Islands and peninsulas are often grazed in the fall when cattle gain access by crossing wetlands that dried out or became shallow during the summer. Exclusion of cattle may require additional fencing or an agreement with the neighboring landowner to restrain livestock. To prevent cattle damage to fences in the fall, add a low electric wire and keep the fence energized until the cattle are removed.

Management of Predators

It is crucial that skilled trappers maintain islands and peninsulas free of predators. Mammalian predators must be removed annually with quick-kill body traps set in boxes or, if necessary, leg-hold traps. Trap from the time the fences are energized or lakes become ice-free until mid-July when nesting is completed. Set traps only on the managed portion of the peninsulas and islands and not on the adjacent mainland or shoreline. Disperse traps throughout the upland habitats to capture foxes, badgers, skunks, and ground squirrels and along the shorelines to capture minks and raccoons. Most predators are trapped along the fence or moat, along the shoreline, or at natural coverts such as rock piles, dens, or tall emergent plants. During the development of a new site, the placement of 6–12 inch (about 15–30 cm) culverts along the shoreline may be useful for trapping predators. Cover the culvert with soil, but leave the ends open to provide natural pathways for minks, raccoons, and striped skunks. Small islands (<3 acres [<1.2 ha]) are often free of predators, and annual trapping may not be necessary.

In the western United States and Canada, ring-billed and California gulls nest on islands and occasionally feed on ducklings and duck eggs. Breeding gulls can be deterred from nesting on islands by establishing tall cover on potential breeding sites or by adding artificial material to bare areas.

Barrier and Island Management Costs

The average capital cost of constructing barriers in North Dakota in the 1980's was about $7,600 (mean length = 1,090 feet [332 m]) for fences and $207,000 (mean length = 2,070 feet [631 m]) for moats. The estimated cost of each fledged duck was about $12 from fenced sites and $62 from sites with moats. On existing islands where predator removal was applied, the estimated cost per fledged duckling was about $2. The cost of ducks fledged on constructed islands is the highest because of the high cost of heavy construction ($15,000–$20,000 for a 1-acre [0.4 ha] island).

A feasible strategy for identifying suitable islands and peninsulas for cost-effective management starts with the survey of the management district. First, record the location of all islands that exceed 0.1 acre (0.04 ha) and all peninsulas that exceed 2 acres (0.8 ha). Secondly, visit each site and rate its suitability for waterfowl management based on the lake, its distance from shore, and the number of wetlands within 1 mile. Rate the nesting cover and give preference to islands with low shrubs or tall grass–legume mixtures. On islands with suitable conditions for nesting waterfowl with a history of poor nesting success, only control of predators is needed. Other islands may require management of nesting cover, the addition of low shrubs or a grass-legume mixture, or the removal of tall shrubs and trees. The third most cost-effective option is the construction of electric fences at peninsulas to create island-like nesting habitat. As a final option, islands can be constructed or peninsulas modified at sites with an optimal chance for high use by breeding waterfowl and high nesting success.

Monitoring and Evaluation

Keep a permanent record about information on predators and bird nesting on islands and peninsulas (Fig. 2). Periodically conduct a survey to evaluate nesting and nesting success by waterfowl on islands and peninsulas. Techniques for searching for nests and evaluating nesting success can be found in Klett et al. (1986).

ISLAND [ ] OR PENINSULA [ ] SURVEY

Physical Information

Name________________ No.________ Size (Ac)________ Wetland Size (Ac) ________

Site Tn ________ N, Rg _____ W, Sec ________, Qtr ________________ Town________________

Wetland (Stewart & Kantrud 1971) Class ________ Sub-Class ________________ Cover Type ________________

Dist. to Near Shore (Ft)________________ Ownership (FWS,BLM,BOR,STA,PRI) ________________

Shoreline Vegetation(%) Bare__________ Grass __________ Emergent __________ Forb __________

Low Shrub (<3')__________ Tall Shrub (> 3') __________ Tree __________

Upland Vegetation (%) Bare __________ Grass __________ Emergent __________ Forb __________

Low Shrub (<3')__________ Tall Shrub (> 3') __________ Tree __________

No. Wetlands within 1 Mile ________________ Wetland Acres within 1 Mile ________________

Predator Information

Yr	Mo	Day	Species	No. Seen	No. Scats	No. Tracks

Nesting Bird Information

Yr	Mo	Day	Species	No. of Nests	% Suc.

Fig. 2. Suggested form for recording data on islands and peninsulas with nesting habitat for waterfowl.

Suggested Reading

Duebbert, H. F., E. T. Jacobson, K. F. Higgins, and E. B. Podoll. 1981. Establishment of seeded grasslands for wildlife habitat in the prairie pothole region. U.S. Fish and Wildlife Service Special Scientific Report—Wildlife 234. 21 pp.

Greenwood, R. J., P. M. Arnold, and B. G. McGuire. 1990. Protecting duck nests from mammalian predators with fences, traps, and a toxicant. Wildlife Society Bulletin 18:75–82.

Johnson, D. H., and T. L. Shaffer. 1990. Estimating nest success: when Mayfield wins. Auk 107:595–600.

Klett, A. T., H. F. Duebbert, C. A. Faanes, and K. F. Higgins. 1986. Techniques for studying nest success of ducks in upland habitats in the prairie pothole region. U.S. Fish and Wildlife Service Resource Publication 158. 24 pp.

Lokemoen, J. T. 1984. Examining economic efficiency of management practices that enhance waterfowl production. Transactions of the North American Wildlife and Natural Resources Conference 49:584–607.

Lokemoen, J. T., H. F. Duebbert, and D. E. Sharp. 1984. Nest spacing, habitat selection, and behavior of waterfowl on Miller Lake Island, North Dakota. Journal of Wildlife Management 48:309–321.

Stewart, R. E., and H. A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. U.S. Fish and Wildlife Service Resource Publication 92. 57 pp.

Appendix. Common and Scientific Names of the Plants and Animals Named in the Text.

Common name	Scientific name
Plants	
Tall wheatgrass	*Agropyron elongatum*
Intermediate wheatgrass	*Agropyron intermedium*
Smooth brome	*Bromus inermis*
Fireberry hawthorn	*Crataegus chrysocarpa*
Alfalfa	*Medicago sativa*
Sweetclovers	*Melilotus* spp.
American plum	*Prunus americana*
Wood's rose	*Rosa woodsii*
Western snowberry	*Symphoricarpos occidentalis*
Animals	
Northern pintail	*Anas acuta*
American wigeon	*Anas americana*
Northern shoveler	*Anas clypeata*
Green-winged teal	*Anas crecca*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*
Lesser scaup	*Aythya affinis*
Redhead	*Aythya americana*
Canada goose	*Branta canadensis*
Coyote	*Canis latrans*
Piping plover	*Charadrius melodus*
California gull	*Larus californicus*
Ring-billed gull	*Larus delawarensis*
Striped skunk	*Mephitis mephitis*
Mink	*Mustela vison*
Ruddy duck	*Oxyura jamaicensis*
American white pelican	*Pelecanus erythrorhynchus*
Raccoon	*Procyon lotor*
American avocet	*Recurvirostra americana*
Ground squirrels	*Spermophilus* spp.
Common tern	*Sterna hirunda*
Badger	*Taxidea taxus*
Gray fox	*Urocyon cinereoargenteus*
Red fox	*Vulpes vulpes*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

13.2.12. Artificial Nest Structures for Canada Geese

I. J. Ball
Montana Cooperative Wildlife Research Unit
University of Montana
Missoula, MT 59812

Under natural conditions, Canada geese are protected from predatory mammals by selecting nest sites on islands, muskrat lodges, cliffs, or snags, or nests made by ospreys or other motors. The limited availability of safe natural sites seems to hold many goose populations below limits set by other habitat factors. The use of artificial structures to provide safe nest sites for Canada geese in North America began more than 50 years ago; structures are now among the most widely used, and most successful, of goose management practices.

Structures are considered any artificial device, with the exception of earthen or rock islands, intended to provide a safe nest site for Canada geese. In some situations artificial islands are preferable to structures, but artificial islands are beyond the scope of this chapter.

Deciding Whether to Use Structures

The purpose of structures is to increase nest success, usually by reducing nest predation or flooding. Structures are quite effective, often supporting nest success rates of 85–90% versus 65–75% on most natural islands or marshes. An increase in the number of pairs that uses structures is not usually accompanied by a proportional or long-term decrease in the number of pairs using adjacent natural sites. Hence, structures tend to increase a population's base as well as its average productivity. However, a population will not increase if the additional goslings do not fledge (population limited by brood habitat) or if adult mortality is excessive. Structures can do nothing to improve the former situation, and pioneering use of structures is likely to be very slow if adult mortality is excessive.

Numerous important considerations about structures are not fundamentally biological in nature: aesthetic issues, agency policies, costs, durability, maintenance demands of nest materials, and potential for crop depredation or other nuisance problems that sometimes accompany an increasing goose population. Primary advantages of nest structures for geese are that occupancy and nest success usually are very high, capital costs are relatively low, structures are adaptable and popular for use on private lands, and results usually are rapid and tangible. The need for continuing maintenance is probably the most commonly overlooked disadvantage. In addition, poorly designed or maintained structures can cause accidental goose mortality, and some people object to structures because of their obtrusiveness or artificiality. Nest structure programs for geese probably fail more because of inadequate maintenance than for all other reasons combined. Consequently, a program should not be initiated unless the necessary maintenance can be continued for at least 10 years.

Durability of Structures

Shifting ice is a powerful force and the most important threat to structure durability in most areas. Ice damage is rare on properly installed structures in ponds less than about 50 yards in diameter. However, potential problems increase as the water area increases, and placement of nest structures then becomes exceedingly important. Relative security from ice damage increases as water depth decreases; the distance from shore decreases; the amount of emergent vegetation increases; and the lee protection afforded by points, coves, bays, and islands increases.

Structures installed in relatively deep water are particularly vulnerable to ice damage: ice movement tends to be associated with deeper water, and increasing water depth also multiplies the mechanical advantage or leverage of the ice. Potential structure sites where the water depth (including unconsolidated sediments) exceeds 3 feet should be avoided unless the site is well sheltered or special precautions are taken to prevent ice damage. Ice can damage structures either by bending the structure support pipe or by tipping it (i.e., pushing the upper portion of the pipe laterally through the bottom substrate so that the pipe leans but is not bent). Selecting shallow and sheltered sites helps prevent either problem. In addition, bending can be prevented by increasing the rigidity of the support pipe. This may involve using pipe with thicker walls, adding a "sleeve" of larger pipe that extends from a foot below the bottom substrate to near the water surface, or by filling the pipe with concrete. Tipping, on the other hand, is prevented by seeking a firmer bottom substrate, increasing seating depth of the pipe into the bottom substrate, or by welding fins onto the pipe to increase its resistance to being tipped. Support pipes must be seated at least 3 feet into firm bottom substrate. Support pipes 8–10 feet in length are adequate for most overwater sites (3–4 feet seating depth, 1½–3 feet water depth, and 3 feet structure height). Substantially longer pipes will be necessary where deeper water or soft bottom substrate occurs.

Along rivers or streams, flood damage may replace ice as the major concern. Placement of structures over water is not recommended in riverine systems except in the most sheltered locations. Shoreline sites on inside bends, oxbows, and the downstream ends of islands tend to be relatively secure, but even these may be vulnerable during floods. Placing structures on or adjacent to islands is not recommended unless persistent problems from predation or flooding are known to occur.

Nest Materials

Under natural conditions, geese often nest and incubate successfully on substrates such as gravel, cobble, ledges, and stick nests, without the fine-textured nest material and cover required by ducks. Geese have nested successfully in structures with no nest material at all, and one was observed nesting successfully in a bald eagle nest-atop the deteriorating carcass of the previous resident! Geese obviously are quite flexible with respect to nest material, but managers still should think carefully about nest material choices. Some materials will last several years without maintenance, while others will deteriorate substantially in a few months or may even be blown away in the first windstorm.

Loose vegetation is the most common material used in structures. Flax straw is preferred because it resists deterioration well and the stems bind together so the risk of removal by wind is decreased. Coarse grass hay or grain straw are acceptable substitutes, although annual replenishment usually will be necessary. Alfalfa hay should not be used because it deteriorates rapidly. Loose vegetation must be protected from wind loss in most types of structures. A simple and effective method to protect material from wind is to construct a sturdy "tic-tac-toe" frame from steel rods 1/4 to 3/8 inches in diameter or from 1-inch-diameter willow sticks that are notched and wired securely at the junctions. The center square of this frame should be 18 inches or more across, and the length of the arms must allow the frame to settle within the structure as the nest material deteriorates. Nest material also may be wired down or secured by a 3- to 6-inch-wide sod "collar" laid over the outside edges of the vegetation.

Bales of straw or grass hay can be used as nest material on certain types of structures, and these often last 3 or more years without maintenance. Again, flax is preferred, with coarse grass hay or grain straw acceptable substitutes. The bales are wired tightly together with the cut ends at the top and bottom, then are wired securely to the structure platform. Tightly packed bales are best, but a 2-inch depression, 8–10 inches in diameter, should be cut near the center to reduce the chances of down being blown away during incubation recesses.

Nest material of bark or wood chips will last several years in many types of structures, provided the chips are large enough to resist the wind. Suppliers of landscape materials can provide large decorative bark chips (roughly 1 × 3 × 5 inches). These chips are reasonably wind resistant and are highly acceptable to geese. A mixture of large and small chips (or even flax straw) works well because geese arrange the coarsest chips around the outside edge of the structure, which tends to keep the lighter material from blowing out. Chipped or mulched cedar is highly resistant to deterioration and insect nest parasites but must be mixed with larger, heavier chips to reduce wind losses. Sawdust should not be used because it traps moisture and also is vulnerable to wind. Many other nest materials have been used in structures, and some seem to offer major advantages. Sod, both in large pieces and in strips, is quite durable. A product called expanded shale offers essentially unlimited durability and can be mixed with chips or flax straw; pea gravel probably would work as well but weighs about twice as much.

In summary, careful selection of nest materials can offer major advantages in reduced structure maintenance. In situations where routine annual maintenance is not a problem, then properly installed loose grain straw or grass hay is adequate. Otherwise, more durable materials should be considered.

Avoiding Safety Problems

In many ways, structures are inherently safer than natural nest sites, but safety problems are likely to arise unless care is taken. The most common safety problem in nest structures is for goslings to be trapped in the structure after nest material settles, deteriorates, or blows out. Goslings often cannot negotiate a vertical rise of more than 4 inches. Rigorous maintenance of nest material will prevent this problem, but maintenance often does not occur in spite of the best intentions. Consequently, any nest structure should provide a fail-safe method for gosling exodus regardless of the nest material status. Some practical solutions to this problem include wood shavings fiberglassed to the inside walls of conical fiberglass baskets, escape ports (3 inches in diameter), ramps (6 inches wide and ≤45°) made from wood or 1/2-inch-mesh galvanized wire, and slatted sidewalls with 2-inch vertical gaps.

Other relatively common entrapment problems (and their solutions) include:

- Goslings become entangled in wire mesh (all wire mesh used in structures should be smaller than 1/2 inch or bigger than 2 inches);
- Goslings are trapped between a deteriorating large bale and the wire mesh used to wrap it (if you wrap bales, use mesh bigger than 2 inches); and
- Adults are entangled in cord used to secure nest material (use soft, single-strand wire or other methods to retain nest materials).

Evidence of entrapment mortality disappears rapidly because of scavengers or decomposition, so the appropriate preventive measures must be taken before a problem is recognized.

With the advantage of an elevated nest site, geese are quite effective at protecting their nests from predation. Occasionally, an unusually aggressive raccoon will prove to be the exception. Suspending a 30- × 4-inch PVC pipe around the support pole immediately below the structure, or trapping and removing the offending individual are two effective solutions. On rare occasions, common ravens have learned to raid structures when the geese take incubation breaks. The removal of offending individuals (within legal constraints) is the only known solution.

Placement of Structures

Geese are highly traditional, and populations seem to expand from established areas outward. Usually, the largest water areas in a particular area will be pioneered first. As a general guideline, structures should be placed in or near areas used by geese during the breeding season, but where secure nest sites are either lacking or saturated.

Territorial strife among breeding pairs tends to increase when structures are spaced less than about 100 yards apart, particularly when the two structures are within sight of each other. Providing loafing sites near each structure, reducing line-of-sight visibility by careful placement relative to obstructions, and reducing structure height may help to minimize such conflicts. However, the 100-yard spacing rule remains a good guideline for maximizing occupancy and minimizing nest abandonment caused by social strife.

Structures placed 10–15 yards offshore are readily accepted by geese in most areas. These offshore structures provide adequate safety where water depth of 18 inches or more forces potential predators to swim to the site and the structure support provides some resistance to climbing. On certain easily climbed structures such as large bales, greater distance from shore (50 yards or more) and visual isolation provided by emergent vegetation may reduce predation risks. In areas where geese accept structures installed on shore, ice damage is eliminated (although problems with predation or human disturbance may increase). In situations where geese have been slow to accept shoreline structures, some managers have had good results by installing a structure at the site of a previously unsuccessful ground nest or by installing structures 10–15 yards offshore and then moving them progressively closer to shore over 2–3 years of use.

Little objective information exists on preference of geese for structures of different heights, but the following suggestions are offered as practical guidelines. Overwater sites should be high enough to avoid flooding during the highest water levels, with a target of about 3 feet in height during the nesting period. This height seems to deter most swimming predators, reduces visual contact between pairs, and is aesthetically acceptable. For structures installed on land, a height of 7–8 feet is recommended to discourage most leaping predators and to prevent livestock from removing nest material. Additional height over this minimum seems to reduce the effects of human disturbance but also makes installation and maintenance increasingly difficult and dangerous. For tree-mounted structures, heights of 10–20 feet may best reduce the chances that predators will detect the nest and will help decrease obtrusiveness by placing the structure above the lowest branches.

Costs

The initial cost of artificial nest structures varies substantially depending on design and materials. Including labor, the cost ranges from a low of $20 to a high of perhaps $200. To make realistic estimates of cost per gosling produced, managers must consider initial cost (materials and labor), annual maintenance cost, occupancy rates, nest success, and average structure life. Often, managers tend to focus primarily on the material cost of structures with little consideration of installation and maintenance costs. For structures requiring annual maintenance visits, the maintenance cost easily can exceed initial cost over the life of the structure. Average structure life, an extremely important but often overlooked cost variable, ranges from about 2 years for large bales, 10–15 years for most other structures, to perhaps more than 35 years for the most durable designs. Reducing initial cost by using surplus or salvage materials is a common temptation. This may be wise in some instances, but it can represent a serious error if the area begins to resemble a junkyard.

Aesthetics

Placement and structure color are key aesthetic issues-structures that are not easily seen are least likely to offend. In addition, complaints about aesthetics can be avoided by minimizing the following structure characteristics: height, size, reflectivity or glossiness, complexity of lines, and angularity of lines. Nest structures that are in disrepair (leaning, no nest material, etc.), and those that are recognizable as an everyday item (tires and washtubs, for example), seem to generate the most complaints. Aesthetic issues are important to many people, and the pressure to maintain visually pleasing environments will increase. With recognition and care, the most reasonable aesthetic concerns can be met.

Monitoring

The most important variables in a structure monitoring program are occupancy (percent of structures occupied) and nest success (percent of known-fate nests in which at least one egg hatches). Clutch size and egg viability usually are of lesser interest because they are well documented in the literature. A basic monitoring program documenting occupancy and nest success provides most of the data necessary to evaluate the progress of the structure program, but additional data may be useful to determine annual variation in productivity. Furthermore, changes in egg viability may provide an early warning of developing problems with pesticides or other contaminants.

To minimize risks of nest abandonment, nests should not be checked until late incubation. If structures are checked only once each year (probably the most defensible strategy for most management programs), then the ideal schedule is to begin cheeks immediately after about 90% of the nests have been terminated. The evidence available for determining nest success begins to deteriorate soon after activity in a nest ceases, so delayed monitoring is accompanied by a loss in accuracy. Successful nests contain egg membranes that are leathery, relatively intact, and usually detached from eggshell fragments. Chalky, greenish-white waste products from the goslings often can be found encased in the membranes. Structure location should be marked on a detailed map, and each structure should be marked with a unique identification number (on both the structure and the map). The potential value of monitoring structures is decreased substantially unless occupancy and success rates are summarized and evaluated annually.

Types of Structures

Dozens of structure designs have been used successfully for Canada geese, and managers often develop strong opinions about what design is best. There is little reason to believe that any one type is better or worse than another with respect to acceptability by geese. However, structures do differ substantially in durability, aesthetics, and costs. Choosing the best design involves-careful thought about local conditions: icing patterns; costs and seasonal availability of labor; availability of emergent vegetation for physical protection and visual screening; water depth; substrate firmness; availability of materials; shipping costs for commercially made structures; and availability of trees or other natural supports. The structure types presented here represent examples of designs that have been used successfully in many situations. Detailed plans for these designs are available from the author.

Single-post Structures

Advantages of single-post structures (Fig. 1) include durability, simplicity of construction and lines, low to moderate costs, ease of installation (often 15–20 min), and commercial availability if desired. Geese will accept nest compartments varying from 22 to more than 42 inches in diameter, but 26–32 inches is probably best for practical reasons. Depth should be 8–12 inches to retain nest material, but provisions must be made for safe exodus by goslings. Shape is not critical, but conical shapes seem to retain nest material particularly well and provide for gosling exodus. Rounded "tank end" or "pot" shapes seem to be most acceptable aesthetically. Fiberglass, rubber, or wood (1 inch or more in thickness and of a rot-resistant species) are preferred materials. Positive drainage must be provided. Structures made of wire (<1/2- or >2-inch mesh size) may be acceptable in some situations, but nest material in wire structures is easily blown away. Wooden structures soon weather to drab colors, but structures made of other materials should be painted to blend with surroundings.

Supports may be wooden posts or metal pipes. Wooden posts (≥6 inches in diameter) are adequate in some situations, but are less resistant to climbing predators than pipe and will rot quickly unless they are treated or remain saturated with water. Furthermore, buoyancy can cause wooden posts to

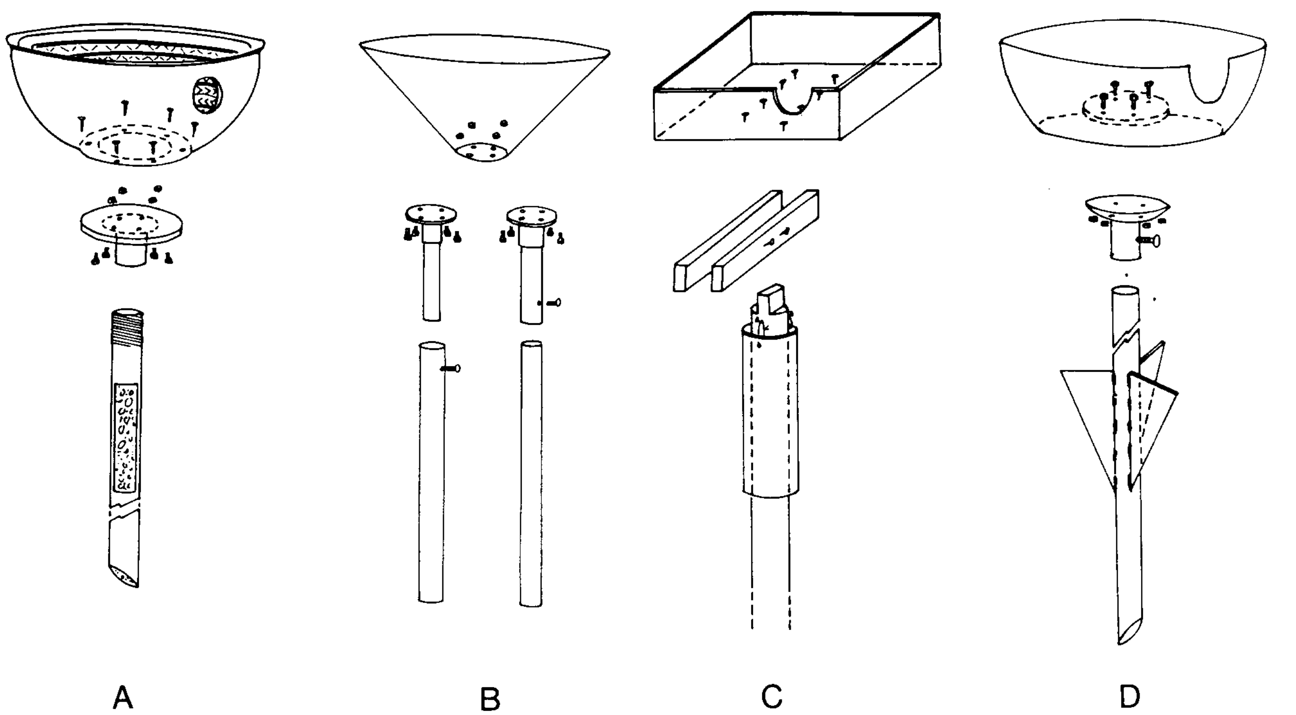


Fig. 1. Single-post structures. *A*. Inverted, painted tire attached to threads on the support pipe with a treated plywood disk and a plumbing floor flange. A driving cap is essential to prevent thread damage during installation. The support pipe can be filled with concrete to prevent bending. *B*. Fiberglass cone basket with welded mounting plate and adjustable ferrule mounts. *C*. Wooden box with predator guard made of PVC pipe. The box also can be built 12–18 inches deep with slatted sides to maintain nest material but allow goslings to exit through the 2-inch gaps between slats as the fill level drops. *D*. Fiberglass tub with a mounting plate made from a farm implement disk. The pole is finned to prevent tipping.

rise and tip unless they are deeply seated. Steel pipes from 1 ½ to 4 inches in diameter have been used successfully. A useful standard is 2-inch heavy-duty (sometimes called “schedule 80”) pipe with a 2-inch inside diameter and a 2⅜-inch outside diameter. This pipe is sturdy enough for any but the harshest conditions and is available in many areas at salvage prices as drill stem. If the nest compartment drains to the support pipe, or if standard weight pipe (“schedule 40”) is used, then a hole should be drilled into the pipe a few inches above the water line to prevent flooding of the nest or splitting of the pipe by ice expansion.

Platforms

Platforms (Fig. 2) with four legs seem to offer some advantage in stability where soft bottom substrate occurs and where the upper nest structure is extremely heavy (as when two bales are used as nest material). Costs tend to be relatively high because four supports are required, and because installation is time-consuming (usually 4 or more person hours). The complicated lines of platforms reduce aesthetic acceptability to many people, but using bales as nest material can be a major advantage.

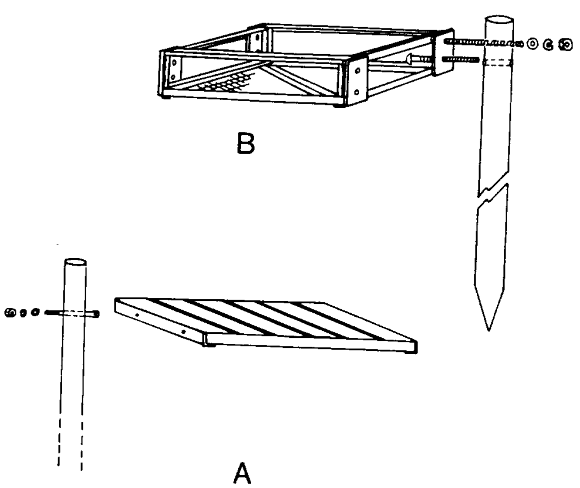


Fig. 2. Platform structures *A*. This basic version consists of four heavy pipe legs that bolt to a simple angle-iron frame (36 × 48 inches) supporting the wooden platform. Resistance to ice damage can be increased somewhat by constructing a rock crib between the legs. *B*. The reinforced platform increases ice resistance substantially because structural rigidity of the sturdy 36- × 42-inch frame is transferred to the legs. Two bales are wired to the simple platform or wedged into the upper framework of the reinforced platform.

Tree Structures

Most of the considerations for tree structures (Fig. 3) are similar to those for single-post structures. Advantages of tree structures are that the support is provided by nature and that carefully designed and installed tree structures can be extremely inconspicuous. Potential disadvantages are that trees are easily climbed by raccoons and that tree growth often destroys wooden structures.

If the available trees are long-lived and secure, relatively high costs for the structure may be justifiable. Conversely, if short-lived tree species are involved or if many trees are lost annually to beavers or bank erosion, then the more efficient strategy is to use less expensive structures with shorter potential lifespans. Tree structures present difficulties and potential dangers during maintenance, so providing durable nest materials is even more important than in other types of structures.

Large Bales

During the past several decades, the use of large round or rectangular bales as nest structures has become popular in many areas. Potential advantages are that no maintenance is needed between installation and replacement, bales are seen as somewhat natural, and their placement provides a

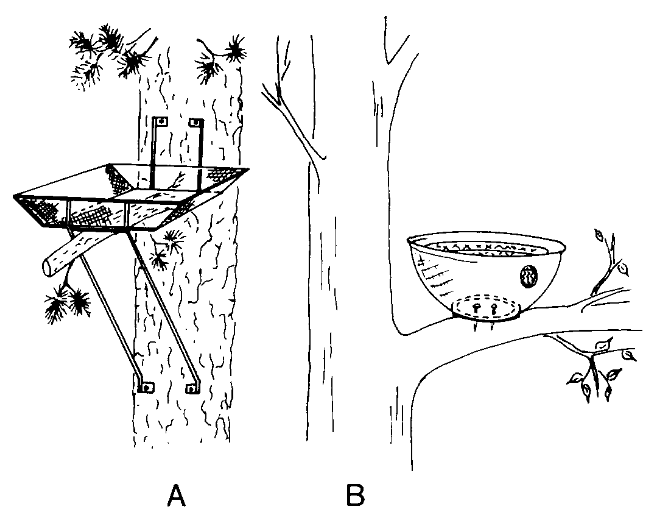


Fig. 3. Tree structures. *A*. Expanded steel structure attaches to tree with lag screws and bends to accommodate tree growth. *B*. Inverted, painted tire with treated plywood disk bottom attaches to tree with ringnails. Attachment may be in a crotch, on a large horizontal limb, or on a sawed-off vertical limb. If logging could occur, aluminum nails should be used.

practical and popular activity for public participation. Costs may be relatively low, but are not necessarily so if purchase price increases with demand or if high transportation and salary costs must be paid.

The most serious disadvantage is that bales seldom last more than 3 years, and often last only 1 or 2 years. Wrapping bales in wire mesh may extend their life somewhat, but the wire can trap goslings as the bale shrinks and the wire will remain in the marsh, creating litter or entanglement problems. The best compromise may be to use tight flax bales, double-wrapped with polypropylene twine and banded securely with plastic or metal strapping. This approach provides bales that usually last 2 or 3 years and greatly reduces the amount of litter left in the marsh. In grazed areas, cows will destroy bales if water levels drop. Bales are less resistant to leaping or climbing predators than most other structure types and occasionally provide den sites for predators.

Installation depth is critical for bales, with 18–30 inches strongly preferred. If the total depth of ice and water exceeds 12 inches, many round bales will tip over at ice-out unless the ice is completely removed from the hole and the bale settled firmly on bottom. Tipping, which occurs because the ice melts rapidly at the south side of the bale, reduces occupancy and life of bales. Large rectangular bales usually will drop through the ice with the cut ends up and down if placed on the ice with their long axis oriented north-south.

Culverts

One of the few fundamentally new approaches to nest structures in the past several decades has been the use of culverts tipped on end and filled with soil. Culverts offer the important advantages of being virtually maintenance free and exceedingly long-lived. Disadvantages are that heavy equipment may be needed for installation and that removal (if desired) can be very difficult.

Concrete culverts, as well as those made of smooth or corrugated steel, have been used successfully, although steel will no doubt rust through in time. Corrugated steel has some aesthetic drawbacks, although these can be minimized with careful site selection. Culverts will tip at ice-out nearly every time if merely placed on top of the ice. Culverts less than 30 inches in outside diameter are not recommended because of tipping problems, and the diameter should at least equal the water depth for the same reason. Culvert lengths of 6 feet are usually best, providing for 3 feet of structure height and 3 feet of water and settling of the culvert into the substrate. The choice of culvert diameter is a trade-off between resistance to tipping and culvert weight. A concrete culvert 30 inches in inside diameter with 3-inch walls weighs about 370 pounds per lineal foot or about 2,200 pounds for a 6-foot section. Even larger culverts (48 inches in inside diameter) have been used with excellent results. These are exceptionally resistant to ice damage, and geese can be excluded from one side of them with 6- × 6-inch wire mesh so that vegetative cover and security for nesting ducks are produced.

Heavy equipment is needed for moving the largest culverts, and installation requires either a dry wetland basin or thick, solid ice conditions. Culverts should be settled firmly into the substrate. Fill material can be rocks or gravel to slightly below waterline, but should be good soil from there up. If the fill is installed dry, it will settle substantially when it gets wet. The two solutions to this problem are to revisit the site after water levels rise and top off the fill or to carry enough water to saturate and settle the fill. Bottom sediments make adequate fill unless there are salinity or alkalinity problems. Culverts can be seeded with preferred plant species or merely allowed to develop with weedy species.

Floating Structures

Floating structures are highly acceptable to geese, but practical problems have plagued most projects. Ice damage usually is severe unless floating structures are removed each fall. Furthermore, floating wooden structures will become waterlogged and will sink unless flotation materials are added. Anchors are apt to drag and anchor cables or ropes often break. Finally, muskrats often destroy unprotected foam flotation material or sink structures by piling debris upon them. For these reasons, floating structures are not recommended for geese unless other options are unavailable and unless extreme care is taken to avoid the most common problems of this kind of structure.

Suggested Reading

Atkins, T. D., and T. L. Fuller. 1979. An improved nesting structure for Canada geese. Wildl. Soc. Bull. 7:192–193.

Brakhage, G. K. 1965. Biology and behavior of tubnesting Canada geese. J. Wildl. Manage. 29:751-771.

Giroux, J., D. E. Jelinski, and R. W. Boychuk. 1983. Use of rock islands and round straw bales by nesting Canada geese. Wildl. Soc. Bull. 11:172–178.

Higgins, K. F., H. W. Miller, and L. M. Kirsch. 1986. Waterfowl nesting on an earth-filled cement culvert. Prairie Nat. 18:115–116.

Mae-key, D. L., W. C. Matthews, Jr., and I. J. Ball. 1988. Elevated nest structures for Canada geese. Wildl. Soc. Bull. 16:362–367.

Messmer, T. A., M. A. Johnson, and F. B. Lee. 1986. Homemade nest sites for giant Canada geese. North Dakota Cooperative Extension Service, North Dakota State University, Fargo. Bull. WL-910. 8 pp.

Rienecker, W. C. 1971. Canada goose nest platforms. Calif. Fish Game 57:113–123.

Will, G. C., and G. I. Crawford. 1970. Elevated and floating nest structures for Canada geese. J. Wildl. Manage. 34:583–586.

Appendix A. Common and Scientific Names of Animals Named in Text.

Canada goose	*Branta canadensis*
Beaver	*Castor canadensis*
Common raven	*Corvus corax*
Bald eagle	*Haliaeetus leucocephalus*
Muskrat	*Ondatra zibethicus*
Osprey	*Pandion haliaetus*
Raccoon	*Procyon lotor*

Appendix B. English-Metric Conversion.

1 inch	= 2.5400 centimeters
1 foot	= 0.3048 meter
1 yard	= 0.9144 meter
1 pound	= 0.4536 kilogram

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Fish and Wildlife Leaflet 13
Washington, D.C. • 1990

13.2.14. Management of Habitat for Breeding and Migrating Shorebirds in the Midwest

Jan Eldridge
Bell Museum of Natural History
University of Minnesota
Minneapolis, MN 55455

Shorebirds have always relied on the extensive network of natural wetlands from Texas to North Dakota. This network has now been fractured by wetland drainage and agriculture to the point where suitable wetlands are absent in much of the Midwest. Habitat loss and the resulting risk of population decline highlight the importance of management of shorebirds on refuges, hunting clubs, and preserves for both breeding and migrating species.

Because shorebirds, like waterfowl, depend on wetlands throughout the year, the loss of natural wetlands in the Midwest poses a real threat. Unfortunately, shorebirds are slow to recover from population declines caused by human disturbance; for example, the Eskimo curlew has never recovered from being overhunted at the turn of the century. Many species, particularly those that nest in the lower 48 states, have declined in this century because of habitat loss. Arctic nesting species are relatively safe in remote breeding grounds, but are vulnerable to degradation of habitats critical to migration through the Midwest.

This chapter provides guidance for wetland managers in midwestern states for attracting migrating and breeding shorebirds. These suggestions will benefit most of the 40 species that migrate or breed in 12 states of the mid-continent region: Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin (Table). Emphasis is on migrating species because they can benefit the most from the kind of managed wetland habitat usually available on mid-continent refuges. The unique value of managed wetlands is their capacity to buffer the effects of both drought and flooding in surrounding wetland habitat.

Management of Breeding Shorebirds

Management of grassland can create essential upland habitat for breeding shorebirds through grazing, mowing, or prescribed burning. Before European settlement, breeding shorebirds specialized in exploiting the grassland mosaics left in the path of roaming buffalo herds or created by prairie fires. Today the appropriate habitat is becoming increasingly rare because native rangeland is converted to cropland throughout the Midwest. Breeding shorebirds nest in a wide range of habitat from unvegetated wetland beaches to moderately tall, dense grass in the uplands. Long-billed curlews, marbled godwits, willets, killdeer, and mountain plovers forage and nest in the short (<15 cm; <6 inches) sparse vegetation of open grasslands and often nest hundreds of yards from wetlands. Wilson's phalaropes and upland sandpipers use somewhat taller (10–30 cm;

Table. *Shorebirds that breed, migrate, or winter in twelve midwestern states.*

Species	Breeding	Migrating	Wintering
Snowy plover	X	X[a]	
Piping plover	X	X	
Mountain plover	X	X	
Semipalmated plover		X	
Killdeer	X	X	X
Lesser golden-plover		X	
Black-bellied plover		X	
Black-necked stilt	X	X	
American avocet	X	X	
Spotted sandpiper	X	X	
Ruddy turnstone		X	
Upland sandpiper	X	X	
Sanderling		X	
Dunlin		X	
Baird's sandpiper		X	
Red knot		X	
White-rumped sandpiper		X	
Stilt sandpiper		X	
Western sandpiper		X	
Pectoral sandpiper		X	
Least sandpiper		X	
Semipalmated sandpiper		X	
Willet	X	X	
Common snipe	X	X	X
Short-billed dowitcher		X	
Long-billed dowitcher		X	
Marbled godwit	X	X	
Hudsonian godwit		X	
Long-billed curlew	X	X	X
Eskimo curlew		X	
Whimbrel		X	
Ruff		X	
American woodcock	X	X	X
Lesser yellowlegs		X	
Greater yellowlegs		X	
Solitary sandpiper	X	X	
Buff-breasted sandpiper		X	
Red phalarope		X	
Red-necked phalarope		X	
Wilson's phalarope	X	X	

[a] An X indicates presence in at least one of the states of the mid-continent region during the indicated time. More detailed accounts of breeding and wintering range can be found in Hayman et al. 1986.

4–12 inches) vegetation for nesting. Phalaropes are often in wet meadows adjacent to permanent or semi-permanent wetlands, but upland sandpipers occupy drier grassland sites not associated with wetlands. American avocets and endangered piping plovers nest on bare to sparsely vegetated beaches of saline wetlands.

Nesting shorebirds avoid tilled fields and prefer native grassland to planted grass. Timely management on native grasslands can increase diversity and provide habitat for many species of breeding shorebirds. Prescribed burning benefits all nesting shorebirds. Moderate to heavy grazing or mowing, especially on wetter sites, may benefit nesting habitat for long-billed curlews, killdeer, mountain plovers, willets, and marbled godwits. Upland sandpipers benefit from light grazing or mowing in the wetter, eastern half of the Midwest. To the west, on drier sites, such management may be unnecessary. Grazing and associated trampling can be effective at controlling vegetation on wetlands managed for godwits and willets; but piping plovers abandon beaches grazed by livestock.

For many breeding shorebirds, landscape context or juxtaposition of habitats is important. During the breeding season, long-billed curlews, killdeer, mountain plovers, and upland sandpipers forage and nest in the same type of upland habitats; but Wilson's phalaropes, American avocets, piping plovers, marbled godwits, and willets depend on the invertebrates in surrounding wetlands. American avocets and piping plovers require shallow, saline basins for feeding and brood rearing. Wilson's phalaropes feed in open water to depths of 30 cm (12 inches) in seasonal to permanent wetlands. Marbled godwits and willets are most abundant in areas with a variety of wetland types; they feed at or near shorelines with minimal vegetation. Ephemeral and temporary ponds are important feeding sites early in reproduction, whereas seasonal, semi-permanent, and saline wetlands provide foraging habitat throughout nesting and brood rearing.

Management of Migrating Shorebirds

In the spring, shorebirds that nest in the Arctic usually migrate through the Midwest after the breeding species have already arrived. The migrating shorebirds stop opportunistically to feed. They accumulate fat reserves that are necessary for continued migration and possibly for reproduction. During migration, many species look for a specific combination of habitat elements that include:

- a wetland in partial drawdown,
- invertebrate abundance of at least 100 individuals per square meter,

- a combination of open mudflat and shallow water (3 to 5 cm; 1 to 2 inches) in a wetland basin with gradually sloping sides, and
- very little vegetation.

Any one of these elements may be available, but without invertebrates, the birds do not stay.

The key to managing habitat for migrating shorebirds is to encourage invertebrate production and then make the invertebrates available to the birds. Aquatic invertebrates increase when wetlands are fertilized by mowing and grazing, but water control in the impoundment makes the job easier. The proper regime of drawdown and flooding can stimulate plant growth and decomposition and create a detrital food source for invertebrates. When the water is drawn down slowly (2 to 4 cm per week) during the appropriate times of the year, shorebirds are attracted to the available invertebrates. In general, water depth in which birds forage and body size of the birds correlate; larger birds tend to forage in deeper water. Some species may be attracted by shallow water, others, by mudflats. Some forage at the edge of the receding water line. If the interface between mud and water remains constant, they can deplete the invertebrates available to them. A slow, continuous drawdown provides the birds with new habitat and invertebrates. Each individual shorebird may only stay for a few days, but over several weeks, thousands of individuals of many species may benefit.

Timing of Migration

Shorebirds migrate through the Midwest over a wide span of time in the spring and an even wider span in fall. Because the timing of migration varies with latitude, managers should link drawdowns to the local migration phenology. The following dates are offered only for general guidance. Spring drawdowns should be scheduled for early to mid-April and through May, depending on the latitude of the refuge. Refuges in Missouri, for example, should begin drawdowns in early to mid-April and continue slowly for several weeks. Refuges in Minnesota and Michigan should begin drawdowns in late April to early May and continue until early June. In late summer, drawdowns can be scheduled from July to October throughout the region. If the wildlife area has more than one impoundment, managers should draw them down asynchronously (see *Fish and Wildlife Leaflet* 13.4.6).

In terms of shorebird conservation, spring drawdowns may be particularly important in northern refuges because wetlands in drawdown are usually rare at this time of the year (droughts are an exception). In southern refuges, drawdowns may be especially important in fall when shorebird habitat is rare in the surrounding unprotected land.

Food Preferences

Shorebirds feed primarily on Chironomidae (midge) larvae during migration through the Midwest. Whether shorebirds prefer midges or simply eat whatever is most abundant in a wetland during a drawdown is not clear. Shorebirds probably pick the largest and easiest to catch aquatic larval form. For example, a study at the Shiawassee National Wildlife Refuge in Michigan demonstrated that shorebirds preferred slow-moving beetle larvae (Haliplidae) to the much smaller midge larvae.

Several studies revealed that, irrespective of wetland type, midge larvae are often the most abundant invertebrate. This is primarily because midges have solved several basic problems in the wetland environment. They adapted to the enormous variation in conditions that are typical of the average wetland; they can cope with freezing, drying, high temperatures, high salinity, and low oxygen. In a word, they are flexible and, as a result, adaptively radiated into a variety of niches in the wetland basin.

Chironomidae Life History

Midges have four life stages: egg, larva, pupa, and adult. The larvae progress through four instar stages during which they grow from 2 mm to as large as 24 mm. Because development is temperature dependent, four to five generations may be present in a single season in warm southern wetlands, whereas in the Arctic, one generation may take 7 years to pass through all stages. Irrespective of length of development, midges spend most of their life as larvae. The egg, pupa, and adult stages pass quickly, each in a matter of days.

Because midges are such a major component of the wetland environment, it should not be surprising that they follow the general rules of most aquatic invertebrates:

- species diversity increases with structural diversity of vegetation,
- species diversity increases with water permanence.

However, species diversity may not be the best goal of water management designed specifically for shorebirds. For shorebird management, midge biomass, not diversity, should be the primary goal.

The most important midges for migrating shorebirds are the Chironominae species known as bloodworms, which are usually in the genus *Chironomus*. The larva are bright red because they contain hemoglobin and can withstand water with low levels of dissolved oxygen. They grow to be as long as 24 mm and are often among the earliest colonizers in newly available habitat. They function in a wetland by burrowing throughout the detritus, and they consume algae, primarily diatoms, that flourish in the detrital layer. Their burrowing churns and aerates the bottom, accelerating decomposition and microbial activity. They are often most abundant in areas of shallow, open water unshaded by submergent and emergent vegetation, thus promoting algal growth. They form tubes of detritus and usually feed from these tubes. Because they flourish in warm, shallow water and are bright red, they are prime targets for foraging shorebirds.

Management of Habitat for Midge Larvae

During spring, shorebirds congregate where large bloodworms have overwintered and are exposed in the shallows of gradually receding wetlands. The purpose of management specifically for shorebirds should be to imitate these conditions. Because many waterfowl hens and broods also consume midge larvae, management of habitat for shorebirds is also beneficial for waterfowl. Early colonizing midges, such as *Chironomus tentans*, flourish in wetlands maintained in an early successional stage typical of moist-soil-unit management. This keeps the plant and midge community simple and can lead to a large population (and biomass) of detrivorous midge larvae. The community remains simple when water fluctuates annually or biannually. Disking in the moist-soil units also keeps the community of plants in early succession. Wetland managers should try a variety of approaches because the success of any approach varies with location and climate. Although management in spring is stressed, each management regime can be used in late summer by simply delaying the drawdown until the peak of the southbound shorebird migration. On refuges with more than one managed wetland, water regimes should be manipulated asynchronously so that in any given year some shorebird habitat is available during both spring and fall.

No management is complete without some level of evaluation to determine whether midge larvae and shorebirds have responded as expected to the water management. An attempt should be made to census shorebird populations on the managed wetlands and to sample midge larvae in the wetland sediment. Censuses of shorebirds can be conducted as part of a routine wildlife inventory for the refuge, and core samples can easily be taken for the midge larvae. Cores should be taken with a simple core sampler (a graduated cylinder with a diameter of approximately 7 to 10 cm is an excellent core sampler). The core should be taken to a depth of approximately 3 cm in the mud and should be washed through a screen. The midges can be most accurately counted while they are alive and colorful. The number of midge larvae per square meter of mud flat can be extrapolated from the simple count of larvae in the core sample. This number should be at least 100 midge larvae per square meter to successfully attract and hold shorebirds.

Management Regimes for Shorebirds

Temporary Wetland (Moist Soil Unit) —Winter Drawdown

Begin a slow drawdown in early to mid-July. The slow drawdown allows midge larvae to form cocoons and prepare for desiccation. Leave the wetland moist throughout the summer to encourage production of moist soil (annual) plants. The wetland can remain dry throughout the winter because vegetation decomposes more rapidly if exposed than if inundated. Return water slowly to the basin early the following spring to inundate the decomposing vegetation. Flooding the basin rapidly may float unthawed soil, causing increased turbidity later. The newly flooded wetland has a flush of nutrients and the overwintering larvae grow rapidly. Keep the water shallow and warm to encourage algal growth and nutrients for midge production. At the appropriate time of shorebird migration, start a gradual drawdown, always maintaining at least 3 to 5 cm of water in the wetland basin.

Temporary Wetland (Moist Soil Unit) —Summer Drawdown

Repeat the described steps for a spring drawdown to allow annuals to grow on moist mudflats. Return water to the basin in late summer after substantial annual plant biomass develops. Because midge larvae may die when conditions are too severe, inundate the basin during the winter in areas of late summer drought and hard winter freeze. Larvae continue to grow until late fall and overwinter as larger, older forms, providing spring migrants with a better food resource.

Temporary Wetland (Moist Soil Unit) —Disking and Flooding

Disk the moist soil unit in late summer and flood shallowly so the basin contains an interspersion of mudflat, shallow water, and deeper water to provide habitat as the wetland dries. When the manipulation coincides with fall migration, the shorebirds respond almost immediately.

Semipermanent Wetland—Upland Flooding

Flood the uplands surrounding the emergent vegetation zone in the early spring. This kills the wet meadow plants, and midges rapidly colonize the detritus. Maintain the water high and then slowly lower it to expose the decomposing vegetation during the peak of shorebird migration. Gradually lower the level to normal in the late summer for the southbound migration or draw it down the following spring.

Semipermanent Wetland—Periodic Drawdown

Semipermanent wetlands managed for vegetation and invertebrate diversity undergo drawdown once every 3 to 10 years depending on the size of the basin. This type of management can be coordinated with shorebird migration by drawing the wetland down slowly during the spring or late summer migration. In a complex of wetlands, the drawdowns can be conducted asynchronously so at least one basin is available to shorebirds each year.

Cautions

The recommendations outlined here are based on the assumption that the wetland does not have a history of problems, such as invasion of perennial plants (purple loosestrife, willow, or woolgrass) or outbreaks of avian disease such as botulism.

Conclusions

The management regimes outlined in this report need extensive trial, but, given what is known about shorebird and midge biology, they should prove helpful in attracting shorebirds to refuges. The key to success is to keep upland vegetation grazed or mowed and to time the drawdowns so they coincide with migration in the area of the refuge. Finally, conduct all water manipulations slowly so the invertebrates can adjust to the changes.

Suggested Reading

Driver, E. A. 1977. Chironomid communities in small prairie ponds: some characteristics and controls. Freshwater Biology 7:121–133.

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148. 29 pp.

Hayman, P., J. Marchant, T. Prater. 1986. Shorebirds: an identification guide to the waders of the world. Houghton Mifflin Company, Boston, Mass.

Oliver, D. R. 1971. Life history of the Chironomidae. Annual Reviews of Entomology 16:211–230.

Recher, H. F. 1966. Some aspects of the ecology of migrant shorebirds. Ecology 47:393–407.

Reid, F. A. 1985. Wetland invertebrates in relation to hydrology and water chemistry. Pages 72–79 *in* M. D. Knighton, editor. Water impoundments for wildlife: a habitat management workshop. U.S. Forest Service, St. Paul, Minn.

Reid, F. A., W. D. Rundle, M. W. Sayre, and P. R. Covington. 1983. Shorebird migration chronology at two Mississippi River Valley wetlands in Missouri. Transactions of the Missouri Academy of Science 17:103–115.

Rundle, W. D., and L. H. Fredrickson 1981. Managing seasonally flooded impoundments for migrant rails and shorebirds. Wildlife Society Bulletin 9:80–87.

Ryan, M. R., R. B. Renken, and J. A. Dinsmore. 1984. Marbled godwit habitat selection in the northern prairie region. Journal of Wildlife Management 48:1206–1218.

Swanson, G. A. 1978. A simple lightweight core sampler for quantitating waterfowl foods. Journal of Wildlife Management 42:426–428.

Wiggins, G. B., R. J. MacKay, and I. M. Smith. 1980. Evolutionary and ecological strategies of animals in annual temporary pools. Archiv fuer Hydrobiologie Supplementband 58:97–206.

Appendix. Common and Scientific Names of the Birds Named in Text.

Spotted sandpiper	*Actitis macularia*
Ruddy turnstone	*Arenaria interpres*
Upland sandpiper	*Bartramia longicauda*
Sanderling	*Calidris alba*
Dunlin	*Calidris alpina*
Baird's sandpiper	*Calidris bairdii*
Red knot	*Calidris canutus*
White-rumped sandpiper	*Calidris fuscicollis*
Stilt sandpiper	*Calidris himantopus*
Western sandpiper	*Calidris mauri*
Pectoral sandpiper	*Calidris melanotos*
Least sandpiper	*Calidris minutilla*
Semipalmated sandpiper	*Calidris pusilla*
Willet	*Catoptrophorus semipalmatus*
Snowy plover	*Charadrius alexandrinus*
Piping plover	*Charadrius melodus*
Mountain plover	*Charadrius montanus*
Semipalmated plover	*Charadrius semipalmatus*
Killdeer	*Charadrius vociferus*
Common snipe	*Gallinago gallinago*
Black-necked stilt	*Himantopus mexicanus*
Short-billed dowitcher	*Limnodromus griseus*
Long-billed dowitcher	*Limnodromus scolopaceus*
Marbled godwit	*Limosa fedoa*
Hudsonian godwit	*Limosa haemastica*
Long-billed curlew	*Numenius americanus*
Eskimo curlew	*Numenius borealis*
Whimbrel	*Numenius phaeopus*
Red phalarope	*Phalaropus fulicarius*
Red-necked phalarope	*Phalaropus lobatus*
Wilson's phalarope	*Phalaropus tricolor*
Ruff	*Philomachus pugnax*
Lesser golden-plover	*Pluvialis dominica*
Black-bellied plover	*Pluvialis squatarola*
American avocet	*Recurvirostra americana*
American woodcock	*Scolopax minor*
Lesser yellowlegs	*Tringa flavipes*
Greater yellowlegs	*Tringa melanoleuca*
Solitary sandpiper	*Tringa solitaria*
Buff-breasted sandpiper	*Tryngites subruficollis*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

13.2.15. Human Disturbances of Waterfowl: Causes, Effects, and Management

Carl E. Korschgen
U.S. Fish and Wildlife Service
Northern Prairie Wildlife Research Center
La Crosse Field Station
P.O. Box 2226
La Crosse, WI 54602

and

Robert B. Dahlgren
U.S. Fish and Wildlife Service
Office of Refuge Biology
P.O. Box 2484
La Crosse, WI 54602

Human disturbances of waterfowl can be intentional or unintentional. They may result from overt or directed activities or may be ancillary to activities not initially thought to be of concern to birds. Some of these disturbances are manifested by alertness, fright (obvious or inapparent), flight, swimming, disablement, or death. Therefore, persons responsible for waterfowl management areas should be aware of the problems from human disturbance and should design management and facilities that increase public appreciation of waterfowl.

In the last 20 years, the intensity of water-based recreation increased drastically, especially on inland waters. Waterfowl are wary, seeking refuge from all forms of disturbance, particularly those associated with loud noise and rapid movement. Occasionally, the problem of human disturbance of waterfowl resulted in formal litigation. In Nevada, for example, the Refuge Recreation Act of 1962 was affirmed to permit recreational use only when it did not interfere with the primary purpose for which the Ruby Lake National Wildlife Refuge was established. Compatibility of an activity is based on site-specific effects on the major purposes for which a refuge was established. In a recent survey of harmful and incompatible uses on national wildlife refuges, 42 use categories were determined that could be potential disturbances of waterfowl.

Activities That Cause Disturbances

Given the frequency of human disturbance of waterfowl, information from research about this issue is scant. A review of several thousand journal articles and books revealed that most disturbances are created by water users (chiefly boaters, anglers, hunters) and aircraft (Table). Human activities cause different degrees of disturbance to waterfowl and may be grouped into four main categories. Listed in order of decreasing disturbance these categories are

1. rapid overwater movement and loud noise (power-boating, water skiing, aircraft);
2. overwater movement with little noise (sailing, wind surfing, rowing, canoeing);

3. little overwater movement or noise (wading, swimming); and
4. activities along shorelines (fishing, bird-watching, hiking, and traffic).

Disturbances displaced waterfowl from feeding grounds, increased energetic costs associated with flight, and may have lowered productivity of nesting or brooding waterfowl. Many authors either directly or indirectly implicated themselves as a cause of disturbance during their studies of waterfowl.

Effects on Breeding Waterfowl

Annual increases in waterfowl numbers are determined by several components of reproduction, including the number of breeding pairs, hatching success, and survival of the young. Human disturbance can reduce several of these components, and, in time, result in a declining waterfowl population.

Declining Numbers of Breeding Pairs

Disturbances during critical times of the nesting cycle eventually cause ducks to nest elsewhere or not to nest at all. In Maine, American black ducks and ring-necked ducks did not nest under conditions of excessive human disturbance. Mallards at the Seney National Wildlife Refuge in Michigan failed to nest in areas open to fishing. Some Wisconsin lakes bordered by homes were so heavily used for recreation that breeding ducks did not use otherwise suitable habitat. In Germany, an 85% decrease of the breeding stock of ducks at two small ponds presumably was caused solely by disturbance from an increasing number of anglers during the waterfowl breeding season. Numbers of mallards, green-winged teals, northern shovelers, pochards, and tufted ducks decreased from 26 pairs to 4 pairs during an 8-year period. Human activity on islands can altogether discourage nesting in waterfowl.

Increased Desertion of Nests

Studies of several species of waterfowl identified human disturbances as the cause of desertions or abandonments of nests, especially during early incubation. Disturbance from observers caused a 10% nest abandonment rate by mallards using artificial nest baskets in an Iowa study. Frequent visits to goose nests by biologists

Table. *Human disturbances of waterfowl by source of disturbance, effect, and number of citations in 211 journal articles on the subject.*

Subject	Number of citations
Sources of Disturbance (in alphabetic order)	
Aircraft	
Airplanes	15
Helicopters	10
General	22
Anglers (see fishing)	
Baiting/artificial feeding	7
Barges/shipping	9
Boating (boats, canoes, rowing, airboats, sailing)	66
Cats	2
Development (industrial, pollution, urban, construction)	24
Dogs	6
Farming	19
Fishing	
Commercial	5
Sport (angling)	50
Hazing (scaring)	12
Human activity/disturbance, general	58
Hunting	
Sport	71
Subsistence	2
Military	5
Noise	22
Recreation	
General	18
Aquatic	27
Research/investigator	55
Roads	
General	10
Traffic	11
Trains	1
Trapping	
Furbearer	1
Waterfowl	5
Effects (in alphabetical order)	
Breeding chronology interrupted	2
Brood breakup	14
Brood rearing disrupted	7
Energetic cost (flight) increased	23
Family breakup	6
Feeding interrupted or decreased	52
Molting birds harrassed	9
Nest/nesting	
nest disturbed by researchers	55
nest disturbed by others	27
nesting success reduced	14
Predation on clutches and chicks increased because of research	31
Wariness (alertness, tolerance distance) increased	43

caused nest desertion rates as high as 40%. Canada geese nesting in southeastern Missouri were very sensitive to persons fishing in their nesting areas. Establishing areas closed to fishing during the nesting period decreased nest desertions.

Reduced Hatching Success

Human disturbance has three basic effects on nesting success, that is:

1. exposure of eggs to heat or cold by flushing of hens may kill the embryos;
2. predation of eggs may increase when hens are flushed from nests; and
3. predation of eggs and hens may increase at nests when humans create trails or leave markers by which predators find nests.

When nests of cackling Canada geese were checked several times before hatch, twice the number of eggs were lost to predators. Where human activities disturbed Canada geese or common eiders that were nesting among black-backed gulls, herring gulls, or parasitic jaegers on islands or tundra colonies, the gulls and jaegers often quickly located and consumed eggs in waterfowl nests unoccupied because of human disturbance.

Decreased Duckling Survival

Disturbance by humans during the brood rearing season can break up and scatter broods or frighten parents into running ahead of their ducklings or goslings. Young waterfowl briefly separated from their mother are vulnerable to predators and susceptible to death from severe weather or lack of experience in obtaining food. Disturbances drastically increase kills by gulls of common eider ducklings. For example, the number of eider ducklings killed by gulls in Sweden was 200–300 times greater when broods were disturbed by boats. In northern Maine, American black duck and ring-necked duck broods averaged two fewer ducklings because of mortality from disturbance by motorboats. Human disturbance caused a higher than normal mortality rate of trumpeter swan cygnets in a study area in Alaska. Human disturbance can be quite brutal and direct; water skiers and power boaters have run over white-winged scoter hens and broods, and some boaters have used paddles to kill ducklings.

Effects on Nonbreeding Waterfowl

Migratory and wintering waterfowl generally attempt to minimize time spent in flight and maximize time for feeding. Flight requires considerably more energy than any other activity, except egg laying. Human disturbance compels waterfowl to change food habits, feed only at night, lose weight, or desert the feeding area. Waterfowl respond both to loud noises and rapid movements, such as boats powered by outboard motors, and to visible features, such as sailing boats. Large flocks of waterfowl are more susceptible to disturbances than small flocks.

Not all waterfowl species are equally sensitive to disturbance, and some may habituate to certain disturbances. Pink-footed geese were disturbed at a distance of 500 m when more than 20 cars per day used a road in the fall. Traffic of as few as 10 cars per day also had a depressing effect on habitat use by geese. Thus, the surrounding buffer area must exceed 500 m to render habitat acceptable to flocks of pink-footed geese. Some waterfowl, especially diving ducks (notably canvasbacks and lesser scaups) and geese (notably brants and snow geese) are especially vulnerable to disturbance. Density and pattern of disturbance may influence diving ducks more than dabbling ducks in most areas. Repeated disturbances also can deny birds access to preferred feeding habitats. Use by diving ducks of several good feeding areas along the Upper Mississippi River has been limited primarily by boating disturbances that cause 90 percent of the waterfowl to concentrate on 28 percent of the study area during daytime.

Increased Energy Expenditure and Depleted Fat Reserves

In the absence of disturbance, brants in Great Britain spent an average of 1.1% of their time in flight, but disturbance on weekends caused the time spent in flight to increase as much as sevenfold and prevented brants from feeding for up to 11.7% of the time. Detailed studies are few, but observations suggest that the effects of intensive recreation during the fall and winter could be deleterious to migrating and wintering waterfowl.

Researchers who attempted to quantify the harm from disturbances on migrating and wintering waterfowl indicated that frequency of disturbance, number of affected birds, and changes in behavior are greater than most suspected. For example, each duck and American coot on Houghton Lake, Michigan, was disturbed on the average of 1.5 times per weekday and more than 2 times during weekend days. On Navigation Pool 7 of the Upper Mississippi River, an average of 17.2 boats passed through the study area each day and resulted in 5.2 disturbances per day and a minimum of over 4 min of additional flight time per disturbance of waterfowl. Birds may have flown up to an additional hour each day because of human disturbances. Over 2500 tundra swans left their most important feeding area on the Upper Mississippi River in response to two small boats.

Changed Migration Patterns

Prolonged and extensive disturbances may cause large numbers of waterfowl to leave disturbed wetlands and migrate elsewhere. These movements can be local in areas of plentiful habitat or more distant and permanent in areas of sparse habitat, causing shifts in flyway migration patterns. Extensive disturbances on migration and wintering areas may limit the use by waterfowl below the carrying capacity of wetlands. Daily disturbance by boaters may have been responsible for eliminating the brant population that once spent November and December on Humboldt Bay, California.

Management Considerations

Fortunately, numbers of breeding waterfowl usually increase in response to reduction or elimination of human disturbances. For the benefit of waterfowl, the harm from human disturbances must be minimized or eliminated. Management alternatives that reduce human disturbances of waterfowl include:

1. increasing the quantity, quality, and distribution of foods to compensate for energetic costs from disturbances;
2. establishing screened buffer zones around important waterfowl roosting and feeding areas;
3. reducing the number of roads and access points to limit accessibility to habitats;
4. creating inviolate sanctuaries; and
5. reducing the sources of loud noises and rapid movements of vehicles and machines.

Disturbances occur chiefly during all critical parts of the annual cycle of waterfowl—nesting, brood rearing, migration, and wintering. Each part of the cycle is crucial to the breeding and survival of waterfowl populations. Common to all parts of the cycle is disturbance while feeding, which may increase flight time and decrease feeding time. Disturbances of nesting birds may cause abandonment of the nest, disruption of the pair bond, reduction in clutch size, increased egg mortality, abandonment of the nesting area, and increased predation of the nest. Disturbances during brood-rearing may cause exhaustion of young and an increase in losses from predation. These disturbances can be lessened or their effects mitigated on refuges or other areas managed for waterfowl. Because disturbances are sometimes caused by professional wildlife managers or researchers and private citizens, creation of sanctuaries is often necessary at critical times and locations. Access to roads and trails can be limited for professionals and for bird-watchers. Activities of other users of wildlife, such as trappers and hunters, may have to be restricted in space and time; boating, angling, camping, and picnicking may be restricted similarly. Human disturbance often is increased by viewing platforms and waterfowl can be viewed at a closer distance if the platform is screened with vegetation and made more like a blind. Proper screens and appropriate control of noise let people really enjoy wildlife close at hand.

Structures such as pumping stations and maintenance buildings on wildlife areas should be screened and placed where necessary human visits cause the least disturbance of waterfowl. Disturbances, particularly at critical times of the year, can be reduced notably by restricting access of pedestrians, autos, and boats; by regulating activities such as farming, grazing, bait collecting, camping, hunting, fishing, and trapping; and by prohibiting the use of nets that can entrap diving ducks. Access by dogs and other pets should not be permitted in critical areas during the nesting and brood-rearing periods. Airboats, aircraft, and all-terrain-vehicles are often useful to managers of waterfowl and wetland, but their use must be carefully planned to minimize harm from sight or sound. Construction of dikes, canals, water control structures, roads, and similar structures and military uses of wetlands or refuge areas should be scheduled for non-critical times in the annual activity cycle of waterfowl.

Disturbance of feeding waterfowl can sometimes be mitigated by acquiring feeding areas on privately owned land to create a sanctuary or by practicing moist soil management and thus increasing the availability of highly nutritious foods in the refuge or wetland areas. With careful planning, deleterious effects of human disturbance on waterfowl can be mitigated or eliminated by creating sanctuaries in time and space (Figs. 1 and 2).

Managers must aggressively protect waterfowl from any human disturbance that reduces productivity and health of populations. To accomplish this goal, managers must resolve conflicting interests between needs of the public and needs of wildlife and researchers must gather more data to provide a greater range of management options.

Suggested Reading

Åhlund, M., and F. Götmark. 1989. Gull predation on eider ducklings *Somateria mollissima*: effects of human disturbance. Biological Conservation 48:115–127.

Bélanger, L., and J. Bédard. 1989. Responses of staging snow geese to human disturbance. Journal of Wildlife Management 53:713–719.

Bouffard, S. H. 1982. Wildlife values versus human recreation: Ruby Lake National Wildlife Refuge. Transactions of the North American Wildlife and Natural Resources Conference 47:553–558.

Braun, C. E., K. W. Harmon, J. A. Jackson, and C. D. Littlefield. 1978. Management of National Wildlife Refuges in the United States: its impacts on birds. Wilson Bulletin 90:309–321.

Burger, J. 1981. The effect of human activity on birds at a coastal bay. Biological Conservation 21:231–241.

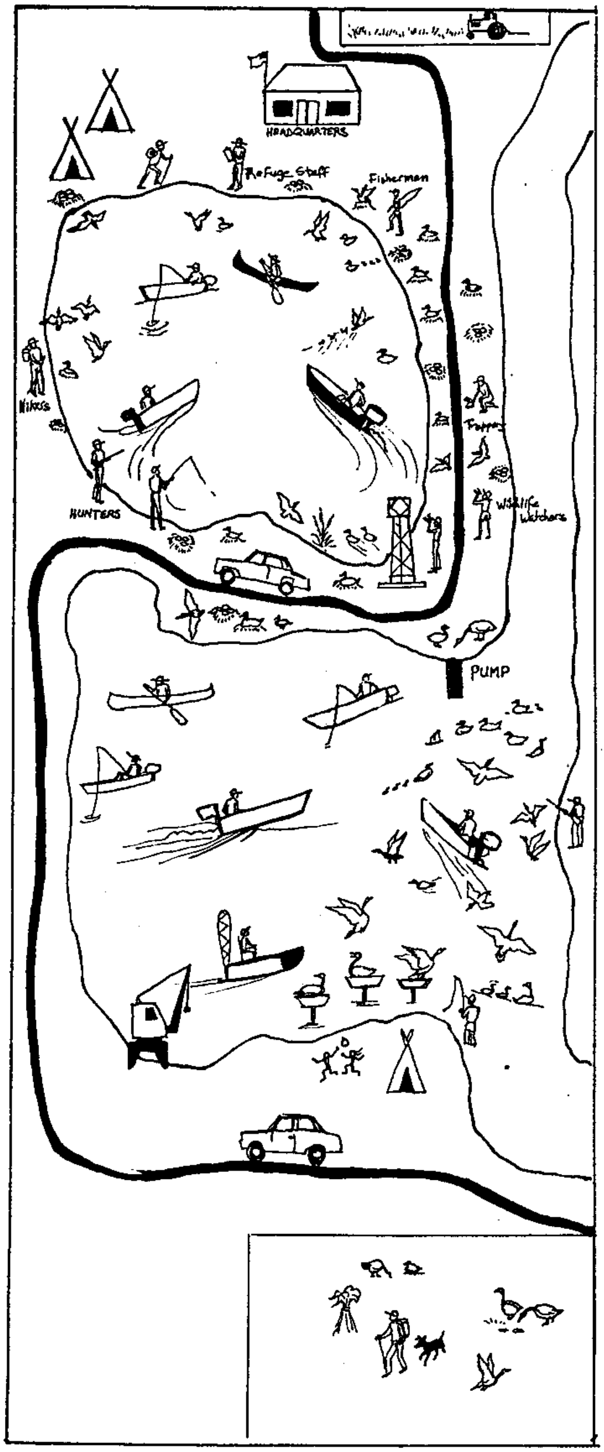
Dahlgren, R. B., and C. E. Korschgen. 1992. Human disturbance to waterfowl: an annotated bibliography. U.S. Fish and Wildlife Service Resource Publication 188. 62 pp.

Edington, J. M., and M. A. Edington. 1986. Ecology, recreation, and tourism. Cambridge University Press, New York. 198 pp.

Korschgen, C. E., L. S. George, and W. L. Green. 1985. Disturbance of diving ducks by boaters on a migrational staging area. Wildlife Society Bulletin 13:290–296.

Liddle, M. J., and H. R. A. Scorgie. 1980. The effects of recreation on freshwater plants and animals: a review. Biological Conservation 17:183–206.

Pomerantz, G. A., D. J. Decker, G. R. Goff, and K. G. Purdy. 1988. Assessing impact of recreation on wildlife: a classification scheme. Wildlife Society Bulletin 16:58–62.



Spring and Summer

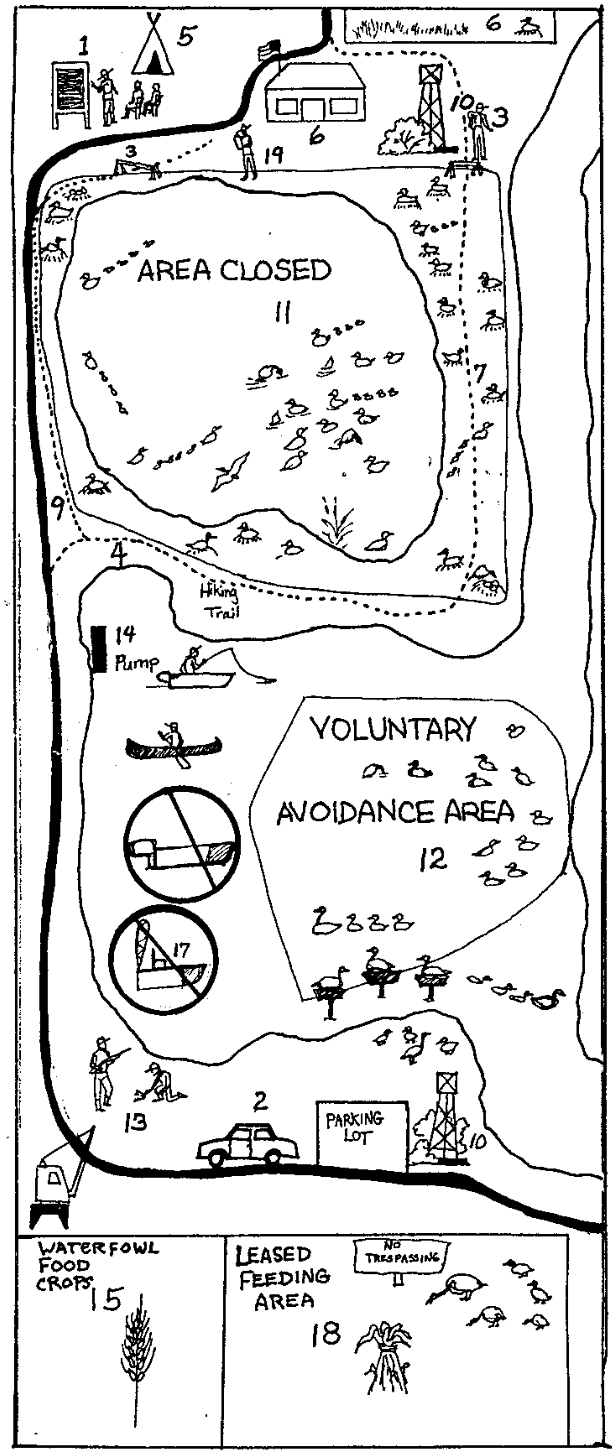
Ducks nest along dikes and in the uplands, and geese nest in tubs on end of lake. Fewer pairs are nesting each year, and many nests are abandoned or destroyed. Predation rates are high, especially in disturbed areas. Disturbance factors seem to be automobiles on tour routes, anglers on shores and in boats on the lake, hikers on trails, and users of the observation tower.

Females hatch large clutches, but survival of young is lower than expected.

Fall and winter

The lake is an important staging area for several species of diving ducks; large numbers of ducks and geese feed in the uplands on and around the refuge. Waterfowl numbers are decreasing despite favorable habitat. The frequency of human disturbance seems to have increased, especially from hunters, late season anglers and boaters, the auto tour, hikers, and wildlife watchers. It is also apparent that refuge staff are spending a lot of time working on minor projects.

Fig. 1. Example of waterfowl refuge with excessive level of human disturbance of waterfowl.



Spring and summer

- Provide educational information so that the public knows the effects of disturbances on the predominant species.
- Seasonally close or restrict use of auto tour. Users of auto tour must stay in vehicles and stop in only designated parking areas.
- Seasonally close or restrict use of hiking and canoe trails.
- Close or restrict the fishing season during peak nesting period.
- Permit camping in only designated areas.
- Delay hay cutting until most clutches have hatched.
- Prioritize and limit special use permits.
- Limit access until most young waterfowl are three weeks old.

Fall and winter

- Provide educational information so that the public knows the migration and wintering requirements of the predominant species.
- Reroute auto tour to areas of secondary importance to waterfowl.
- Move or screen observation towers.
- Close selected areas of the refuge to public access.
- Create voluntary avoidance areas on federal and state waterways.
- Modify regulations to restrict disturbances from hunting and trapping.
- Move water pumping stations away from bird concentration areas.
- Raise high quality waterfowl foods on refuge land.
- Limit size and horsepower of boats on the lake.
- Disallow use of airboats.
- Obtain short term leases and prevent trespass on private lands that contain waste grain.
- Limit the time that refuge staff spend in high waterfowl use areas.
- Delay construction until non peak seasons.

Fig. 2. Examples of management practices that have reduced the level of human disturbance of waterfowl at a refuge.

Appendix. Common and Scientific Names of Birds Named in Text.

Ducks	
Northern shoveler	*Anas clypeata*
Green-winged teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
American black duck	*Anas rubripes*
Lesser scaup	*Aythya affinis*
Ring-necked duck	*Aythya collaris*
Common pochard	*Aythya ferina*
Tufted duck	*Aythya fuligula*
Canvasback	*Aythya valisineria*
White-winged scoter	*Melanitta fusca*
Common eider	*Somateria mollissima*
Geese	
Pink-footed goose	*Anser brachyrhynchus*
Snow goose	*Anser caerulescens*
Brant	*Branta bernicla*
Canada goose	*Branta canadensis*
Cackling Canada goose	*Branta canadensis minima*
Swans	
Trumpeter swan	*Cygnus buccinator*
Tundra swan	*Cygnus columbianus*
Other	
American coot	*Fulica americana*
Herring gull	*Larus argentatus*
Great black-backed gull	*Larus marinus*
Parasitic jaeger	*Stercorarius parasiticus*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

13.3.1. Invertebrate Response to Wetland Management

Leigh H. Fredrickson and Fredric A. Reed
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri–Columbia
Puxico, MO 63960

By gaining greater understanding and appreciation of wetland environments, managers have developed creative insights for waterfowl conservation. Among the most exciting new developments in the understanding of functional wetlands has been the recognition of the important roles of invertebrates in aquatic ecosystems. These roles include trophic linkage from primary production to secondary consumers such as waterfowl, packaging of specific nutritional components such as amino acids and micronutrients for vertebrate predators, and detrital processing of wetland organic material. Although specific invertebrate responses to various management techniques are not always predictable and may differ among invertebrate species, patterns related to water regimes, water chemistry, and vegetative structure have emerged. Managers should consider the following invertebrate responses to natural and manipulated wetland complexes when managing for waterfowl.

Importance to Waterbirds

Although wetland systems are some of the most productive ecosystems in the world in terms of vegetation biomass, few duck species acquire substantial energetic or nutritional resources directly from consumption of plant material other than seeds. Much of the energy from plants is initially transferred to the primary consumers which include a diverse group of invertebrate species. A variety of invertebrates are consumed by waterfowl. Ducks rely heavily on invertebrates as a major food source throughout the annual cycle. Dabbling and diving ducks use invertebrates extensively during protein-demanding periods, such as egg laying or molt (Table 1). Duck species are adapted to consumption of invertebrate prey by selection of microhabitats, structure of the bill and lamellae and foraging strategies.

Relation to Water Regimes

Long-term hydrologic cycles have shaped the life history strategies of wetland invertebrates. These organisms have developed many adaptations that include:

- egg or pupal stages which can tolerate drought periods,
- initiation of egg development only after specific water/oxygen levels have been reached,
- marked seasonality in life cycle,
- rapid development,
- large number of offspring (high reproductive potential)
- obligate diapause (period of nondevelopment) tied to seasonal flooding, and
- parthenogenic reproduction (as in cladocera).

Invertebrates often move into deeper pools, wetland sediments within the water table, and other nearby wetlands when water levels drop or change within a specific wetland. Many species (e.g.,

Table 1. *Invertebrates consumed by laying female waterfowl collected from 1967 to 1980 in North Dakota. Data expressed as aggregate percent by volume. Modified from Swanson 1984.*

Food item	Blue-winged teal (20)	Northern shoveler (15)	Gadwall (saline) (20)	Gadwall (fresh) (35)	Mallard (37)	Northern pintail (31)
Snails	**38**	**40**	**0**	**4**	**16**	**15**
Insects	**44**	**5**	**52**	**36**	**27**	**37**
Caddis flies	7	tr	1	8	9	1
Beetles	3	2	16	4	5	3
True flies	32	2	26	18	6	3
Midges	20	1	26	17	4	20
Miscellaneous	2	1	9	6	7	0
Crustaceans	**14**	**54**	**20**	**32**	**13**	**14**
Fairy shrimps	5	6	tr	0	4	14
Clam shrimps	tr	7	0	14	6	tr
Water fleas	0	33	10	10	3	tr
Scuds	8	0	0	7	tr	tr
Miscellaneous	1	8	10	7	tr	tr
Annelids	**1**	**0**	**0**	**tr**	**13**	**11**
Miscellaneous	2	0	0	0	3	0
Total	**99**	**99**	**72**	**72**	**72**	**77**

leeches, crayfish) will burrow in sediments to avoid desiccation. Adults of several insect groups may fly to other wetlands if conditions become unsuitable. Flight distances may be less than a few yards to another basin within a wetland complex or more than 50 miles to a distant wetland.

Long-term hydrologic changes shape invertebrate life history strategies. Short-term hydrologic regimes may determine the actual occurrence and abundance of invertebrates. Flooding affects wetland invertebrate occurrence, growth, survival, and reproduction. Entirely different invertebrate communities (Fig. 1) are present in wetland basins with differing hydrological regimes (timing, depth, and duration of flooding). As litter is flooded, nutrients and detrital material (as coarse particulate organic matter) are released for a host of aquatic invertebrates (Fig. 2). As material is broken down into finer particles (fine particulate organic matter), organisms that gather detritus or filter feed will take advantage of the newly available foods. Grazing organisms (Fig. 3) feed on free-floating algae or periphyton, which grows on aquatic plant surfaces. When litter material is consumed, invertebrate populations decrease rapidly. Thus, prolonged flooding (longer than 1 year) of uniform depth leads to reduced wetland invertebrate numbers and diversity. Freezing may also lower spring invertebrate populations in northern locations.

Association with Vegetation Structure

Water regimes not only directly affect invertebrate populations, but indirectly affect other fauna through modification of aquatic plant communities. Hydrological regimes influence germination, seed or tuber production and maturation, and plant structure of aquatic macrophytes. Invertebrate associations are influenced by the leaf shape, structure, and surface area of aquatic vegetation. Macrophytes with highly dissected leaves, such as smartweeds, tend to support greater invertebrate assemblages than do plants with more simple leaf structure, such as American lotus (Fig. 4). The composition of invertebrate populations is associated with plant succession.

Discing and other physical treatments are regularly used to modify less desired plant communities. Initial invertebrate response is great following shallow discing in late summer when the shredded plant material is flooded immediately. The shredding of coarse litter material by discing results in quick decomposition in fall, but invertebrate numbers are reduced the following spring. Cutting robust, emergent vegetation above the ice in winter can also result in a rapid invertebrate response, after spring thaw.

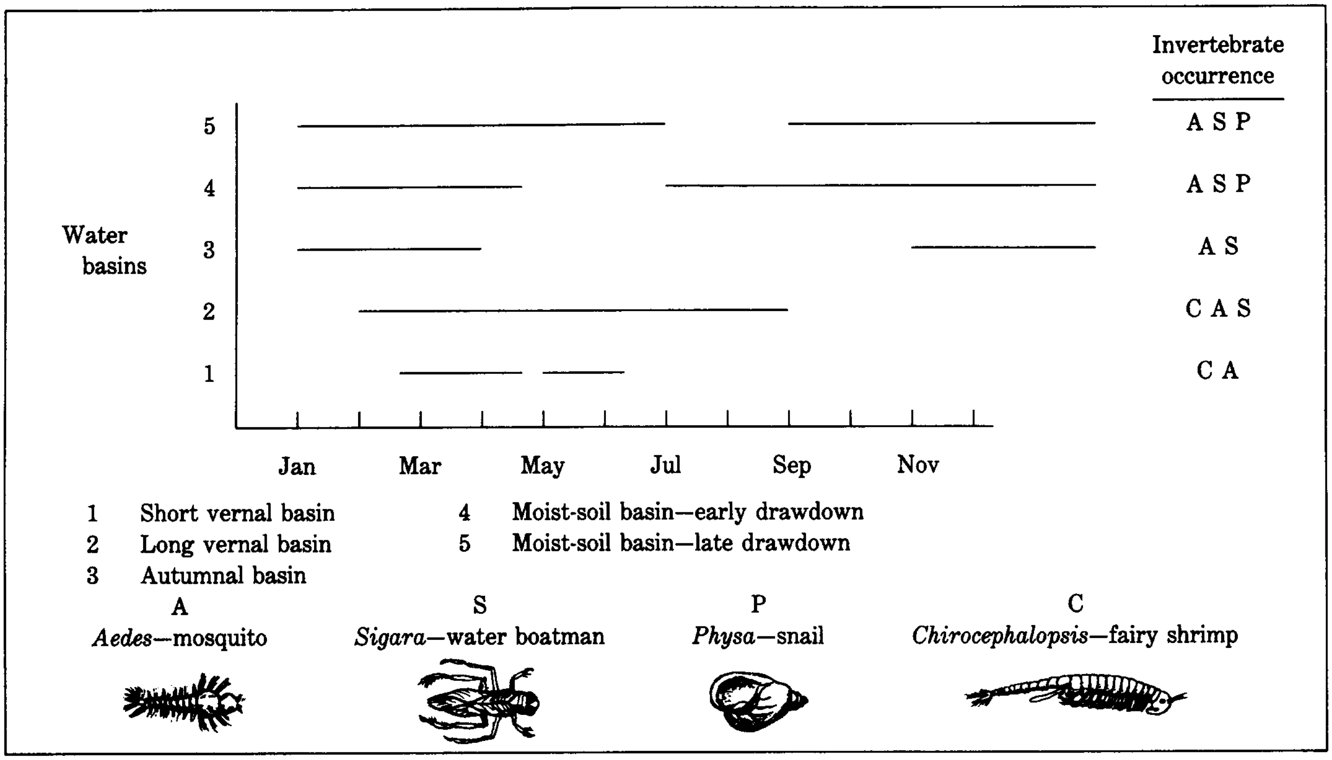


Figure 1. Occurrence of four common invertebrate genera relative to water regimes of five different seasonally flooded basins. Horizontal lines represent presence of water.

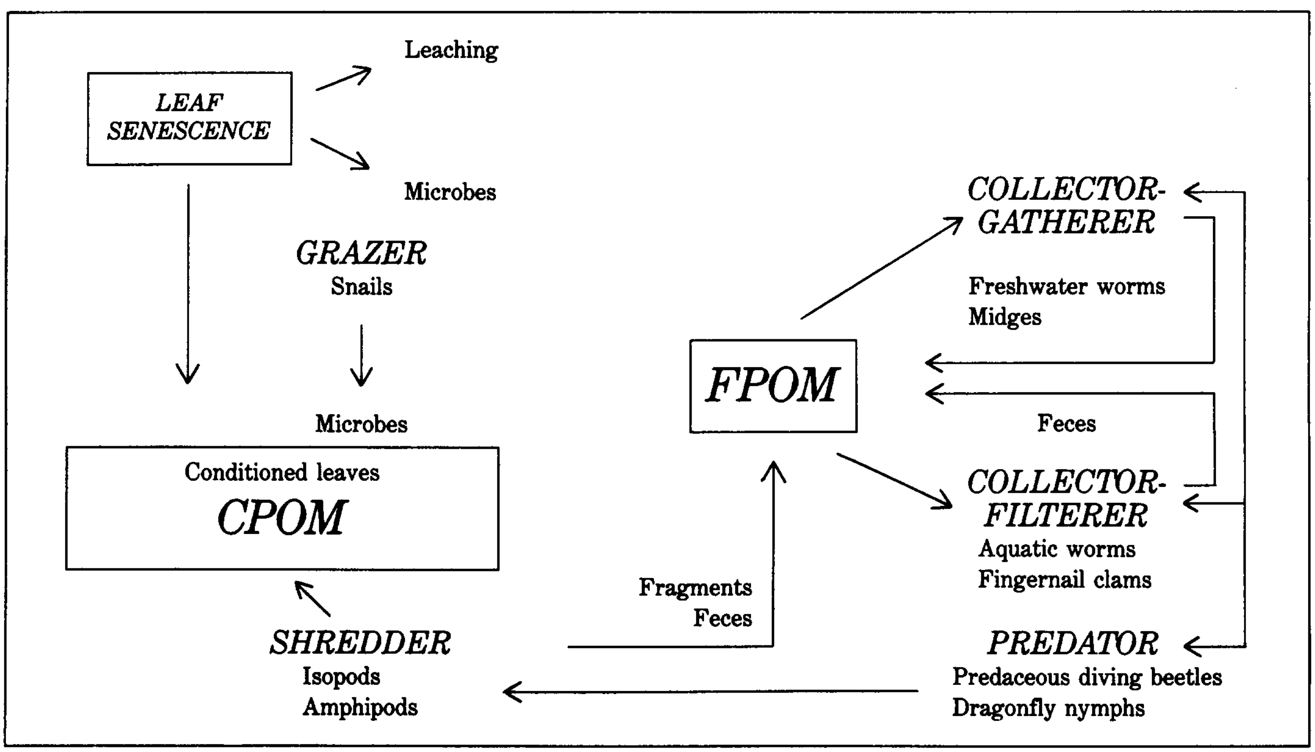


Figure 2. Invertebrate detritivore community. CPOM = Coarse particulate organic matter; FPOM = Fine particulate organic matter.

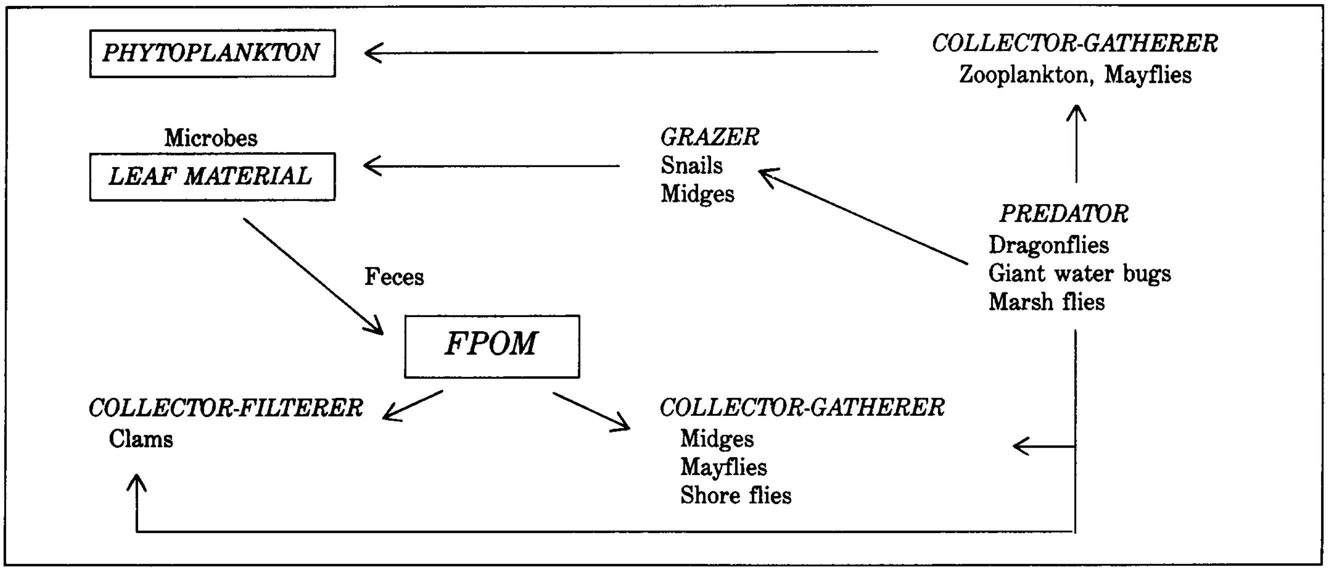


Figure 3. Invertebrate grazer community. FPOM = Fine particulate organic matter.

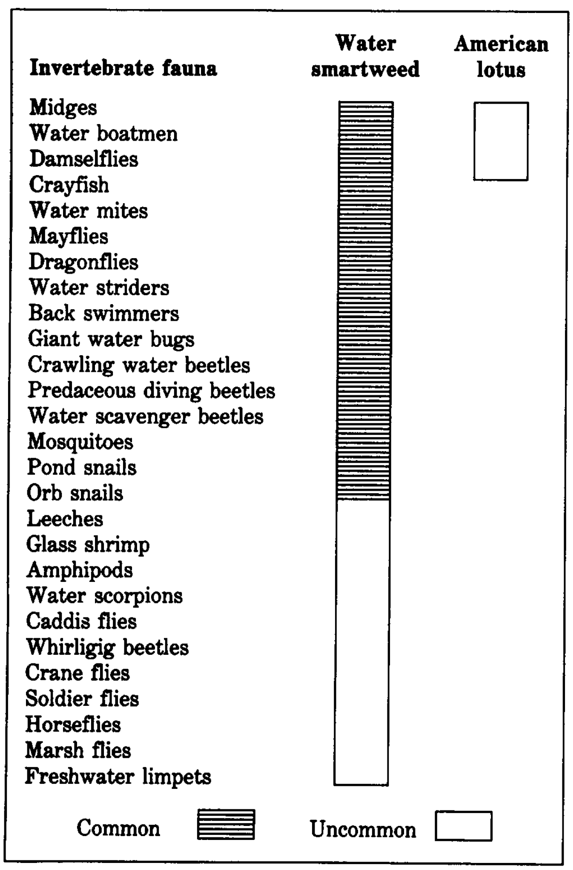


Figure 4. Macroinvertebrates associated with water smartweed and American lotus in seasonally flooded wetlands.

Management Implications

Acquisition of wetlands or protection of previously acquired wetland complexes will continue to be the best means to support diverse invertebrate fauna. The restoration of disturbed wetlands has its greatest potential in areas of marginal agricultural lands. Pesticide use should be eliminated on all refuge areas, regardless of proximity to urban sites where mosquito control is a concern, or the quality of such wildlife areas will be reduced. Inflow waters must be monitored for pollutants and pesticides. The timing of water movements should coincide with the exploitation of leaf litter by invertebrates. Waters should not be drained when nutrient export may be high, such as in early stages of leaf litter decomposition. Present knowledge of water manipulations suggests that management for specific aquatic or semi-aquatic plant communities may be the most practical means of increasing invertebrate production. Managers can enhance the potential for invertebrate consumption by waterfowl if peak periods of waterfowl use of wetlands coincide with reduced water levels. Exploitation of invertebrates by waterbirds can be optimized through shallow water levels, partial drawdowns that concentrate prey, and extended (3–5 week) drawdowns with "feather-edge" flooding to increase the available time and area for foraging.

Suggested Reading

Batema, D.L., G.S. Henderson, and L.H. Fredrickson. 1985. Wetland invertebrate distribution in bottomland hardwoods as influenced by forest type and flooding regime. Pages 196–202 *in* Proc. Fifth Annu. Hardwood Conf., Univ. Ill., Urbana.

Cummins, K.W. 1973. Trophic relations of aquatic insects. Annu. Rev. Entomol. 18:183–206.

Euliss, N.H. Jr., and G. Grodhaus. 1987. Management of midges and other invertebrates for waterfowl wintering in California. Calif. Fish and Game. 73:242–247.

Murkin, H.R., and J.A. Kadlec. 1986. Responses by benthic macroinvertebrates to prolonged flooding of marsh habitat. Can. J. Zool. 64:65–72.

Murkin H.R., R.M. Kaminski, and R.D. Titman. 1982. Responses by dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. Can. J. Zool. 60:2324–2332.

Nelson, J.W., and J.A. Kadlec. 1984. A conceptual approach to relating habitat structure and macroinvertebrate production in freshwater wetlands. Trans. N. Am. Wildl. Nat. Resour. Conf. 49:262–270.

Reid, F.A. 1985. Wetland invertebrates in relation to hydrology and water chemistry. Pages 72–79 *in* M.D. Knighton, ed. Water Impoundments for Wildlife: A Habitat Management Workshop. U.S. Dep. Agric. For. Serv., St. Paul, Minn. 136 pp.

Swanson, G.A. 1984. Invertebrates consumed by dabbling ducks (Anatinae) on the breeding grounds. J. Minn. Acad. Sci. 50:37–40

Swanson, G.A. and M.I. Meyer. 1977. Impact of fluctuating water levels on feeding ecology of breeding blue-winged teal. J. Wildl. Manage. 41:426–433.

Wrubleski, D.A. 1987. Chironomidae (Diptera) of peatlands and marshes in Canada. Mem. Ent. Soc. Can. 140:141–161.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants

American lotus	*Nelumbo lutea*
Smartweed	*Polygonum* spp.
Water smartweed *or* marsh knotweed	*Polygonum coccineum*

Birds

Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*

Invertebrates (Families)

Crayfish	Astacidae
Giant water bugs	Belostomatidae
Midges	Chronomidae
Water boatmen	Corixidae
Mosquitoes	Culicidae
Predaceous diving beetles	Dytiscidae
Water striders	Gerridae
Whirligig beetles	Gyrinidae
Crawling water beetles	Haliplidae
Water scavenger beetles	Hydrophilidae
Pond snails	Lymnaeidae
Water scorpions	Nepidae
Back swimmers	Notonectidae
Orb snails	Planorbidae
Marsh flies	Sciomyzidae
Soldier flies	Stratiomyidae
Horseflies	Tabanidae
Crane flies	Tipulidae

Invertebrates (Orders)

Scuds *or* sideswimmers	Amphipoda
Leeches	Annelida
Fairy shrimp	Anostraca
Water fleas	Cladocera
Beetles	Coleoptera
Clam shrimp	Conchostraca
True flies	Diptera
Mayflies	Ephemeroptera
Water mites	Hydracarina
Isopods	Isopoda
Damselflies, dragonflies	Odonata
Caddis flies	Trichoptera

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.3.2. Initial Considerations for Sampling Wetland Invertebrates

Leigh H. Fredrickson and Frederic A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri–Columbia
Puxico, MO 63960

As the importance of invertebrates to waterbird nutrition and detrital processing has become increasingly evident, the need for effective and efficient invertebrate sampling has grown. Identification of invertebrate responses to management requires sampling and selection of appropriate sampling equipment. Goals must be established according to qualitative or quantitative needs, organism characteristics, and wetland types. Management objectives often can be met by sampling specific invertebrates to index the effect of management rather than through long-term studies requiring large sample sizes and intensive effort. Certain wetland and invertebrate characteristics that should be considered when initiating invertebrate sampling are described below.

Identification of Goals

The initial consideration in any collection of management data is how these data will facilitate more effective management. In most wetland management situations, the first step toward evaluating invertebrate populations is identification of dominant organisms. This can be accomplished by a qualitative approach using simple techniques and relatively few samples. In contrast, when comparisons of sites, techniques, or seasonal and annual variations are desired, quantitative methods are necessary and require more time and effort. Invertebrate communities can be measured using organism occurrence (presence or absence), density (number of organisms per area), and biomass (weight per sample or area). Species diversity, which embraces number and relative abundance of the species, is also commonly used for comparative purposes when monitoring different wetland sites.

Before a biologist can successfully assess invertebrate responses to management, the appropriate taxonomic classification for target species must be identified. The effort required to identify aquatic invertebrates to genus or species is often unnecessary for management purposes. However, grouping invertebrates above the family level may be too broad a classification to identify the functional roles of the organisms within the wetland system or their life history strategies. In general, identification to family is usually adequate for management studies, whereas identification to genus may be appropriate for research endeavors.

Organism characteristics should be considered when developing sampling regimes. Life history considerations should include type and timing of various developmental stages. Invertebrate survival generally drops rapidly during early age classes (Fig. 1). Because of this characteristic, managers should not become alarmed when observing temporal declines in total numbers within a species. Likewise, year-to-year comparisons should be conducted at approximately the same period in an annual cycle.

A good sampling design requires recognition of varying physical parameters of the wetland and water regime. Stream and lake systems usually are sampled in different ways. Extremes in water depth during the annual water regime may dictate the type of sampling gear that will be most effective (Table 1). Where benthos are sampled, substrate type influences choice of equipment. Density and structure of vegetation influence water column sampling. For example, sturdy, emergent vegetation may prevent effective sampling with a sweep net, whereas activity traps can be used effectively in these vegetated zones.

Sampling Technique

The effectiveness of common sampling apparatus in different invertebrate habits is outlined in Table 1. Benthos samplers include dredges and core samplers. Core samplers are extremely effective and inexpensive and can be small and light weight. Core samplers may be made from light-weight PVC pipe, and plastic or metal edges can be added to cut roots or crusted soils. Dredges are poor choices in

Table 1. *The advantages and disadvantages of sampling apparatus for wetland invertebrates.*

Microhabitat	Apparatus	Advantages	Disadvantages
Benthos sediments	Ekman dredge, Ponar dredge	Good for deep water sampling from boat, where bottom sediments are soft	Ineffective in vegetation zones or rocks Difficult to carry Expensive
	Stovepipe sampler	Good for deep sediment samples in moderate water depths	Heavy, difficult to carry in field Expensive
	Core sampler	Can be used effectively in diversity of habitats Volume/depth of sampling easily modified by design Lightweight, inexpensive	Must use with SCUBA in deep water
Water column	Column sampler	Can sample both water column and sediments	May require long field time for small sample size Awkward to carry Expensive
	Sweep net	Provides area-density estimate Lightweight, easy to carry in field Inexpensive	Variation between collectors Difficult to use in dense, robust vegetation
	Activity trap	Standardized procedure Reduced field time Provides samples free of plant/detrital material	Does not give area-density index Predation in traps by fish and invertebrates Passive sampler—may underestimate sedentary organisms
Aerial	Emergence traps	Quantified sample Density estimates	Requires trap construction and maintenance
	Light traps	Time index Ability to collect large qualitative samples	Not an area-density index Mainly nocturnal trap
	Aerial sweep net	Qualitative samples Inexpensive	Not an area-density index Biased sampling
Shoreline	Core samplers	Area-density for semi-aquatic/terrestrial invertebrates Inexpensive	
	Activity traps/ mesh bags	Good time index for mobile invertebrates Good in leaf-based detritivore systems	Passive trap Need to continually move trap in dynamic system Expensive

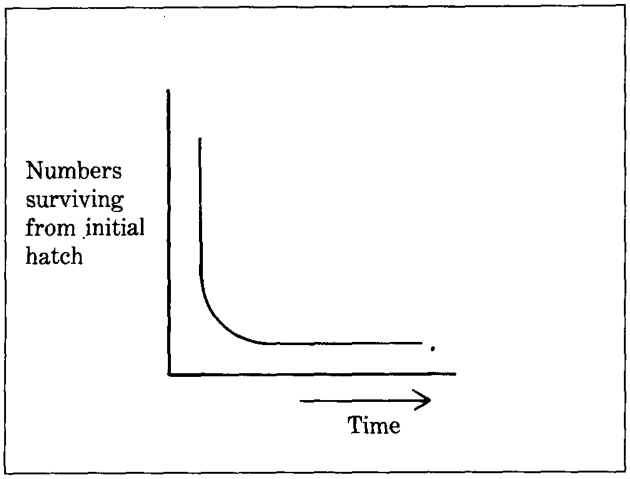


Figure 1. Type III survival curve—typical survival for most aquatic invertebrate populations.

vegetated zones because the springs are usually activated before reaching the sediments, or the jaws will not close sufficiently to contain the entire sample. Nevertheless, in some deep-water areas they offer an acceptable approach. Stovepipe samplers have been used effectively for benthos, but they are often cumbersome for field work. Samples from all these apparatus may be washed through standard sieves to eliminate mud and roots.

Water column samplers include tubular column samplers, sweep nets, and activity traps. Column samplers are expensive and do not work well when submergent vegetation is sampled. Sweep nets are easily manipulated, and field time can be decreased if net inserts are used. Net inserts are constructed of fine netting. These inserts are secured in the larger, coarse net, removed after each sweep, placed in a plastic, zip-lock bag, and transported to the lab. Another insert is used for the next sweep. If more than one technician is available, activity traps may be used for sampling, but those traps are expensive and time-consuming to use. Aerial samples may be collected with quantifiable emergence traps, with qualitative light traps, or with sweep nets. Shoreline samples may be collected with core samples or with replicate mesh traps. Manpower, time investment, and technical expertise must be considered when developing sampling schemes. Diversity among wetlands and their invertebrate communities may require complex sampling methods (Table 2). Field collections for quantitative sampling demand a relatively small amount of time compared to the investment required for sorting, identification, and analysis (Fig. 2).

The techniques listed here provide a framework for sampling. More specific sampling gear can be constructed for the needs of a specific study, but standardization for comparison among other regions is also desirable. Sampling of wetland invertebrates can be conducted for broad qualitative surveys, site or treatment comparisons, or as a long-term index. The needs for long-term sampling should be continually reappraised as long-term management goals are modified.

Table 2. *Examples of potential apparatus selection based on wetland type and project goal.*

Wetland habitat	Project goal	Considerations*	Potential apparatus
Seasonally flooded, annual grasses dominant	Compare general invertebrate fauna associated with dominant plant type	Need index	Sweep net/activity traps
Seasonally flooded, annual grasses dominant	Document peak hatch of midges/ mayflies for potential swallow predation	Need to capture emerging subadults	Emergence traps
Semipermanent, cattails dominant	Compare general invertebrate fauna under varying water regimes	Need index Robust vegetation	Activity traps
Seasonally flooded, pin oak forest	Compare general invertebrate fauna between two greentree reservoirs	Twig/leaf material as substrate	Activity traps/mesh bags
Lacustrine beach	Sample potential foods of a shorebird species	Sample location of feeding birds May include terrestrial environments	Core sampler and sticky traps
Deep, large river	Sample clam population in diving duck feeding area	Deep water, current, and soft substrate	Ponar/Ekman dredge

* Viable replication is a concern in each sample.

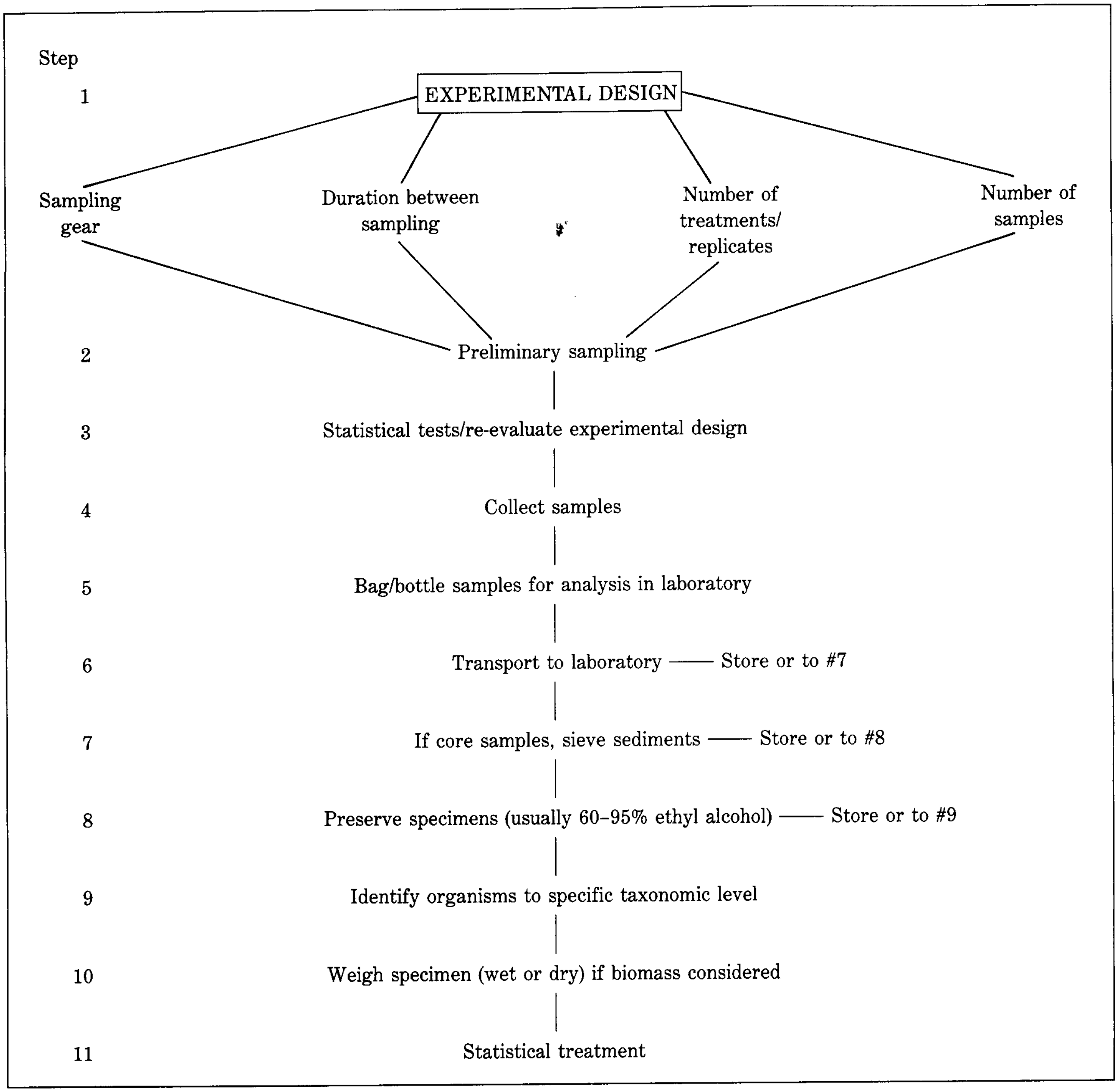


Figure 2. Chronology of steps in wetland invertebrate sampling.

Suggested Reading

Edmondson, W.T. and G.G. Winberg, editors. 1971. A manual on methods for the assessment of secondary productivity in freshwaters. International Biome Program Handbook 17. 358 pp.

Elliott, J.M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. 2nd Ed. Freshwater Biol. Assoc., Spec. Sci. Publ. 25. 160 pp.

Merritt, R.W. and K.W. Cummins, editors. 1984. An introduction to the aquatic insects of North America. 2nd Ed. Kendall-Hunt Publishers, Dubuque, Iowa. 722 pp.

Murkin, H.R., P.G. Abbott, and J.A. Kadlec. 1983. A comparison of activity traps and sweep nets for sampling nektonic invertebrates in wetlands. Freshwater Invetebr. Biol. 2:99–106.

Pennak, R.W. 1978. Fresh-water invertebrates of the United States. John Wiley & Sons, NY. 2nd Ed. 803 pp.

Swanson, G.A. 1983. Benthic sampling for waterfowl foods in emergent vegetation. J. Wildl. Manage. 47:821–823.

Usinger, R.L. 1956. Aquatic insects of California. Univ. Calif. Press, Berkeley. 508 pp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.3.3. Aquatic Invertebrates Important for Waterfowl Production

Jan Eldridge
Bell Museum of Natural History
University of Minnesota
Minneapolis, MN 55455

Aquatic invertebrates play a critical role in the diet of female ducks during the breeding season. Most waterfowl hens shift from a winter diet of seeds and plant material to a spring diet of mainly invertebrates. The purpose of this chapter is to give managers a quick reference to the important invertebrate groups that prairie-nesting ducks consume.

Waterfowl species depend differentially on the various groups of invertebrates present in prairie wetlands, but a few generalizations are possible. Snails, crustaceans, and insects are important invertebrate groups for reproducing ducks (Table). Most species of laying hens rely on calcium from snail shells for egg production. The northern shoveler and gadwall are dependent on crustaceans that swim in the water and forage on algae and fine organic matter. The northern shoveler has an enlarged bill and finely developed lamellae for sieving crustacea from the water. Early-nesting species such as northern pintails and mallards consume early-emerging midge larvae in addition to earthworms, which are often the most available food in ephemeral wetlands shortly after the snowmelt. The diving ducks consume free swimming amphipods or larger insects such as caddis fly and dragonfly larvae that tend to occur in deeper water.

The community of invertebrates present in a wetland can indicate the history of water changes in that wetland. For example, invertebrates such as leeches, earthworms, zooplankton, amphipods, isopods, and gastropods are dependent on passive dispersal (they can't leave the wetland under their own power). As a result, they have elaborate mechanisms to deal with drought and freezing. A second group that includes some beetles and most midges can withstand drought and freezing but requires water to lay eggs in spring. A third group that includes dragonflies, mosquitoes, and phantom midges lays eggs in the moist mud of drying wetlands during summer. A fourth group that includes most aquatic bugs and some beetles cannot cope with drying and freezing, so,they leave shallow wetlands to overwinter in larger bodies of water. Managers can use the presence of these invertebrates to determine the effectiveness of water management regimes designed for waterfowl production.

The following descriptions of invertebrate natural history are based on Pennak (1978).

Invertebrate Natural History

OLIGOCHAETA (Aquatic and Terrestrial Earthworms)

Natural History: Earthworms mix the substrate soils and consume algae and detritus. Their distribution is usually not limited by temperature and many truly aquatic forms survive in low oxygen concentrations. Some earthworms form cysts or cocoons that are transported by birds or the wind.

Table. *Invertebrate classification. The following is a list of the taxonomy of aquatic organisms that will serve most management purposes.*

Phylum	Class	Order
Annelida	Oligochaeta (terrestrial and aquatic earthworms)	
	Hirudinea (leeches)	
Arthropoda	Crustacea	Anostraca (fairy shrimp)
		Conchostraca (clam shrimp)
		Cladocera (water fleas)
		Copepoda(copepods)
		Ostracoda (seed shrimp)
		Amphipoda (scuds and side-swimmers)
	Insecta	Ephemeroptera (mayflies)
		Odonata (dragonflies)
		Hemiptera (true bugs)
		Trichoptera (caddis flies)
		Coleoptera (beetles)
		Diptera (flies and midges)
		Lepidoptera (butterflies and moths)
Mollusca	Gastropoda (Snails)	

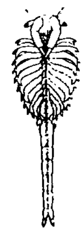
Importance to Waterfowl: Terrestrial earthworms in temporarily flooded, ephemeral ponds early in spring are particularly important to early-nesting mallard and northern pintail hens.

HIRUDINEA (Leeches)

Natural History: Some leeches are blood sucking and forage on birds, mammals, fish, snails, insects, and earthworms. Leeches prefer warm water, and are common in protected shallows. They are primarily nocturnal and require a substrate of rocks or vegetation, so they are uncommon in wetlands that have pure mud or clay bottoms. Leeches survive winter and droughts by burrowing into the mud and becoming dormant.
Importance to Waterfowl: Leeches are not particularly important to waterfowl as food, although they are eaten by mallards in small amounts.

Crustacea

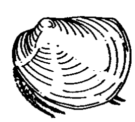
ANOSTRACA (Fairy Shrimp)



General Description: Fairy shrimp generally swim on their backs. They have 2 stalked, compound eyes, 11 pairs of swimming legs that resemble paddles, and no hard external covering.
Natural History: Fairy shrimp are common in small ephemeral and temporary ponds early in spring. They glide upside down, beating their legs in a wave-like pattern from tail to head. Their leg action draws food into the ventral groove toward the mouth. They feed on algae, bacteria, protozoa, and bits of detritus.

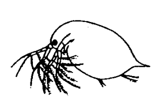
Fairy shrimp lay two kinds of eggs: summer eggs that hatch soon after laying, and resting eggs that sink to the bottom, where they withstand drying or freezing and hatch the next spring. Larvae develop through a series of "nauplius" instars and mature rapidly; some become adults in as few as 15 days.
Importance to Waterfowl: Because fairy shrimp are among the first invertebrates in spring, they are consumed by early laying northern pintail and mallard hens. They also occur in the diets of northern shoveler and blue-winged teal.

CONCHOSTRACA (Clam Shrimp)



General Description: This organism is enclosed in a shell-like outer carapace, and resembles a tiny swimming clam. Clam shrimp have 10–32 pairs of legs and 2 pairs of antennae.
Natural History: Clam shrimp seem to prefer brackish water and swim by moving their large biramous antennae in a rowing motion. Their natural history is similar to that of the fairy shrimp.
Importance to Waterfowl: Clam shrimp form an important part of the diet of laying gadwall hens, and also occur in the diet of mallards and northern shovelers.

CLADOCERA (Water Fleas)

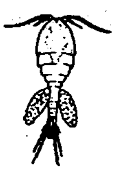


General Description: Water fleas range in size from 0.2 to 3.0 mm long. Superficially, the body appears bivalve with the abdomen and thoracic regions covered by a carapace. The head is compact with two large, compound eyes. Water fleas have large antennae with two segmented rami extending from a large base. They have five to six pairs of biramous legs that are hidden in the carapace.

Natural History: Water fleas use their antennae to swim and appear to hop uncertainly in the water. Their legs produce a current between the valves of their carapace where food collects in the median groove and streams toward the mouth. Algae, detritus, and protozoans are the major items consumed. Water fleas migrate vertically, moving upward in the evening and downward at dawn. They can exist in a variety of temperature and oxygen concentrations.

Water fleas hatch from resting eggs at first thaw. As the water warms they reproduce rapidly, often reaching a large population of 200–500 fleas per liter of water. The population wanes and by summer, few are present in the ponds. Usually they reproduce parthenogenetically; however, as conditions deteriorate later in the season, they produce eggs.
Importance to Waterfowl: Water fleas form a major part of the diet of the laying northern shoveler. Cladocera are also consumed by gadwall and mallard hens.

COPEPODA (Copepods)



General Description: Most copepods are less than 2.0 mm long. Usually they are drab in color; however, in spring, some species are bright orange, purple, and red. The head and part of the thorax are fused in a cephalothorax. The remainder of the thorax and abdomen are segmented. Copepods have large antennae and five thoracic segments that have legs that are used for swimming. They have no abdominal appendages.
Natural History: Most copepods forage on algae, plankton, and detritus. Some forage by scraping food from the pond bottom and some by filtering plankton from the water. Many swim in a smooth, slow motion that is produced by the feeding movements of the mouthparts and antennae, punctuated by jerky leg movements. The front antennae are held stiff and act as a parachute to keep the copepod from sinking.

Copepods breed throughout summer, and are tolerant of oxygen depleted water and adverse conditions such as drying and freezing. Some survive winter as resting eggs, some go into diapause on the wetland bottom and others form cysts or cocoons. Development is through a series of stages before maturity. The time to maturity varies, depending on the environment and the species.
Importance to Waterfowl: Waterfowl do not depend on this group but copepods account for a small portion of the diet of laying northern shoveler and gadwall hens.

OSTRACODA (Seed Shrimp)

General Description: Superficially, ostracods resemble tiny seeds. They are usually less than 1 mm long with an opaque, bivalve shell that varies in color.
Natural History: Seed shrimp tolerate a wide range of environments, temperature, and water chemistry. Most species occur in water less than 1 m deep on varying substrates. Omnivorous scavengers, they forage on bacteria, molds, algae, and fine detritus. Eggs can suspend development in dry and freezing conditions and some live as long as 20 years in the dried condition.
Importance to Waterfowl: Seed shrimp, like copepods, do not dominate the diet of laying females; however, they are consumed in small amounts by gadwall, northern shoveler, and blue-winged teal.

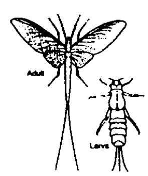
AMPHIPODA (Scuds, Side-swimmers, or Freshwater Shrimp)

General Description: Most amphipods are 5–20 mm long with segmented thorax and abdomen. Their eyes are usually well developed.
Natural History: Amphipods are primarily nocturnal. They swim rapidly just above the substrate, rolling from side to back. Omnivorous scavengers, they consume various plant and animal material. They often browse on the film covering vegetation that is composed of microscopic plants, animals, and detritus.

Amphipods are restricted to cold, shallow water, and an abundance of oxygen is essential. They are generally found in permanent wetlands where they can become abundant, and are not generally adaptable to withstanding droughts.
Importance to Waterfowl: Amphipods are very important to scaup, especially in fall, but they are not particularly important for dabbling ducks. Blue-winged teal, gadwalls, and mallards consume small amounts.

Insecta

EPHEMEROPTERA (Mayflies)

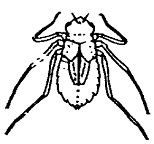


General Description: The aquatic juvenile stage of a mayfly, known as a nymph, is characterized by a long body with a large head, large eyes, and long antennae. The tracheal gills on the abdominal segments are the important feature for distinguishing the mayfly nymph from other insects.

Natural History: Mayflies occur in fresh water with a high oxygen concentration. Most are herbivores or detritivores, however, some are carnivorous and feed on midge larvae. Mayflies are nymphs most of their lives, which can extend for 1–3 years. Adults live 24 h to a few days, mate, lay eggs, and then die.

Importance to Waterfowl: Although mayfly nymphs are not an important item in the diets of waterfowl, they are commonly found in wetlands.

ODONATA (Dragonflies, Damselflies)

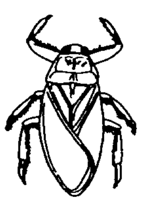


General Description: Nymph—Dragonfly nymphs according to Pennack are "...grotesque creatures, robust or elongated and gray, greenish or somber-colored." The body may be smooth or rough, bearing small spines; it is often covered with growths of filamentous algae and debris. The most striking feature of the larva is the modified mouthparts that are large and folded under the head and thorax.

Natural History: Many dragonflies and damselflies live for 1 year but the large aeschnids live for about 4 years. Odonate nymphs are carnivorous. Nymphs emerge from the water in the morning.

Importance to Waterfowl: Dragonfly nymphs are more important to diving ducks than to dabbling ducks.

HEMIPTERA (True Bugs)



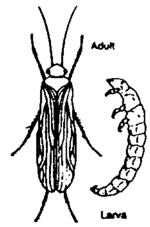
General Description: True bugs have mouthparts that form a piercing beak. Their wings are leathery at the base and membranous at the tip. Their size and shape varies.

Natural History: Aquatic bugs are predaceous, primarily foraging on other insects. They grasp their prey with specialized front legs and suck body fluids with their beak. They winter as adults hidden in the mud and vegetation.

Importance to Waterfowl: Hemiptera occur in small amounts in the diets of gadwall, blue-winged teal, and northern shoveler hens.

TRICHOPTERA (Caddis Flies)

General Description: Adult—Adults are small and inconspicuous. They resemble moths with folded wings and a dodging flight pattern. Caddis

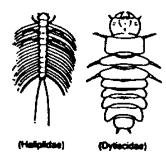


fly larvae are aquatic and most build portable cases of debris.

Natural History: Caddis flies occur in a variety of wetland types that have sufficient oxygen concentrations. They may have one or two generations per year and many larvae overwinter in the wetland. Most are omnivorous but there are grazers, scrapers, suspension feeders, filter feeders, and carnivores.

Importance to Waterfowl: Caddis flies are particularly important to laying canvasbacks and they also occur in the diets of mallard, gadwall, blue-winged teal, and redhead hens.

COLEOPTERA (Beetles)

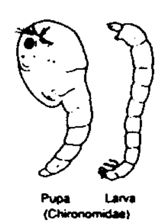


General Description: Beetles are easily distinguished as adults—their forewings are modified into horny shields that cover the abdomen. Larvae are long and thin with six legs—three on a side—characteristic of insects.

Natural History: Most adult aquatic beetles are dependent on air. Adults and larvae occur in shallow water near shore, particularly where there are quantities of debris and aquatic vegetation. Beetles are generally absent from wave-swept shores and deep water. Adults overwinter by burrowing into debris or mud on the bottom of the wetland. The aquatic larvae are highly variable; for example, Dytiscidae (predatory diving beetles) are adapted for a carnivorous life style, whereas Haliplidae (crawling water beetles) larvae are vegetarian, sluggish and sticklike in appearance. Aquatic beetles often have terrestrial pupae.

Importance to Waterfowl: Aquatic beetles occur in small amounts in the diets of gadwall, mallard, northern pintail, blue-winged teal, northern shoveler, redhead, and canvasback hens.

DIPTERA (Flies and Midges)



General Description: This order ineludes all two-winged flies such as horseflies, mosquitoes, crane flies, midges, houseflies, hover flies, and bot flies. Aquatic diptera larvae are highly variable; most are wormlike and lack eyes or jointed thoracic legs. Their bodies are usually soft and flexible. Some larvae such as midges (Chironomidae) have short, stumpy forelegs.

Natural History: Midges are especially important to waterfowl. They occur throughout aquatic vegetation and on the bottom of all types of wetlands. Many hide in fragile tubes they construct of algae and silt. The most abundant type, known as "bloodworms," are bright red in color. Midge larvae are chiefly herbivorous and feed on algae, higher plants, and detritus.
Importance to Waterfowl: Aquatic Diptera are of major importance to blue-winged teal, northern pintail, mallard, gadwall, and redhead hens.

LEPIDOPTERA (Butterflies and Moths)

General Description: Only one family of Lepidoptera have larvae that are truly aquatic. These larvae resemble terrestrial caterpillars—adults are small and inconspicuous.
Natural History: The aquatic moth larvae are found in ponds that are densely overgrown with aquatic vegetation. Larvae often construct cases with two leaves and crawl around with the case. Species winter as immature larvae.
Importance to Waterfowl: Moth larvae are only of minor importance to mallard hens.

GASTROPODA (Snails)

General Description: Most snails are readily identified because of their coiled shell.
Natural History: Most snails are vegetarian. They consume the film of algae that coats submerged surfaces. Many are hermaphroditic and may be self-fertilized or cross-fertilized. Eggs are often deposited in a gelatinous mass in spring, and early development takes place before hatch. When a snail leaves the egg mass, it has taken on the morphological characteristics of the adult. Most snails live 9 to 15 months. In warmer climates, snails may have two to three generations per year. They overwinter by burrowing into the mud and hibernating.

Snails are most common in shallow water, less than 3 m deep. Most species occur in greatest abundance in slightly alkaline conditions. They need calcium carbonate for shell production. They also need water that is clean and has high levels of dissolved oxygen.
Importance to Waterfowl: Snails are very important as a source of calcium for most laying ducks.

Suggested Reading

Drobney, R. D., and L. H. Fredrickson. 1979. Food selection by ducks in relation to breeding status. J. Wildl. Manage. 43:109–l20.

Merritt, R. W., and K. W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall- Hunt Publishing Company, Dubuque, Iowa. 722 pp.

Pennak, R. W. 1978. Freshwater invertebrates of the United States. John Wiley & Sons, New York. 803 pp.

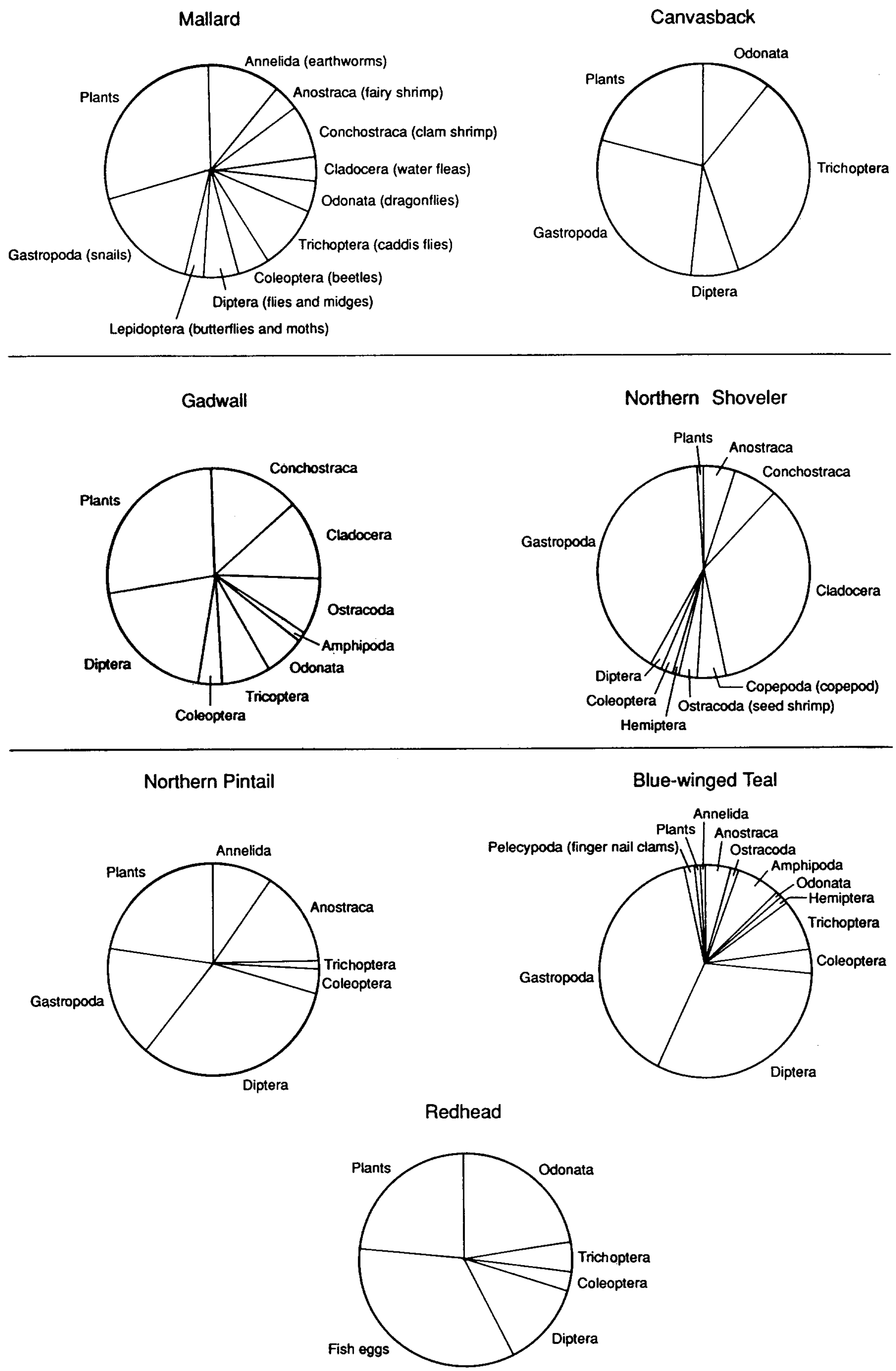
Swanson, G. A., G. L. Krapu, and J. R. Serie. 1979. Foods of laying female dabbling ducks on the breeding grounds. Pages 47–57 in T. A. Bookhout, ed. Waterfowl and wetlands—an integrated review. North-central Section, The Wildlife Society, Madison, Wis.

Swanson, G. A., M. I. Meyer, and V. A. Adomaitus. 1985. Foods consumed by breeding mallards on wetlands of south-central North Dakota. J. Wildl. Manage. 49:197–203.

van der Valk, A. 1989. Northern prairie wetlands. Iowa State University Press, Ames. 400 pp.

Weller, M. W. 1987. Freshwater marshes: ecology and wildlife management. Second ed. University of Minnesota Press, Minneapolis. 150 pp.

Wiggins, G. B., R. J. MacKay, and I. M. Smith. 1980. Evolutionary and ecological strategies of animals in annual temporary pools. Arch. Hydrobiol. Suppl. 58:97–206.



Dietary preferences by laying females of 7 duck species.

Appendix. Common and Scientific Names of Animals Mentioned in the Text.

Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*
Lesser scaup	*Aythya affinis*
Redhead	*Aythya americana*
Greater scaup	*Aythya marila*
Canvasback	*Aythya valisineria*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.3.5. Ecology of Northern Prairie Wetlands

Jan Eldridge
Bell Museum of Natural History
University of Minnesota
Minneapolis, MN 55455

Glaciated wetlands of the prairie pothole region are among the most productive of ecosystems. In terms of primary productivity (vegetation) they rank with the tropical rain forests (Fig. 1). Wetland productivity is controlled by water levels that fluctuate over time. However, primary productivity is highly variable for a variety of reasons including the variance in annual precipitation, the nature of the glacial till, the salinity of the water, the relation of the basin to the groundwater, and the temperature extremes typical of a continental climate.

My purpose is to review the basic patterns that contribute to the productivity of prairie wetlands with the goal of duplicating some of the essential ingredients in managed marshes. The most effective strategy for meeting this goal is through community management. This requires a basic understanding of the dynamics of the marsh ecosystem.

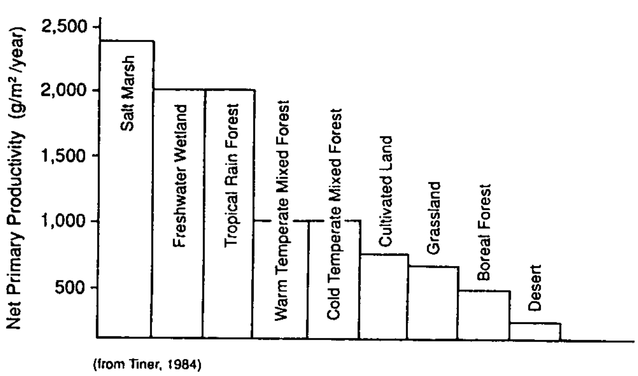


Fig. 1. Net primary productivity (vegetation) of selected ecosystems (from Tiner 1984).

Influence of Climate

The first axiom of marsh management could be derived from Weller (1978) when he observed, "Stability seems deadly to a marsh system." This is primarily because the community of plants and animals typical of any marsh has adapted to the highly variable and unpredictable annual precipitation in the prairie pothole region. The variance in precipitation results in dynamic water level changes in individual basins over time and is reflected in the annual pond count conducted by the United States and Canada (Fig. 2). Only ponds that contain water are counted; as a result, there are more ponds in years when precipitation is above average, than in dry years. The key to understanding a prairie wetland lies in its water dynamics.

Influence of Geology and Hydrology

The reason that wetlands reflect variability in precipitation can be found in the nature of wetland basins. As the last glacier receded about 10,000 years ago, it left large chunks of ice in the glacial till. As these ice chunks melted, shallow depressions were formed. These depressions soon became wetlands because the till in this region is composed

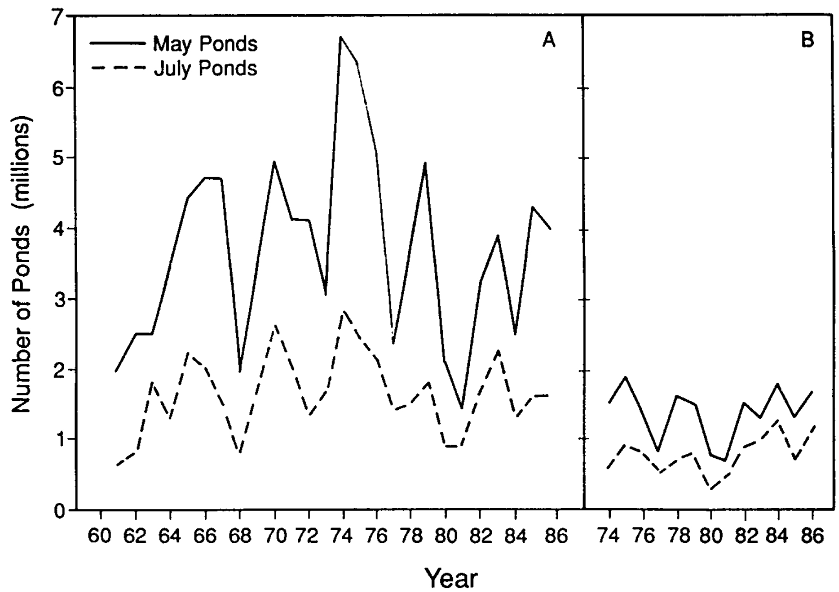


Fig. 2. Pond survey results conducted annually by the United States and Canada.

primarily of impermeable silt and clay. The last glacier was a fairly recent event in geologic time and since its departure, there has not been sufficient time to erode watersheds connecting many of the basins. As a result, the basins fill in response to precipitation in the area and changes in the ground water flow. They drain slowly, often holding water independent of surrounding wetlands.

There is considerable variation between basins in any given area in terms of water permanence and quality. Some wetlands are ephemeral, holding snowmelt only in the spring before the frost leaves the ground. Temporary and seasonal wetlands usually dry by the end of each season. Semipermanent wetlands retain water for a period of years, and permanent wetlands retain their character for decades except in years of extreme drought. Salinity for wetlands usually increases with water permanence.

In a given area, some wetlands may be dry while others are full. Variation in water retention in neighboring wetlands increases habitat diversity for wildlife. The variation can be explained in part by the relation of the basin to the groundwater system. This relation is usually complex and often determines the salinity and permanence of water in the basin. In general, the water level in the basin reflects the local water table. Glacial till is fairly impermeable and as a result, groundwater flow is slow and often uneven. Several patterns in the configuration of groundwater flow have been observed in the prairie pothole region.

- Fairly permanent, saline wetlands result when the water table slopes into a wetland on all sides, and water seeps into the basin but not out. The only way for water to leave is through evaporation or transpiration. As a result, minerals accumulate and the wetland can become very saline.
- When the water table slopes away from the wetland, water leaves the basin and enters the water table, usually in the shallow edges of the basin. This type of wetland contributes to groundwater and is fairly fresh and temporary.
- When the water table slopes into the basin on one side and away from the basin on the other side, the water is brackish and the wetland is semipermanent.

Although these generalized patterns explain some of the variation in wetlands in a particular area, the complete effect of groundwater on wetlands is very complex involving several layers of groundwater flow systems that can extend 10,000 feet below the ground. Other regional climatic patterns also influence salinity in the prairie pothole region. Because the western portion of the region has a drier climate than the eastern portion, evaporation in western wetland basins is greater and, as a result, they become increasingly more saline.

The overriding result of these relations for most wetlands is dynamic fluctuation in water levels and high variance in wetland types within an area. Because basins respond to groundwater, which varies locally, wetlands cycle from wet to dry periods independently. As a result, a group of wetlands in an area forms a diverse set of habitats known as a wetland complex.

Vegetation Structure

Plant species reflect water fluctuations by forming characteristic associations known as zones. Plants within the zones have similar requirements for germination and persistence, and they have similar tolerances for water level permanence and chemistry. For example, in permanently flooded portions of a wetland, submergents such as the widgeongrass, pondweed, and muskgrass dominate. In semipermanently flooded portions, emergents that require mudflats to germinate but that tolerate flooding dominate. Species such as bulrush and cattail are common. In seasonally flooded portions, moist-soil plants such as burreed, smartweed, whitetop, and spikerush dominate, whereas in ephemeral or temporarily flooded areas, species typical of a wet prairie dominate, such as bluestem and prairie cordgrass.

Several basic patterns in the zones can be observed in prairie wetlands.

- The number of zones usually increases with the size of the basin and the time it holds water during the season, so that ephemeral and temporary wetlands may only have one or two zones, whereas larger, semipermanent wetlands may have all of the zones.
- In most wetlands, the height of the emergent vegetation increases in areas where water is more permanent (saline wetlands are an exception).
- The number of different plant species in the zone decreases in areas where water is more permanent.

The plant zones provide structural diversity within the marsh and several zones are more beneficial to vertebrate wildlife than are homogeneous stands. The edge between zones is particularly important; more edge is better for waterfowl because nesting cover becomes more accessible, vegetation diversity increases, and macroinvertebrate production is greater. Macroinvertebrates are particularly important because they are the dominant food of laying hens and broods in wetlands managed for waterfowl production.

Several basic patterns have been reported in plant and invertebrate associations: (1) Invertebrates are more abundant in vegetated areas than in areas devoid of vegetation; (2) invertebrates increase proportionately with plant material, averaging approximately 1 g animal matter to 100 g of plant material; (3) plant species with extensive invertebrate associations are not always the species that ducks consume. Elodea is an example. This plant ranked very low as a food item for waterfowl but was extremely high as a source of cover and habitat for invertebrates (Krull 1970). The plants with more surface structure seem to be ideal for invertebrates.

Vegetation Dynamics and the Food Web

High primary productivity combined with dynamic water fluctuations and severe climate result in rapid nutrient cycling in prairie wetlands. The emergent vegetation acts as a nutrient pump, drawing nutrients from the soil beneath the wetland floor. Much of the aboveground vegetation dies during the winter, so in spring a flush of nutrients enters the wetland in the form of detritus and soluble water-borne nutrients. In addition to seasonal flushes, annual variation in water permanence in the basins results in multi-year variation in nutrient cycles. As the marsh changes, the composition of plant zones changes as plants die and enter the detrital layer.

It is commonly thought that wetland food chains are detritus-driven. In fact, the detritus may function as a substrate for colonizing microorganisms such as various algal types that obtain necessary nutrients directly from the water. The algae are then consumed by larger invertebrates. These larger aquatic invertebrates are the key to the secondary productivity of the marsh ecosystem.

Invertebrates may be divided into a variety of functional groups depending on how they process litter. Shredders and grazers, such as scuds and snails, break up the larger pieces of plant litter. The fine particles of dead plant material are consumed by filter feeders and collectors. Midge larva (Chironomidae) specialize in both functional groups. Some investigators are convinced that these invertebrates consume the detritus to obtain microorganisms, because detritus that is heavily colonized is more rapidly consumed by larger, foraging invertebrates.

In summary, emergent vegetation is high in nutrients, which enter the water column through leaching from standing vegetation that dies, from gradual breakdown of plant litter by larger foraging invertebrates, and from decomposition by microorganisms. There is a flush of nutrients entering the

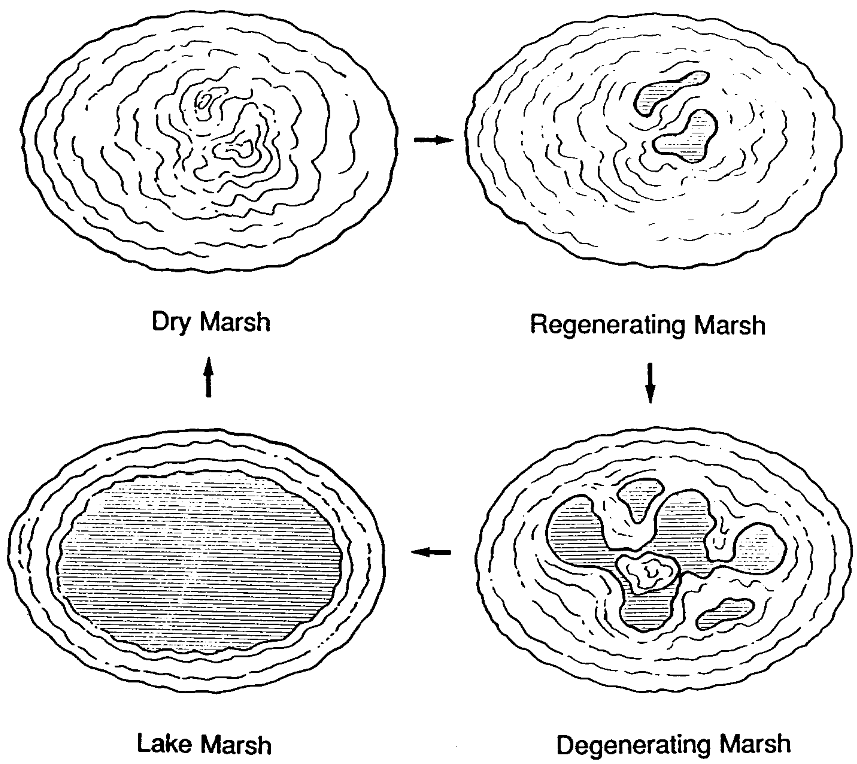


Fig. 3. The four stages of a marsh during a standard wet and dry cycle. Lines represent vegetation zones that become apparent in the regenerating marsh stage, and black represents open water (adapted from van der Valk 1989).

water in the spring, as well as a multi-year nutrient cycle as the vegetation zones respond to changes in the wet and dry cycle.

The vegetation in a marsh responds to dynamic water fluctuations in characteristic ways. This is particularly true for semipermanent wetlands with a capacity to hold water to a depth of 1 m. Four idealized vegetation stages have been identified that correspond to the way the vegetation responds to a typical wet and dry cycle (Fig. 3). Given the variability inherent in the prairies, a typical cyle may be interrupted at any time, but the following stages can be used as a general guide.

Dry Marsh Stage

In the dry marsh stage, a drought exposes part or all of the marsh bottom and many species of annual and perennial emergent plants germinate on the mudflats. Emergents such as cattail require moist mudflats to germinate. As a result, a dense stand of annuals and perennials forms in the wetland basin during a dry year. During this stage, invertebrate production is minimal or nonexistent and the marsh receives relatively little use by wildlife except as a source of cover or for the browse and seeds produced by the annuals.

Regenerating Marsh Stage

In the regenerating marsh stage, water returns to the basin, drowning the moist-soil annuals, but the perennial emergents continue to spread through vegetative propagation. The typical vegetation zones that are characteristic of wetlands develop during this stage. Litter from the annual plants provides an influx of nutrients to the marsh. Some of the soluble nutrients are leached into the water, while other nutrients are consumed by various plankton and detritivores. The emergent stand does not completely close and shade the marsh bottom, so algae flourish on the litter from the dead annuals. The annual litter on the bottom also provides habitat and food for invertebrates such as midges and as a result, invertebrate populations increase. In fact, the substrate and food source provided by the litter from annuals explain the flush of productivity common to newly flooded basins. The rapidly expanding emergent beds also provide

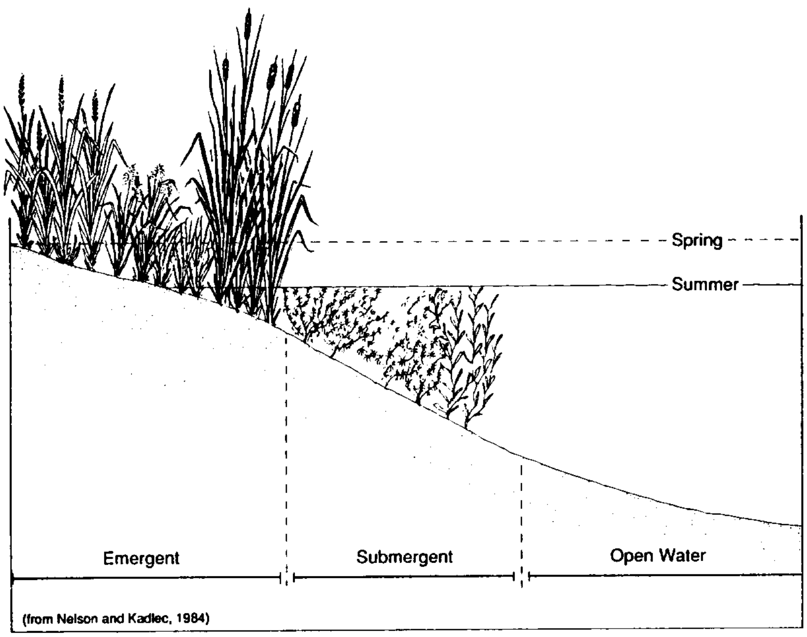


Fig. 4. Seasonal water level changes influence water temperature and create a nutrient-rich current between emergent and submergent vegetation (adapted from Nelson and Kadlec 1984).

food for larger herbivores such as muskrats and as a result, their populations increase.

Degenerative Marsh Stage

After the water has remained in the wetland for several years, the emergents become stressed from water, insects, and senescents. In many areas, muskrats also create openings in the emergent stands. The marsh is in the "hemimarsh" stage when there is a 50:50 ratio of emergent vegetation and open water. At this stage, edge between emergent and submergent vegetation is plentiful, invertebrate populations peak, and waterfowl and other wetland birds respond dramatically. This is the most productive stage of the marsh cycle.

The importance of the edge between emergent and submergent vegetation is particularly relevant for management (often this appears to be the edge between emergent stands of vegetation and open water). Waterfowl prefer the cover provided by a hemimarsh and overwater-nesting birds prefer the isolation provided by the mixture of vegetation; however, they also prefer these marshes because invertebrates are readily available. Invertebrate response is due to the cover provided by the vegetation and to the dynamics of the current at the edge between emergent and submergent vegetation.

Differences in temperature between emergent and submergent vegetation establishe a current between the two areas that is rich in small organic particles from the decomposing vegetation. Many invertebrates forage on algae and fine organic particles and concentrate in edge areas because the current there brings them a rich food supply.

One explanation for this phenomenon is that in spring, when wetlands are flooded, litter accumulates in the emergents and provides structure and substrate for algae and a source of fine organic particles (Fig. 4). As spring progresses, the water recedes and warms. Decomposition accelerates and water quality in the emergent litter deteriorates (reduced oxygen and higher temperature). Invertebrates move to the flooded openings where the growing, submerged vegetation provides substrate and the currents provide a source of organic food particles. As a result, invertebrate populations tend to congregate at the edge between submerged and emergent vegetation. More edge means more invertebrates for waterfowl that rely on invertebrates for food during spring and early summer.

Lake Marsh Stage

As time passes, the wetland lake enters the lake marsh stage where only a ring of emergents remains around the outside of the basin. Floating algae may be the dominating vegetation and midge larvae the dominating macroinvertebrate. The marsh may continue at this stage for many years until a drought, begins the cycle again.

Marsh Management

Managed wetlands with water control can hedge against drainage and drought in surrounding land. In wetlands on floodplains, water control can mitigate against damage caused by flooding and fish invasion. Marsh management in impoundments with water-control capability should duplicate the water dynamics of a natural prairie wetland. The basic goals of wetland management for a semipermanent wetland are as follows:

- Cycle the wetland through drawdown, dense marsh, and open marsh phases.
- Fluctuate water levels to maximize the amount of edge between vegetation zones for increased invertebrate productivity. The ratio of interspersion between emergent and submergent vegetation should be about 50:50 for as long as possible (2 to 5 years on the average). Many semipermanent wetlands do not have natural openings in the the emergent of vegetation stands because the basin is too shallow to drown out cattails and because muskrats are not common enough to creat openings. In these impoundments, artificial openings can be created through grazing, burning, or tillage.
- When conditions in the basin deteriorate, cycle the water back as rapidly as possible, depending on the cycle of other basins in the complex.

This water regime outline is typical for semipermanent wetlands; however, a wetland complex includes a variety of wetland types. Seasonal and temporary wetlands can be created by cycling the water each year and allowing the wetland to slowly dry in summer. Water can be returned to the basin in the fall or the following spring. The plant zones will be simple and the invertebrates that inhabit the basin will differ depending on when the water is returned. These seasonally managed wetlands can be very productive and provide an excellent invertebrate food source for waterfowl.

On refuges, the key to successful water management is to provide a variety of wetland habitats. Water levels in a managed complex should be fluctuated so that basins cycle into the most productive stages asynchronously to provide some optimum habitat each year. The management of a group of wetlands should duplicate the diversity and variation common to a prairie wetland complex by cycling the drawdowns at different times and with differing durations.

The techniques for using drawdowns vary with the area and the latitude of the basins. For example, in the North, nutrient cycling in wetland basins may take longer and the basins may be more vulnerable to damage from overwinter drawdowns, such as invertebrate die-off. In addition, the soil freezes to the surface layer of ice and, in spring, if water returns to the basin before the thaw, the frozen soil will float with the ice. As the ice melts, the soil settles in an unconsolidated layer to the bottom, where it will cause increased turbidity and loss of vegetative growth.

The following guidelines may serve to improve management results:

- Increase water levels slowly after germination in late summer or fall. Flooding during the growing phase clouds the water and decreases light penetration. This approach has the added advantage of providing easy access to annual seed production for fall migrating waterfowl.
- Encourage establishment of the hemimarsh stage by artificially clearing trails in dense stands of emergent growth or by encouraging muskrat populations to increase naturally. If muskrats are present, they will harvest the emergent vegetation for lodges and food.
- Establish submergents vital to invertebrates by allowing several years of stable water levels of moderate depth.

Effective evaluation is the most important aspect of any marsh management program. Evaluations should include inventories of wildlife response to vegetation and of invertebrate response within each managed basin. Overviews and summaries of wildlife response at a refuge may be helpful; however, a basin-specific evaluation will reveal if a management regime is working. The common denominator of all wetlands is variation, so management in each area must vary as well. If management is not accompanied by evaluation, it will be impossible to know if the management regime is providing the habitat necessary for wildlife.

Suggested Reading

Fredrickson, L. H., and F. A. Reid. 1988. Waterfowl use of wetland complexes. U.S. Fish Wildl. Serv., Fish Wildl. Leafl. 13(2.1). 6 pp.

Krull, J. R. 1970. Aquatic plant-invertebrate associations and waterfowl. J. Wildl. Manage. 34:707-718.

Nelson, J. W., and J. A. Kadlec. 1984. A conceptual approach to relating habitat structure and macroinvertebrate production in freshwater wetlands. Trans. N. Am. Wildl. Nat. Resour. Conf. 49: 262-270.

Pennak, R. W. 1978. Freshwater invertebrates of the United States. John Wiley & Sons, New York. 803 pp.

Stewart, R.E. and H.A. Kantrud. 1971. Classification of natural ponds and lakes in the glaciated prairie region. U.S. Fish Wildl. Serv., Resour. Publ. 92. 57 pp.

van der Valk, A. 1989. Northern prairie wetlands. Iowa State University Press, Ames. 400 pp.

Tiner, R.W. 1984. Wetlands of the United States: current status and recent trends. U.S. Fish and Wildlife Service, National Wetlands Inventory. 59 pp.

Weller, M. W. 1978. Management of freshwater marshes for wildlife. Pages 267-284 *in* R. E. Good, D. F. Whigham, and R. L. Simpson, eds. Freshwater wetlands: ecological processes and management potential. Academic Press, New York.

Weller, M. W. 1987. Freshwater marshes: ecology and wildlife management. University of Minnesota Press, Minneapolis. 2nd ed. 150 pp.

Appendix. Common and Scientific Names of Plants and Animals Named in the Text.

Plants	
Widgeongrass	*Ruppia* spp.
Pondweed	*Potamogeton* spp.
Elodea	*Elodea* spp.
Muskgrass	*Chara vulgaris*
Bullrush	*Scirpus* spp.
Cattail	*Typha* spp.
Burreed	*Sparganium* spp.
Smartweed	*Polygonum* spp.
Whitetop	*Scolochloa festucacea*
Spikerush	*Eleocharis*
Bluestem	*Andropogon* spp.
Prairie cordgrass	*Spartina pectinata*
Invertebrates	
Scuds *or* Side-swimmers	Amphipoda
Snails	Gastropoda
Midges	Insecta, Diptera, Chironomidae
Vertebrates	
Muskrats	*Ondatra zibethicus*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.3.6. Ecology of Montane Wetlands

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Road
Fort Collins, CO 80526

Most waterfowl managers envision typical waterfowl habitat as the undulating or flat terrain characteristic of the prairie pothole region of the north-central United States or the aspen parklands of Canada. However, several other habitats in North America provide valuable resources for breeding and migrating waterfowl. Among these is the Rocky Mountain region of the western United States, which stretches in a band 100–500 miles (160–800 km) wide and 1,240 miles (1,984 km) long from south-central New Mexico to northern Montana (Figure).

Some Rocky Mountain wetland complexes contain waterfowl breeding densities that equal or exceed those of prairie breeding habitat, and also serve as important staging, migratory, and wintering areas. To aid waterfowl management endeavors in this region, this leaflet summarizes aspects of wetland ecology and waterfowl biology in montane habitats. Although emphasis is placed on the Rocky Mountain region, many of the wetland characteristics and waterfowl relationships in this area are similar or identical to those found in other montane regions of the United States.

Comparisons with Prairie Wetlands

As in other regions, waterfowl that breed in montane habitats require suitable upland nesting areas coupled with a diverse wetland community, from which they obtain aquatic invertebrates, plant foods, and isolation from territorial birds of the same species. These wetland complexes also attract spring and fall migrants and, in some instances, wintering waterfowl.

Montane waterfowl habitats have several attributes that set them apart from their grassland counterparts. First, montane wetland communities are relatively intact compared with the widespread wetland degradation typical of the northern Great Plains. This more nearly pristine condition reflects the rugged topography and generally poor soils of the region, which favor ranching, timber harvest, and mining rather than farming. Additionally, some areas are afforded legal protection as wilderness areas or research natural areas. Second, except where locally affected by mining operations and ski areas, for example, upland plant communities are still dominated by native plant species despite some grazing and timber harvest. Third, although the magnitude of the snowpack and rainfall varies annually, precipitation is almost always sufficient to provide adequate spring water for ducks and geese. Thus, montane wetlands are relatively stable compared with those in the prairie states.

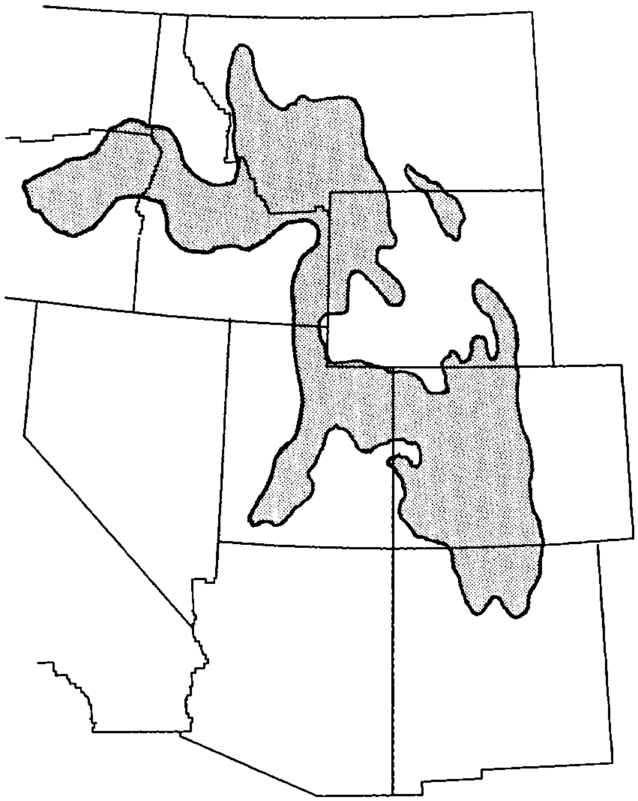


Figure. Distribution of montane wetlands (*shading*) in the Rocky Mountain region of western United States.

The geology and topography of montane regions create a greater diversity of wetland types than may be found in the prairies. Rocks weather slowly, and annual primary production decreases with elevation, so wetland succession proceeds much more slowly in montane wetlands than in low-elevation ponds. Elevational gradients interacting with precipitation patterns and growing season affect soil type, nutrient cycling, water chemistry, and associated plant and animal communities. Most high-elevation wetlands are slightly acidic to circumneutral and contain relatively small amounts of dissolved nutrients compared with typical prairie wetlands. Accordingly, only some types of montane wetlands are frequented by waterfowl, unlike their wide use of most prairie ponds. Recognition of the wetland types inhabited by waterfowl and an understanding of basic wetland function is therefore important to the success of any waterfowl management initiative in montane habitats.

Montane Wetlands Important to Waterfowl

Intermountain Basin Wetlands

The intermountain basins or "parks" of the western United States contain the most important habitats for montane waterfowl. The flat or rolling topography typical of mountain parks, which originated from tectonic and volcanic events during the formation of mountain ranges, is underlain by deep layers of alluvial material eroded from the surrounding mountains and transported to nearby basins by wind and water. Although relatively few in number—33 parks have been identified in the Rocky Mountain region—intermountain basins are often several hundred square miles in area. Many parks are considered cool deserts because of the low precipitation created by the rain shadow from surrounding mountains. The average frost-free period may be less than 2 months. Despite low seasonal temperatures, ratios of precipitation to evaporation are usually less than 1, causing the development of pedocal soils. Where alkali deposits occur in poorly drained areas, salt-tolerant plants such as black greasewood and saltgrasses are common. Less saline areas typically contain wheatgrasses, bluegrasses, sedges and rushes, or shrubs such as sagebrush and rabbitbrush. Ranching and hay cultivation are the most common land uses, but some grain crops and cold-weather vegetables are grown in more temperate parks.

Many intermountain basins contain few wetlands; some, such as the 5,000-square-mile (12,950-km^2) San Luis Valley in south-central Colorado, possess abundant wetlands. Wetlands are formed by spring runoff, which creates sheet water and recharges the persistently high water tables, and by artesian flows and impoundments. Lakes and reservoirs provide important migratory staging and molting habitats, and lake margins attract breeding waterfowl. Rivers and old oxbows are also frequented by waterfowl. Dissolved nutrients and high amounts of organic matter create some wetlands that rival prairie potholes in their fertility. High densities of aquatic invertebrates such as freshwater shrimp and the larvae of dragonflies, midges, flies, and mosquitos are common in intermountain basin wetlands.

Beaver Ponds

Beaver ponds most commonly occur in mid-elevation, montane valleys where slope is less than 15%. Because beaver ponds are often clustered in flowages along suitable lengths of streams and rivers, they provide a valuable wetland community well suited to the needs of breeding waterfowl. Densities of 3 to 6 ponds per mile (5–10 ponds per kilometer) of stream are common, increasing to as many as 26 ponds per mile (42 ponds per kilometer) in excellent habitat with high beaver populations. Wetlands created by beaver possess relatively stable water levels maintained by precipitation and runoff. However, beaver flowages themselves may be somewhat ephemeral in nature, and usually are abandoned within 10–30 years, after beaver deplete their food resources. Floods sometimes destroy beaver dams that are constructed in narrow valleys or on major streams or rivers.

Beaver ponds act as nutrient sinks by trapping sediments and organic matter that otherwise would be carried downstream. This function enhances wetland fertility and the plant and aquatic invertebrate communities exploited by waterfowl. Invertebrates typical of running water systems are replaced by pond organisms such as snails, freshwater shrimp, and the larvae and immature stages of caddisflies, dragonflies, flies, and mosquitos. Structural cover provided by flooded willows, alders, sedges, burreeds, and other emergents affords ideal habitat for waterfowl breeding pairs and broods.

Glacial Ponds

Glacial ponds include (1) small wetlands formed behind lateral and terminal moraines, and (2) kettle ponds created by the same glacial process that found the prairie potholes—large chunks of ice embedded in glacial outwash melt after a glacier retreats, forming depressions that later fill with water. Glacial wetlands most commonly occur in mountainous terrain. Often, these ponds are dependent solely on spring runoff and summer precipitation for water. Therefore, water levels recede during summer, while density and abundance of herbaceous, emergent vegetation increases. Despite dynamic water level fluctuation, natural succession is slow; peat accumulations indicate that some glacial ponds have persisted as wetlands for more than 7,000 years.

Northern mannagrass, sedges, and reedgrasses are common emergent plants in glacial ponds, as are submersed species such as pondweeds, watermilfoils, and cowlilies. Glacial ponds are often surrounded by forested uplands and rocky moraines. These physical features and the relatively small size of glacial ponds may restrict the types of waterfowl using them to dabbling duck species that can take off in confined areas. The shallow water depths typical of kettle ponds often are unsuitable for sustaining fish populations, which might otherwise compete with waterfowl for aquatic invertebrate foods. The absence of fish and the abundant underwater substrate provided by herbaceous vegetation promote a rich invertebrate fauna dominated by larvae or immature stages of caddisflies, dragonflies, beetles, and mosquitos.

Ecological Relations

Elevational changes result in ecosystem regions or life zones characterized by differences in precipitation, humidity, temperature, growing season, wind, exposure, and soil conditions. The four life zones recognized in the Rocky Mountain region—Lower Montane, Upper Montane, Subalpine, and Alpine—possess unique flora and fauna. Only the wetlands found in the first three zones are used extensively by waterfowl. Alpine wetlands receive occasional use by migrating and postbreeding waterfowl, but the duration of the ice-free period and growing season is too brief to enable waterfowl to breed.

Montane habitats separated by relatively small distances often vary markedly in annual precipitation. Much of this variation is attributable to altitude and slope. Western slopes usually receive more snowfall than eastern slopes or areas in the rain shadow of surrounding mountains. For example, portions of the San Luis Valley in south-central Colorado (8,200 feet or 2,500 m elevation) receive less than 7 inches (18 cm) of moisture per year, whereas the nearby western slopes of the San Juan Mountains at the same elevation receive over 40 inches (102 cm) per year. Accordingly, west- and north-facing slopes usually support different plant communities than southern and eastern slopes.

Snowmelt begins in late April and May in Lower and Upper Montane zones but occurs 3 to 4 weeks later in Subalpine areas. The shade provided by a forest canopy further delays snowmelt, thus providing wetlands in forested areas a more constant supply of water. However, the flora and fauna in such wetlands may develop more slowly than in ponds in open terrain. This delayed development is a result of the constant supply of cold snowmelt water, as well as shading from the forest canopy, which reduces sunlight penetration.

The effects of precipitation patterns and snowmelt on floristic and faunal development have important implications for breeding waterfowl. In prairie habitats, breeding waterfowl often use wetlands of different water permanencies to optimize their exploitation of aquatic invertebrates. Temporary prairie wetlands are heavily used in early spring because their invertebrate faunas develop quickly in the warm, shallow water. More permanent wetlands, in which development of invertebrates is delayed, receive increasing use in the spring and summer. In montane habitats, however, this temporal pattern of use in relation to water permanency is superimposed on a spatial component that includes exposure and time of runoff. Small, shallow snowmelt ponds, which are the counterparts of temporary ponds in the prairies, usually lack invertebrate faunas of value to waterfowl. Instead, the shallow margins of permanent wetlands are the areas in which the invertebrate fauna is richest in early spring.

The timing of snowmelt runoff is also critical to understanding waterfowl exploitation of montane habitats. Many species (e.g., mallards and green-winged teal) begin nesting long before runoff begins to fill wetlands in most intermountain basins. The early application of water in such areas by pumping or by releasing water from reservoirs is vital in providing habitat to attract and hold breeding pairs and for promoting development of aquatic invertebrates needed by prelaying female ducks. At higher elevations, where natural kettle ponds, lakes, and beaver flowages have retained water through winter into early spring, runoff often increases water levels through late spring and into early summer, increasing the amount of wetland habitat through the middle of the nesting period.

Nutrient availability is important in regulating wetland primary productivity, which in turn affects periphyton, invertebrate, and waterfowl abundance. Surface runoff is far more important than groundwater flow or direct precipitation in determining water level dynamics and nutrient input to montane wetlands. Thin, coarse soils on granite bedrock tend to be acidic and low in nutrients, whereas soils near limestone and shale outcroppings are more finely textured, higher in nutrients, and buffered by calcium carbonate. Wetlands fed by runoff from the latter soils tend to receive higher nutrient loads from runoff, and therefore have higher productivity than wetlands associated with granitic soils. Some common wetland plants such as alders and rushes host nitrogen-fixing bacteria that incorporate atmospheric nitrogen into wetlands, providing a supplemental source of nutrients. Waterfowl and beaver are the primary animal groups to import nutrients to montane wetlands, although defecation by large herbivores such as moose, elk, mule deer, bighorn sheep, cattle, and domestic sheep may also be important.

Waterfowl Resources

Waterfowl populations in montane habitats have not been well studied. Most research has been conducted at mid-latitude habitats between 7,000 and 10,000 feet (2,100–3,000 m) elevation. Despite the relatively harsh climate and infertility of montane wetlands, waterfowl are surprisingly abundant in these areas. Generally, peak waterfowl populations occur during spring and fall migration periods, particularly in intermountain basins. As prairie-nesting species migrate northward in spring, resident birds establish territories in preparation for breeding. In beaver pond and glacial wetland habitats, numbers of waterfowl decline as females proceed with incubation and males seek larger wetlands during the time of molting. Often, a molt migration occurs from higher elevation forested habitats to large lakes and reservoirs in intermountain basins. During fall, postfledging young birds also move toward lower-elevation staging areas in mountain parks. Most mid-latitude montane wetlands freeze during October, greatly reducing the amount of available wetland habitat. Some wetland areas, however, such as the San Luis Valley of south-central Colorado, retain open water reaches as a result of warmer flows from springs and artesian wells. Major river systems also afford winter habitat, particularly if cereal grain crops or other foods are located nearby.

Species composition of the waterfowl community varies seasonally and in relation to habitat type (Table 1). Mallards and green-winged teal are usually the most common nesting species in both intermountain parks and higher-elevation

Table 1. *Relative species abundance in different montane wetlands during spring and fall migration (*M *or* m*), breeding (*B *or* b*), and wintering (*W *or* w*) periods. Uppercase letters denote greater relative abundance than lowercase letters.*

Species	Montane wetland type: Intermountain basin	Beaver pond	Glacial wetland
American wigeon	M,B	b	b
Barrow's goldeneye	m	m,b	m,b
Blue-winged teal	m,b	—	—
Bufflehead	m,b	m,b	m,b
Canada goose	M,B,w	b	—
Cinnamon teal	m,B	—	—
Common merganser	m	m,b	m,b
Gadwall	M,B	b	b
Green-winged teal	M,B,w	m,B	m,b
Lesser scaup	M,B	—	—
Mallard	M,B,w	m,B	m,B
Northern pintail	M,B,w	—	—
Northern shoveler	M,B	—	—
Redhead	M,B	—	—
Ring-necked duck	m,b	M,B	M,B
Ruddy duck	m,b	—	—
Trumpeter swan	b[a]	—	—

[a] Primarily riverine habitats.

Montane and Subalpine zones. Gadwalls, northern pintails, American wigeon, cinnamon teal, northern shovelers, redheads, lesser scaup, and Canada geese are other common breeders in intermountain basins. Trumpeter swans are important year-round residents in the northern Rockies. In beaver and glacial ponds of the Upper Montane and Subalpine zones, ring-necked ducks, Barrow's goldeneyes, buffleheads, and gadwalls are common. The peak of nest initiation for early-nesting ducks (mallards and green-winged teal) varies from early May to early June, depending on snow conditions and wetland availability. Late-nesting species such as ring-necked ducks begin nesting nearly a month later than early-nesting species.

Breeding densities vary greatly among montane habitats (Table 2), largely as a function of wetland density and availability of open water to attract and hold spring migrants. Wetlands larger than 1 acre (0.405 ha) receive most of the use by breeding ducks, although much smaller wetlands are also frequented. Considerably larger wetlands are needed to attract molting birds and fall migrants. Some intensively managed habitats achieve remarkably high breeding densities. For example, the 22-square-mile (57-km^2) Monte Vista National Wildlife Refuge in the San Luis Valley of Colorado averaged 277 duck nests per square mile (107 duck nests per square kilometer) during a 27-year period, and some individual wetland units exceeded 3,000 nests per square mile (1,158 nests

Table 2. *Waterfowl breeding pair densities in montane habitats. Habitat type denotes either forested montane (*FM*) or intermountain basin (*IB*) study sites.*

Density		Area sampled		Elevation		
pairs/mi^2	pairs/km^2	mi^2	km^2	feet	m	Location (habitat type)
1.6	0.62	36	93.2	7,500–10,000	2,285–3,047	Uinta Mountains, Utah (FM)
1.6	0.62	18	46.6	9,000–10,000	2,742–3,047	White River Plateau, Colo. (FM)
4.1	1.58	685	1,774.0	8,000–10,000	2,437–3,047	San Juan Mountains, Colo. (FM)
21.8	8.42	7	18.1	8,500–9,500	2,590–2,894	Park Range, Colo. (FM)
0.5	0.19	900	2,331.0	8,400–9,900	2,559–3,016	South Park, Colo. (IB)
5.2	2.01	5,000	12,950.0	7,400–8,000	2,255–2,437	San Luis Valley, Colo. (IB)
27.2	10.50	598	1,549.0	8,000–9,000	2,437–3,047	North Park, Colo. (IB)

per square kilometer) in some years. This compares favorably to nesting densities in the best prairie habitat, where, except in island nesting situations, 400–700 duck nests per square mile (150–270 duck nests per square kilometer) are typical. Moreover, nest success averaged 50%, a rate about four times as high as that in much of the northern Great Plains. The unfragmented habitat and balanced predator communities typical of many montane areas undoubtedly contribute to these high nest success rates. The combination of high nest success and potentially high breeding densities underscores the pronounced management potential of some montane habitats.

Waterfowl Habitat Management

Most waterfowl habitat management is directed at correcting problems caused by humans. Montane wetlands management is no exception, although the causes of habitat deficiencies are often different than those found in prairie habitats. In Upper Montane and Subalpine zones, logging activities may cause disturbance, reduce the amount of available nesting cover surrounding wetlands, and cause erosion and sediment deposition in ponds. Reseeding and stabilizing uplands may be necessary to promote the timely regrowth of grasses and forbs. Disturbance from recreationists can also become a problem in popular areas, and seasonal restrictions on activities in buffer zones surrounding wetlands may be necessary. Grazing by domestic livestock and native ungulates can have locally severe effects on riparian vegetation and surrounding uplands. Eliminating grazing, reducing stocking rates, and fencing portions of wetlands can reverse the habitat degradation. Mining activities often physically alter or destroy wetlands, and can create acid runoff that drastically alters water chemistry and devastates invertebrate communities. Reclamation of wetlands despoiled by mining activities, although technically possible, is often difficult and costly. Beaver, which create beneficial wetland habitat, can also become a nuisance if populations grow beyond carrying capacity and begin to degrade streamside vegetation. Control by trapping or transplanting may be warranted in such instances. Agricultural practices have affected plant communities and wetland abundance in several intermountain basins, as they have in the prairie states. In these instances, the conventional waterfowl management practices developed in the prairies can be successfully employed to improve waterfowl habitat.

Some human activities have caused irreversible damage to waterfowl habitat. Among these are residential developments along riparian corridors, and dams and water diversions that have either flooded former shallow wetland habitat or dewatered once productive wetlands. Fortunately, however, many montane habitats, particularly those in the Upper Montane and Subalpine zones, have been insulated sufficiently from human activities that no management activities are warranted. In these pristine habitats, actions are best directed toward habitat preservation rather than improvement. By conducting a biological reconnaissance of waterfowl populations and identifying limiting factors before initiating management actions, managers can avoid trying to fix something that isn't broken.

Selected Reading

Frary, L. G. 1954. Waterfowl production on the White River Plateau, Colorado. M.S. thesis, Colorado State University, Fort Collins. 93 pp.

Hopper, R. M. 1968. Wetlands of Colorado. Colorado Department of Game, Fish and Parks Technical Publication 22. 88 pp.

Peterson, S. R., and J. B. Low. 1977. Waterfowl use of Uinta Mountain wetlands in Utah. Journal of Wildlife Management 41:112–117.

Rutherford, W. H., and C. R. Hayes. 1976. Stratification as a means for improving waterfowl surveys. Wildlife Society Bulletin 4:74–78.

Szymczak, M. R. 1986. Characteristics of duck populations in the intermountain parks of Colorado. Colorado Division of Wildlife Technical Publication 35. 88 pp.

Windell, J. T., B. E. Willard, D. J. Cooper, S. Q. Foster, C. F. Knud-Hansen, L. P. Rink, and G. N. Kiladis. 1986. An ecological characterization of Rocky Mountain montane and subalpine wetlands. U.S. Fish and Wildlife Service Biological Report 86(11). 298 pp.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Birds	
Northern pintail	*Anas acuta*
American wigeon	*Anas americana*
Northern shoveler	*Anas clypeata*
Green-winged teal	*Anas crecca*
Cinnamon teal	*Anas cyanoptera*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Gadwall	*Anas strepera*
Lesser scaup	*Aythya affinis*
Redhead	*Aythya americana*
Ring-necked duck	*Aythya collaris*
Canada goose	*Branta canadensis*
Bufflehead	*Bucephala albeola*
Barrow's goldeneye	*Bucephala islandica*
Trumpeter swan	*Cygnus buccinator*
Ruddy duck	*Oxyura jamaicensis*
Mammals	
Moose	*Alces alces*
Beaver	*Castor canadensis*
Elk	*Cervus elaphus*
Mule deer	*Odocoileus hemionus*
Bighorn sheep	*Ovis canadensis*
Invertebrates (orders)	
Freshwater shrimp	Decapoda
Beetles	Coleoptera
Flies	Diptera
Midges	Diptera
Mosquitos	Diptera
Dragonflies	Odonata
Caddisflies	Trichoptera
Plants	
Wheatgrass	*Agropyron* spp.
Alder	*Alnus* spp.
Sagebrush	*Artemisia* spp.
Sedge	*Carex* spp.
Rabbitbrush	*Chrysothamnus* spp.
Saltgrass	*Distichlis* spp.
Northern mannagrass	*Glyceria borealis*
Rush	*Juncus* spp.
Watermilfoil	*Myriophyllum* spp.
Cowlily	*Nuphar* spp.
Pondweed	*Potamogeton* spp.
Bluegrass	*Poa* spp.
Willow	*Salix* spp.
Greasewood	*Sarcobatus vermiculatus*
Burreed	*Sparganium* spp.

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Fish and Wildlife Leaflet 13
Washington, D.C. • 1992

13.3.7. Ecology of Playa Lakes

David A. Haukos[1]
U.S. Fish and Wildlife Service
Buffalo Lake National Wildlife Refuge
P.O. Box 179
Umbarger, Texas 79091

and

Loren M. Smith
Department of Range and Wildlife Management
Texas Tech University
Lubbock, Texas 79409

Between 25,000 and 30,000 playa lakes are in the playa lakes region of the southern high plains (Fig. 1). Most playas are in west Texas (about 20,000), and fewer, in New Mexico, Oklahoma, Kansas, and Colorado. The playa lakes region is one of the most intensively cultivated areas of North America. Dominant crops range from cotton in southern areas to cereal grains in the north. Therefore, most of the native short-grass prairie is gone, replaced by crops and, recently, grasses of the Conservation Reserve Program. Playas are the predominant wetlands and major wildlife habitat of the region.

More than 115 bird species, including 20 species of waterfowl, and 10 mammal species have been documented in playas. Waterfowl nest in the area, producing up to 250,000 ducklings in wetter years. Dominant breeding and nesting species are mallards and blue-winged teals. During the very protracted breeding season, birds hatch from April through August. Several million shorebirds and waterfowl migrate through the area each spring and fall. More than 400,000 sandhill cranes migrate through and winter in the region, concentrating primarily on the larger saline lakes in the southern portion of the playa lakes region.

The primary importance of the playa lakes region to waterfowl is as a wintering area. Wintering waterfowl populations in the playa lakes region range from 1 to 3 million birds, depending on fall precipitation patterns that determine the number of flooded playas. The most common wintering ducks are mallards, northern pintails, green-winged teals, and American wigeons. About 500,000 Canada geese and 100,000 lesser snow geese winter in the playa lakes region, and numbers of geese have increased annually since the early 1980's. This chapter describes the physiography and ecology of playa lakes and their attributes that benefit waterfowl.

Origin, Physiography, and Climate

Playas are shallow (generally less than 1 m deep), circular basins averaging 6.3 ha in surface

[1] Present address: Department of Range and Wildlife Management, Texas Tech University, Lubbock, Texas 79409.

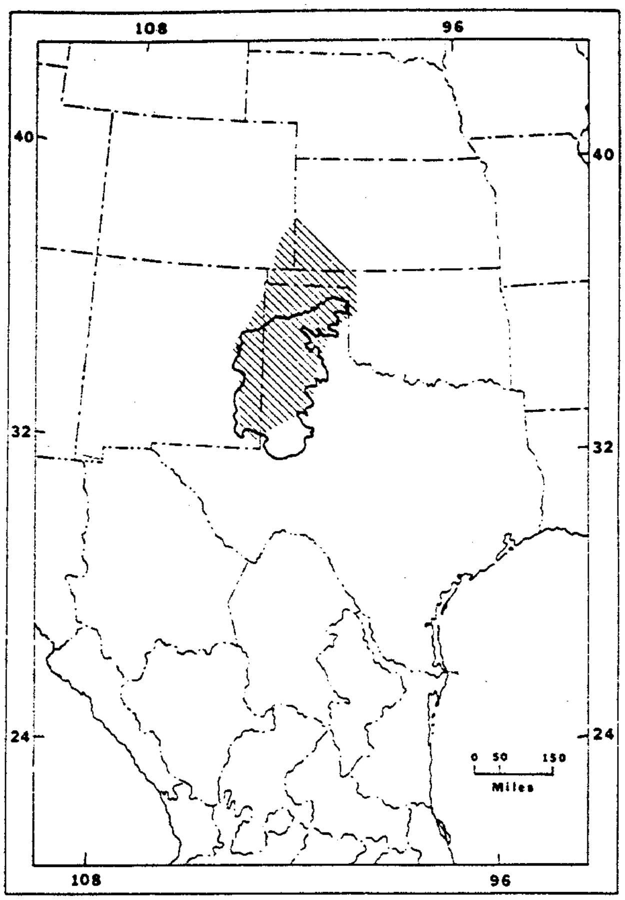


Fig. 1. The playa lakes region of the southern great plains (*hatched* area); most playas are on the southern high plains (*outlined* area).

area; 87% are smaller than 12 ha. Watershed size averages 55.5 ha and ranges from 0.8 to 267 ha. Where it is high (central Texas panhandle), the density of playas is 0.4/km^2. Playas provide more than 160,000 ha of wetland habitat.

Several theories have been proposed for the formation of playas. The most recent theory proposes that playa basins form and expand as a result of hydrologic and geomorphic processes when water collects in depressions on the prairie. As the ponded water percolates into the subsoil, carbonic acid forms from the oxidation of organic material. The acid dissolves the underlying carbonate material (caliche). Loss of caliche leads to enhanced permeability of surface water that increases downward transport of solutes, particulate rock, and organic matter and expands the basin in a circular fashion from a central point. Land subsides from loss of caliche and the basin deepens.

Theoretically, a playa can form whenever a depression develops on the prairie. A few lakes are documented as having formed from depressions created during highway construction in the 1940's. Potentially, existing playas can continually expand. Decaying vegetation provides a constant source of organic matter. However, the maximum size of a playa is limited by the size of its watershed, which determines the amount of runoff into the basin.

Playas are the primary recharge areas for the Ogallala aquifer of the southern high plains. Groundwater recharge is primarily along edges of playas. Infiltration in the center of the playa is limited because of pore filling when clays and organic matter percolate downward during basin formation. Historically, people assumed that water in playas was lost only by evaporation and transpiration. Although evaporation and transpiration are still considered a major loss of water in playas, the lack of increasing salt content in the water and soil of playas during declining water levels indicates some water loss from percolation.

Unlike most wetlands, floors of playas are not rounded, but plate-like (Fig. 2). As a result, water depth is relatively constant throughout much of the basin. Soils of the playa floor are predominantly clays, differing from the loams and sandy loams of the surrounding uplands. Therefore, locations of playas are easily recognized from soil maps.

The climate of the playa lakes region is semi-arid in the west to warm temperate in the east. In the Texas panhandle, mean temperature ranges from 1 to 3° C during winter and from 25 to 28° C in summer. Precipitation is mainly from localized thunderstorms during May and June and again during September and October. Precipitation averages 33 to 45 cm and is lowest in the southwest and highest in the northeast of the region. However, the entire region is rarely subject to average precipitation. Usually, rainfall is well above or below average and dependent on location. Average annual evaporation is 200–250 cm.

Because very few are directly associated with groundwater, playas can fill from only precipitation

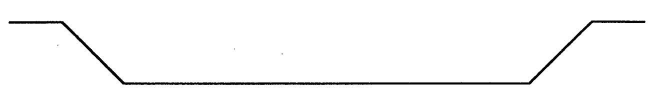


Fig. 2. A typical plate-like floor of a playa lake.

and irrigation runoff. Most playas are dry during one or more periods of each year, usually late winter, early spring, and late summer. Several wet-dry cycles during one year are not uncommon for a playa and depend on precipitation and irrigation patterns.

Importance of Playa Lakes to Crop Irrigation

Most playas (>70%) greater than 4 ha were modified for inclusion in crop irrigation systems. A pit or ditch was dug in these playas to concentrate and recirculate onto surrounding cropland any water collected in playas from precipitation and irrigation runoff. Using water from playas to irrigate crops is less expensive than pumping aquifer water. Furthermore, water from playas for irrigation reduces demand on the Ogallala aquifer. Therefore, many landowners depend on the water in their playas to maintain profitable farming.

Extensive irrigation of crops in the playa lakes region since the mid-1940's has resulted in a net loss of water from the aquifer. Consequently, dominance of dryland agriculture is predicted in the area by the early 21st century. High water-use plants, such as corn, may be grown less frequently in the playa lakes region. Because corn is an important food for wintering waterfowl, increases in another crop (e.g., grain sorghum) or native food plants will have to compensate for its loss.

Playa Lake Vegetation

Establishment of vegetation depends on the existing moisture regime of the playa when other environmental conditions are suitable (i.e., temperature, photoperiod). Vegetation in dry playas resembles upland vegetation and includes species such as summer cypress, ragweed, and various prairie grasses. Moist and flooded conditions in playas favor vegetation representative of other North American wetlands; barnyard grass, smartweeds, bulrush, cattail, spikerush, arrowhead, toothcup, and dock.

Specifically, 14 physiognomic types of vegetation by moisture regime (frequency and longevity of flooding) and crop irrigation or other physical disturbance (grazing, cultivation, irrigation modifications) were identified in playas. The two most common types are broad-leaved emergent and wet meadow, which are dominated in varying proportions by willow and pink smartweed and barnyard grass.

Unlike most other North American wetlands, playa lakes are dominated by annuals. This is a response to the unpredictable, rapidly changing moisture regime in a playa during the growing season. Water loss from percolation, evaporation, transpiration, and irrigation and runoff from rainfall and irrigation can alter the moisture regime of a playa daily. Annual species are capable of responding to changing moisture regimes by rapidly germinating, maturing, and setting seed. Furthermore, the lack of a depth gradient throughout playas, combined with the dominance by annuals, limits the development of concentric bands of monotypic vegetation characteristic of northern glacial wetlands.

Native vegetation in playas is important to wintering waterfowl. The cover of native vegetation reduces stress during harsh winter conditions, and seeds of native species provide forage. Recent studies revealed ducks prefer seeds from native vegetation over agricultural grains. Seeds preferred by waterfowl wintering in the playa lakes region are from plants such as barnyard grass, smartweeds, and dock that germinate in moist-soil conditions (mudflats; saturated, exposed soil).

Recent research revealed that survival of wintering ducks in playas is higher and body condition is better during wet years (above-average rainfall) than during dry years (below-average rainfall). This is so because during wet years the abundance of preferred native food and cover (e.g., smartweeds and barnyard grass) is greater and readily available without energy expenditure for flights to agricultural fields. Therefore, management of playas should emulate conditions that favor development of vegetation communities (broad-leaved emergent and wet meadow) in playas during wet years.

Invertebrates in Playas

The influence of invertebrates on waterfowl use of playas is poorly understood. However, invertebrates are always in the diet of ducks in playas. Although playas have a wide variety of invertebrates (Table 1), life histories of most species are unknown. Invertebrate diversity is influenced by time and space. The composition of invertebrate communities changes profoundly, as yet unpredictably, as a function of the length of

Table 1. *Orders and families of insects in playa lakes.*

Order	Families
Ephemeroptera	Baetidae, Caenidae
Odonata	Gomphidae, Aeshnidae, Libellulidae, Coenagrionidae, Lestidae
Orthoptera	Tetrigidae, Tridactylidae
Hemiptera	Belostomatidae, Corixidae, Gelastocoridaeridae, Notonectidae, Mesoveliidae, Hebridae, Veliidae, Gerridae, Saldidae
Trichoptera	Leptoceridae
Coleoptera	Dytiscidae, Gyrinidae, Hydrophilidae, Heteroceridae, Curculionidae, Carabidae, Haliplidae
Diptera	Tipulidae, Culicidae, Ceratopogonidae, Chironomidae, Tabanidae, Stratiomyidae, Ephydridae

time a playa is flooded. Additionally, invertebrate community structure seems to be playa-specific (R. W. Sites, University of Missouri, Columbia, personal communication). Such changes in invertebrate structure may influence future management of playas because certain communities of invertebrates may be more desirable than others for waterfowl.

Diseases of Waterfowl in Playas

Disease is a major source of nonhunting mortality of waterfowl wintering in the playa lakes region. During any year, avian cholera and botulism can kill thousands of waterfowl in playas. Avian cholera was first documented in North America in the playa lakes region. With high densities of waterfowl concentrations on small quantities of water, such as during drought, the potential exists for major dieoffs of waterfowl. However, currently, location and timing of disease outbreaks in the playa lakes region cannot be predicted.

Management of Playas for Waterfowl

Almost all playas are in private ownership (>99%) and, therefore, the key to long-term management of these wetlands rests on incentives for private landowners. Because playas are not interconnected by courses of surface water, each playa lake and its watershed are an independent system and should be managed as such. We tested and confirmed the usefulness of management of playas that focuses on producing forage (seeds) and on increasing cover for wintering ducks.

Vegetation in playas has adapted to unpredictable wet–dry cycles. Indeed, a playa is most productive when its moisture regime fluctuates from dry to wet a few times during the growing season. Therefore, managing playas by stabilizing water levels results in less than maximum production of vegetation.

Because of the unpredictability of rainfall in the playa lakes region, all management plans for wintering waterfowl include options for flooding playas during winter. This aspect cannot be overemphasized; the cost of management must incorporate the expense of maintaining a flooded playa to satisfy management objectives (e.g., hunting season, migratory periods, wintering populations). Whether a playa will receive enough runoff from fall rains to be flooded when necessary cannot be predicted and managers must be prepared to pump water from other sources (e.g., aquifer, irrigation pit) to maintain water in a playa during desired periods of the year.

During construction of irrigation pits, landowners can terrace one or more sides of the excavation in a stair-step manner, which allows a littoral zone to be present at all times during fluctuations of water levels. These artificial littoral zones produce more vegetation, seeds, and invertebrates than standard steep-sided irrigation pits. Although it is a successful approach to using previously unproductive pit areas, such management has several drawbacks.

Usually, landowners already constructed all the pits that they want and very few playas remain in which pits can be built. Managing pits only affects a small amount of habitat, generally less than 1 ha. Longevity of the terraces and the cost of long-term maintenance are unknown. Furthermore, given the current permit requirements on modification of wetlands, such construction may not be approved.

Moist-soil management, common in other areas, has proved successful in playas. Moist-soil management involves drawdown or irrigation of wetlands for creation of saturated, exposed soil to promote germination and growth of mudflat species. In playas, prominent mudflat species are smartweeds and barnyard grass. Specific drawdown and irrigation schedules promote mudflat vegetation communities that are typical of playas during wet years (Table 2).

The cost of moist-soil management is less than 10% of the cost of winter flooding alone. However, playas that are managed for production of native foods can carry 10–20 times more ducks than playas managed for winter flooding. Therefore, landowners who flood their playas for wintering ducks should manage their lake for moist-soil vegetation during the growing season to receive a better return on their investment.

Moist-soil management favors establishment of smartweeds and barnyard grass, which are preferred for their greater total seed production and better nutritional characteristics than other species in playas (Tables 3 and 4). Because these species are in most playas, about 15,000 playas are available for moist-soil management. The increase in native food and cover from moist-soil management should increase the number of wintering ducks leaving the playa lakes region.

Moist-soil management allows landowners to continue using water collected in playas for irrigation of crops because recommended periods of creating moist-soil conditions correspond with irrigation schedules. Therefore, landowners can create moist-soil conditions in their playas by drawing down a flooded playa and irrigating crops or directing irrigation runoff into specific areas of a dry playa. By allowing the farmer to continue the use of water collected in playas for irrigation during the growing season, moist-soil management is made simple and more cooperation from landowners can be expected.

When vegetation is established from moist-soil management, managers have several options to achieve a variety of management goals. Migratory ducks could be supported by flooding managed playas during fall and late winter. A wintering population of ducks can be maintained by managing a complex of playas and implementing a flooding schedule to ensure a constant supply of native food. Depth and timing of flooding will influence shorebird use of managed playas. Maintaining a few centimeters of water in managed playas during shorebird migration allows use by shorebirds. However, the effects of moist-soil management on the invertebrate food source for shorebirds in playas are unknown.

Current moist-soil management in playas was tested for seed-producing annuals and the presence of ducks but not geese. Therefore, current management of geese in playas revolves around providing roosting and foraging areas. Protecting large, open-water playas, which geese use for roosting, is important. Encouraging farmers to leave crop stubble and waste grain in the field provides foraging areas throughout winter for geese.

Few data are available for the management of breeding ducks in the playa lakes region. Maintenance of upland cover near a permanent water source, such as a large irrigation pit, meets most requirements of breeding and nesting ducks. Methods to encourage nesting in uplands rather than in playas, which often results in flooded nests, must be included in the management of breeding birds. Large-scale use of nesting structures is not recommended until the effectiveness of such structures can be determined for playas.

Table 2. *Recommended schedule for moist-soil management of playa lakes.*

Date	Activity	Purpose
Early April	Draw down or flood playa to create moist-soil conditions	Create conditions for desired plants to germinate and grow
Mid-late June	Draw down or flood playa to create moist-soil conditions	Reestablish plants lost to spring flooding
August	Draw down or flood playa to create moist-soil conditions	Maximize seed production for duck food
November–January	Flood and maintain 1 foot (30.5 cm) of water in playa	Create site for ducks to rest and feed

Table 3. *Frequency (%) and seed production (kg/ha) of common plant species from moist-soil managed and unmanaged playa lakes (Haukos, unpublished data).*

	Frequency		Production	
Species	Managed	Unmanaged	Managed	Unmanaged
Barnyard grass	20	4	346	45
Willow smartweed	38	3	730	55
Pink smartweed	22	2	532	105
Dock	3	3	1,233	703
Spikerush	15	35	66	28

Table 4. *Chemical constituents (%) of common plant species from playa lakes (Haukos, unpublished data).*

	Constituent							
Species	Ash	Nonstructural carbohydrates	Crude protein	Crude fat	Hemicellulose	Lignin	Cellulose	Cutin/ suberin
Barnyard grass	6.1	12.6	9.4	7.7	32.5	10.3	27.7	5.1
Willow smartweed	4.7	12.2	9.9	7.1	20.4	14.3	11.9	20.9
Pink smartweed	5.8	14.3	11.5	8.1	16.8	16.2	10.4	17.4
Dock	6.8	12.2	9.1	7.1	16.3	23.4	20.9	14.7
Spikerush	13.2	9.5	6.4	8.4	22.9	7.5	15.9	28.9

Future Research Needs

Most studies involving playas have focused on wildlife or the use of playas for irrigation. Few basic ecological studies have been initiated on playas. Studies relating to the basic functions and structure of playas, as have been conducted of the prairie potholes, would yield immediate benefits by providing a foundation for future studies and management. Future studies of wildlife should focus on using natural forces (i.e., water-level fluctuations, fire) to improve wildlife habitat. These studies should be designed for land in private ownership to elicit the interest and cooperation of owners.

Suggested Reading

Bolen, E. G., G. A. Baldassarre, and F. S. Guthery. 1989. Playa lakes. Pages 341–366 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Bolen, E. G., L. M. Smith, and H. L. Schramm, Jr. 1989. Playa lakes: prairie wetlands of the southern high plains. BioScience 39:615–623.

Fischer, D. H., M. D. Schibler, R. J. Whyte, and E. G. Bolen. 1982. Checklist of birds from the playa lakes of the southern Texas panhandle. Bulletin of the Texas Ornithological Society 15:2–7.

Haukos, D. A., and L. M. Smith. 1991. Vegetation management in playa lakes for wintering waterfowl. Management Note 14. Department of Range and Wildlife Management, Texas Tech University, Lubbock. 4 pp.

Osterkamp, W. R., and W. W. Wood. 1987. Playa-lake basins on the southern high plains of Texas and New Mexico: I. hydrologic, geomorphic, and geologic evidence for their development. Geological Society of America Bulletin 99:215–223.

Appendix. Common and Scientific Names of the Plants and Birds Named in the Text.

Plants

Ragweed	*Ambrosia* sp.
Toothcup	*Ammannia* sp.
Barnyard grass	*Echinochloa crusgalli*
Spikerush	*Eleocharis* sp.
Summer cypress	*Kochia scoparia*
Willow smartweed	*Persicaria* (*Polygonum*) *lapathifolia*
Pink smartweed	*Persicaria* (*Polygonum*) *pensylvanica*
Dock	*Rumex crispus*
Arrowhead	*Sagittaria longiloba*
Bulrush	*Scirpus* sp.
Cattail	*Typha* sp.

Birds

Northern pintail	*Anas acuta*
American wigeon	*Anas americana*
Green-winged teal	*Anas crecca*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
Canada goose	*Branta canadensis*
Lesser snow goose	*Chen caerulescens*
Sandhill crane	*Grus canadensis*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

13.3.14. Detrital Accumulation and Processing in Wetlands

Patrick A. Magee
Gaylord Memorial Laboratory
University of Missouri
Puxico, MO 63960

Wetlands are among the most productive ecosystems on earth (Fig. 1) and are often characterized by lush growths of hydrophytes. However, direct consumption of wetland plants by animals is relatively low, and, therefore, much of the biomass and energy assimilated by hydrophytes becomes detritus or senesced plant litter. Nutrients released by detritus into the water and soil are assimilated by microorganisms, algae, plants, and small aquatic animals. Through this process, energy is transferred from detritus to other biotic components of a wetland. Plant litter ultimately decomposes.

Litter processing is regulated by environmental factors, microbial activity, the presence and abundance of aquatic invertebrates, and in some wetlands by vertebrate herbivores, such as muskrats, nutria, fishes, and snow geese. Microbes usually contribute most significantly to litter decay through oxidation of organic matter. Large numbers of invertebrates may feed and live on plant litter after microbial conditioning. Detritus is one of several important substrates and energy sources for wetland invertebrates that in turn provide forage for vertebrates, such as fishes, waterfowl, shorebirds, and wading birds. When their dietary needs for animal proteins are high (e.g., during molt and reproduction), waterbirds forage heavily on invertebrates. Therefore, the role of invertebrates in detrital processing is of particular interest to wetland managers and waterbird biologists.

Understanding the dynamics of litter processing promotes a broader perspective of wetland functions and more specifically enhances an understanding of detrital-based invertebrate ecology. Here I discuss the production of litter, some details of decomposition and nutrient cycling, and the role of invertebrates in detrital processing.

Production of Detritus

Along with algae, detritus fuels secondary production in temperate regions during the dormant season. In many temperate and arctic wetlands, residual litter provides an initial energy source for secondary consumers at the beginning of the growing season. In contrast, in tropical systems, productivity is high, litter decays rapidly, and, therefore, organic substrate for invertebrate colonization is scarce. Productivity is reduced in some arctic wetlands and slow decomposition favors deep, acidic peat accumulations that support few invertebrates. An optimal quantity of litter from balanced primary production and decomposition favors invertebrate communities on wetland substrates. The amount of produced litter varies tremendously among wetlands (Fig. 1) and depends on a myriad of biotic and abiotic factors.

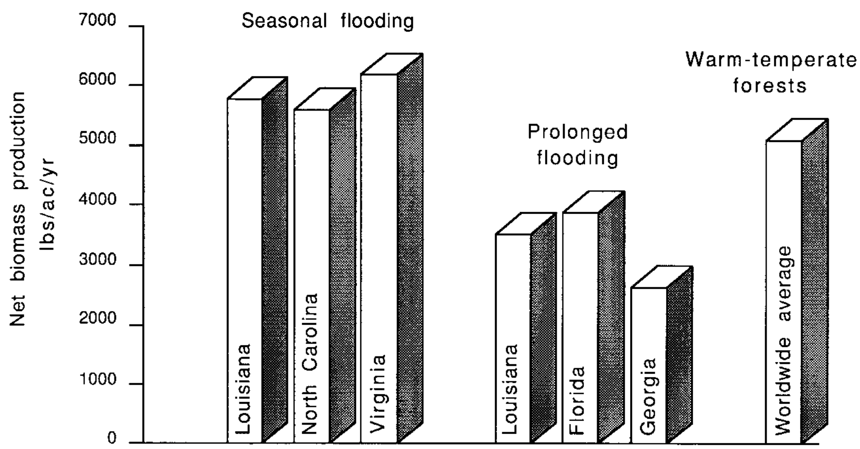


Fig. 1. Litter production varies greatly among wetlands depending on factors, such as plant species, climate, and hydrology. Dynamic hydrology in contrast to prolonged flooding promotes net biomass production in cypress–tupelo forested wetlands. Data presented for Virginia (Great Dismal Swamp) also includes red maple litter production. The worldwide average for warm-temperate forests is shown for comparison.

In temperate regions, deciduous trees and herbaceous plants enter dormancy or die during autumn. Before senescence, large trees and perennial herbs with well-developed root or rhizome systems resorb the nutrients from their leaves and stems for future use. Therefore, plant litter is composed largely of nonnutritive, structural compounds, such as lignin and cellulose. In prairie glacial marshes, litter may enter the system throughout the year. Nearly three fourths of bulrush shoots die before the first killing frost, whereas 80% of cattail shoots are killed by the frost. During the dormant season, wind, waves, and ice formation topple standing litter. Decomposition is most dynamic in fallen litter.

Decomposition

Decomposition is a complex process that is regulated by characteristics of the litter and by external environmental factors (Table). The process can be described as a series of linked phenomena in which one step does not occur until preceding steps make it possible (Fig. 2, also see Fig. 2 in Leaflet 13.3.1.).

The rate of decomposition is important because it affects the release rate of nutrients, the accumulation rate of litter, and the state or quality of the litter substrate. Litter from many submergent and floating plants, such as watershield, decays rapidly (Fig. 3). On the other

Table. *Some factors of litter decomposition rate.*

	Rate of decomposition	
Properties	Fast	Slow
Intrinsic	Low lignin	High lignin
	High phosphorus	Low phosphorus
	High nitrogen	Low nitroge
	Low carbon to nitrogen	High carbon to nitrogen
	Low carbon to phosphorus	High carbon to phosphorus
	Low tannic acid	High tannic acid
	Few polyphenols	Many polyphenols
	Leaf tissue	Woody tissue
Environmental	Microbes present	Low microbial biomass
	Shredders present	Low shredder biomass
	Water present	Water absent
	Flowing water	Stagnant water (less O_2)
	High water temperature	Low water temperature
	Water with high pH	Water with low pH
	Low latitudes	High latitudes
	Low elevations	High elevations

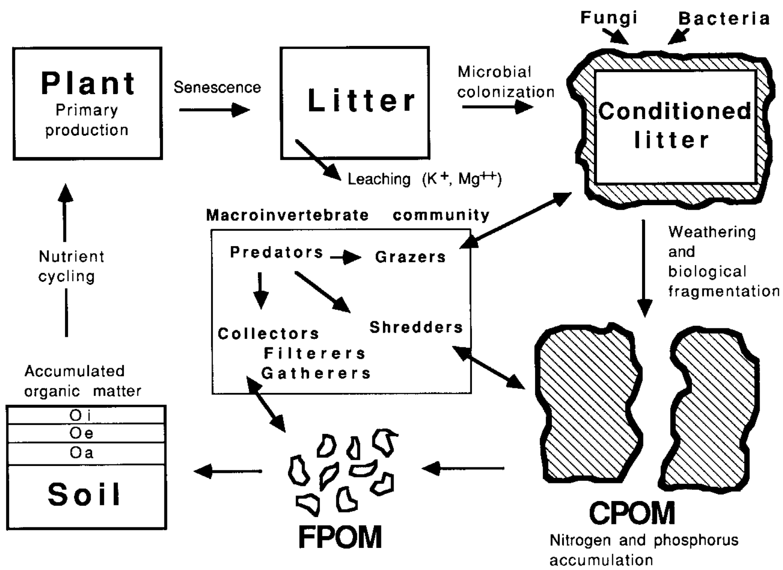


Fig. 2. Litter decomposition is a complex, dynamic process in which detritus is slowly fragmented to fine organic matter and eventually to minerals. Detritus provides energy and nutrients that support microorganisms and macroinvertebrates. Oi, Oe, and Oa refer to organic litter horizons. FPOM = fine particulate organic matter, CPOM = coarse particulate organic matter.

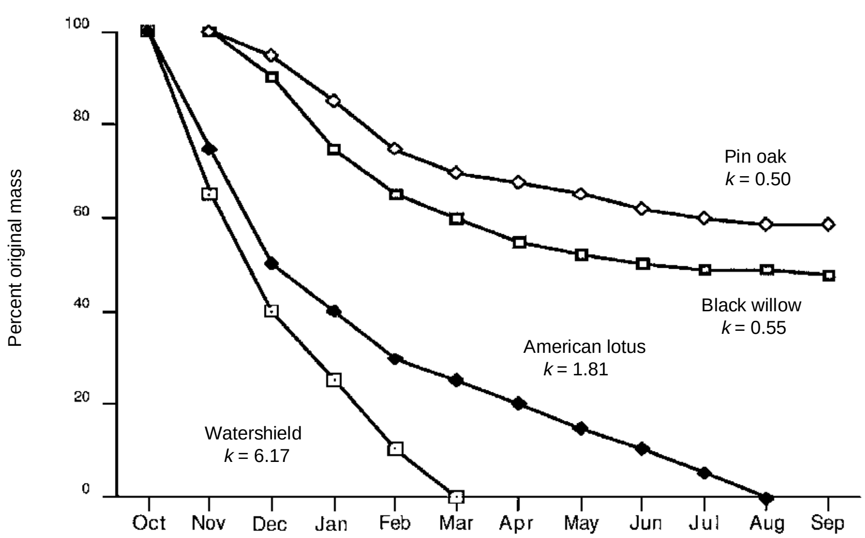


Fig. 3. Decay rates of the leaves of four common wetland plants over a 12-month interval starting from senescence. The annual decay coefficients (k) are determined from a negative exponential decay model and represent a single value that can be used to compare decay rates among species.

hand, robust emergent plant litter and leaves from certain trees decay slowly. The leaves of pin oaks, for example, require 4–7 years to completely mineralize (Fig. 3). In forested wetlands with slowly decaying leaves, accumulated layers of litter reflect each year's growth and state of decay. The result is a substrate with a diverse vertical profile. Plant parts decay at different rates; leaves decompose more rapidly than stems or woody tissues. Furthermore, plants with high quantities of lignin, such as common reed and burreed, have the slowest decay rates. Decomposition is usually slow in northern wetlands (i.e., >50% of plant litter remains after 3 years of decay) partly because of cold temperatures. In contrast, in a warm, tidal wetland, more than three fourths of the litter decayed within 3 months. Because of the interactions between the environment and a plant's characteristics, the composition of litter substrate varies.

Decomposition of litter by a complex interaction of physical, chemical, and biological processes has at least two phases. In the first phase of decomposition (leaching), loosely bound nutrients, such as calcium, potassium, and magnesium, are rapidly released from newly senesced plant litter. Cattail, for example, lost 76% of sodium, 93% of potassium, 70% of calcium, and 65% of magnesium after 1 month of decay. Black willow leaf litter lost 85% of its potassium within the first 2 weeks of decay. Sometimes the leaching phase is so rapid that labile nutrients are flushed from the litter within 48 h of flooding.

Not all nutrients immediately escape from the litter. Nitrogen (Fig. 4) and calcium, for example, may accumulate in the litter as a result of immobilization and colonization by microbes. Litter can act as an important sink for these nutrients, which are slowly released during the second phase of decomposition.

The second phase of decay consists of mechanical fragmentation of litter by ice, wind and wave action, and biological fragmentation by invertebrates called detritivores (Fig. 2). Most importantly, however, biologically mediated chemical transformations of litter by microbes promote gradual loss of recalcitrant litter tissues, such as lignin and cellulose. All of these processes convert litter from large, structurally complex forms to smaller, simpler materials. Largely intact litter with a >1-mm diameter is called coarse particulate organic matter (CPOM), whereas highly fragmented litter is fine particulate organic matter (FPOM). Eventually, plant litter is converted to its simplest forms and becomes incorporated into the soil or dissolved in the water column.

The Role of Microbes and Invertebrates

Before most invertebrates begin processing litter, microbes colonize litter surfaces at densities of 410,000–410,000,000 individuals /cm2. These microbes are the fungi (e.g., phycomycetes) and bacteria (e.g., actinomycetales, eubacteriales, myxobacterales, pseudomonaiales) that digest cellulose.They are the key organisms that erode the structural framework of the litter. Their abundance and activity reflect environmental conditions; bacteria are more numerous on submerged than on standing dead litter, although water temperature and oxygen availability affect bacterial response. In many wetlands, microbes regulate decay and account for as much as 90% of litter weight loss. Many fungi produce external enzymes that break down cellulolytic tissues in detritus. In this process, sucrose is broken down into glucose and fructose, but only a portion of these sugars are assimilated by microbes. The remainder are available to protists, zooplankton, and macroinvertebrates.

Macroinvertebrates are a diverse group and fill many niches in wetland communities. As litter decomposes, these niches become available sequentially by size of litter fragments and by the activities of other invertebrates and microorganisms (Fig. 2). Litter is food and habitat for many aquatic invertebrates. Followmg leaching, litter is primarily composed of nonnutritive,

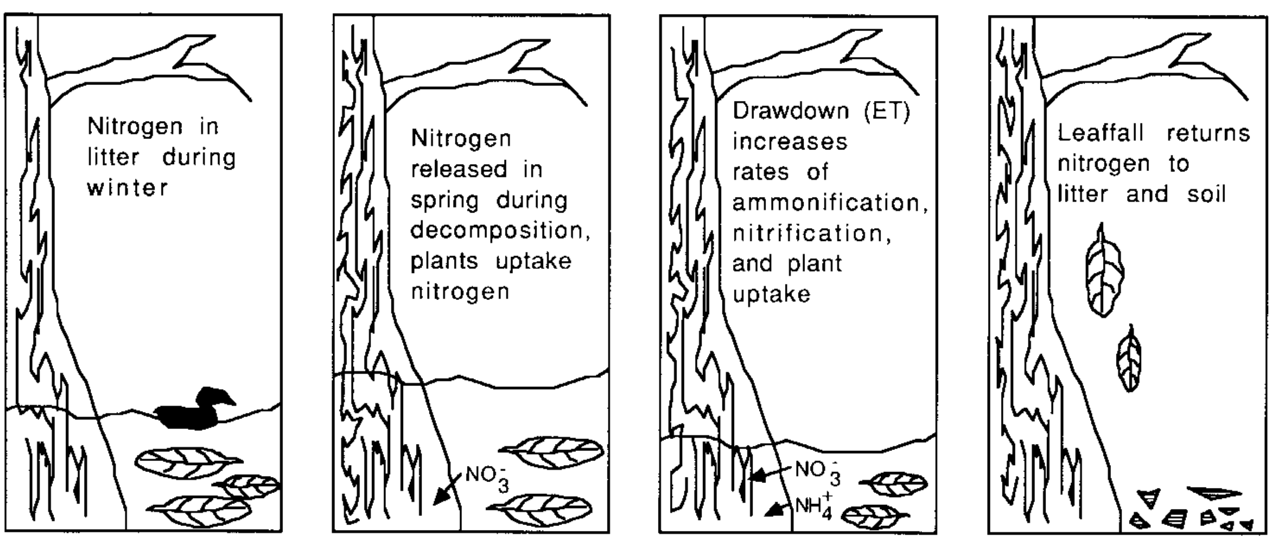


Fig. 4. Nitrogen cycling in wetlands involves a labyrinth of chemical transformations of nitrogen into forms that may or may not be available to plants. Microorganisms play a key role in mediating nitrogen availability in the benthos and soil.

complex carbohydrates that are difficult or impossible for detritivores to digest. Therefore, the key link between macroinvertebrates and litter processing is the presence of microbes. Not only do these bacteria and fungi break down litter directly, they also condition litter by making it palatable to invertebrates.

Detritivores, called shredders, are the first to fragment CPOM because they are voracious feeders with low assimilation rates; much of the litter they consume is excreted in a highly fragmented state. The surface area increases after the litter passes through the digestive tract of invertebrates and thereby enhances microbial growth. Crustaceans, such as aquatic sowbugs, freshwater scuds, and crayfish, are prominent shredders in many forested wetlands. Crayfish and many insects are common shredders in moist-soil wetlands in Missouri.

Grazers, another group of detritivores, scrape algae and microbes off surfaces of CPOM, allowing recolonization by new microbes. Grazing tends to increase microbial growth and activity. Snails, such as the pond and orb snail, are the most conspicuous grazers in wetland systems.

Collectors feed on fine particulate organic matter (FPOM) that is produced mainly by shredders. One group of collectors is mobile and gathers FPOM from sediments. For example, some midge larvae and mayflies, called collector–gatherers, obtain nutrients and energy by foraging on small litter fragments. Another group of collectors, including fingernail clams, filters FPOM from the water column.

A dynamic invertebrate community develops in detrital-based systems as water temperatures increase and litter processing is most active. Shredders reach peak density and biomass and create more foraging opportunities for collectors. Given these conditions, highly mobile, predaceous invertebrates, such as dragonflies, respond to available prey (i.e., shredders and collectors).

Considerations in Management

Wetlands are productive because the base of the biotic pyramid is large and diverse and nutrient cycling is dynamic. Because energy flows from the lowest levels of the pyramid, detritus sustains much of the biomass and structure of the community (Fig. 5). Furthermore, detrital processing releases and transforms nutrients tied up in plant tissues and makes them available for uptake by wetland flora and fauna. Management, particularly hydrological manipulations, may enhance energy and nutrient flow in wetlands.

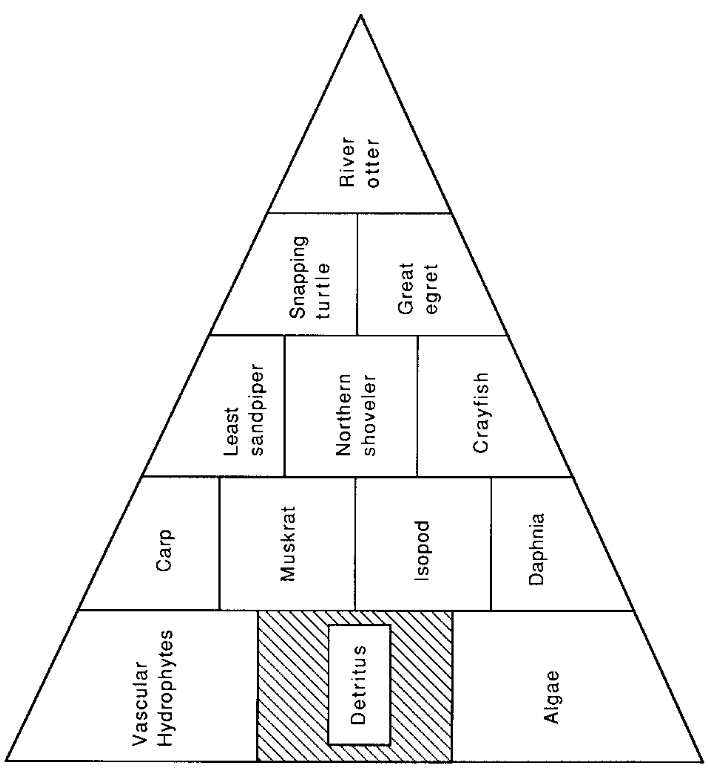


Fig. 5. Detritus is a fundamental component of food–energy pyramids in wetland ecosystems. During the dormant season in temperate wetlands, only detritus and algae supply energy and nutrients to sustain higher trophic levels.

Detritus becomes an important energy source when wetlands are flooded. Inundation triggers the dynamic process of litter decomposition. Decay rates are often much higher in wetlands than in adjacent uplands, indicating in part the level of activity and the biomass of aquatic biological decomposers. Maintenance of long-term hydrological regimes is the key to maintaining the balance between litter decay and accumulation and to sustaining the biotic components of detrital processing and wetland productivity. For example, aquatic invertebrates have evolved diverse adaptations for living in seasonally flooded environments, and, without dynamic flooding regimes, many of these organisms are incapable of completing their life cycles. In the short term, the annual timing, rate, depth, and duration of flooding affect the diversity and abundance of invertebrates at a particular site.

Hydrology also influences nutrient cycling in wetlands. Because of leaching and subsequent decomposition, the water column is rich in nutrients for several months after flooding. Therefore, rapid drawdowns when nutrient content is high can flush nutrients from the system. Slow and delayed drawdowns retain nutrients and enhance long-term wetland productivity.

Stabilized flooding regimes may harm detrital nutrient dynamics. Anaerobic conditions can develop in detritus, especially when water is stagnant. Subsequently, denitrification, which is the loss of nitrogen from the litter, may result in a net export of nitrogen from the system. Denitrification is less common in aerated litter layers than in wetland soils and is minimal under dynamic flooding strategies.

Secondary production in wetlands may be hindered by runoff of sediments and chemicals from agricultural lands or storm flow. When sedmients envelop litter, the substrate is less hospitable to the epifauna because oxygen is deficient. Furthermore, as more sediments are suspended in the water column, penetration of light is reduced and chemical imbalances may occur. Although hydrophytes are excellent purifiers of polluted waters, excessive amounts of fertilizers and pesticides may have a direct detrimental effect on wetland biota. Maintaining upland borders that filter sediments and chemicals before they settle in wetland basins is important for sustained detrital processing.

Litter quality and quantity also affect secondary production. Mechanical fragmention of litter increases the surface area for microbial and invertebrate colonization. Hydrophytes, such as American lotus, with its large, round leaves, have relatively small surface areas and low invertebrate densities. Mowing or shallowly disking lotus increases the surface area of this simple substrate by artificially hastening litter fragmentation. Such control of nuisance vegetataon enhances short-term production of invertebrates.

The balance between litter removal and accumulation affects wetland productivity. Small litter accumulations may not provide adequate substrate for invertebrates; however, large accumulations may alter surface hydrology through peat formation or nutrient binding. Litter removal may be accomplished by flooding if surface flow is sufficiently great to simulate this natural function. Prescribed burns not only remove excess organic matter but release minerals bound in the litter.

Habitats with diverse litter layers in various stages of decay are optimal for the management of invertebrates. Where litter accumulation is scant or heavy, however, invertebrate production may be impeded because of unfavorable conditions associated with hydrology, substrate, and nutrient availability.

Suggested Readings

Cummins, K. W, M. A. Wilzbach, D. M. Gates, J. B. Perry, and W. B. Taliaferro. 1989. Shredders and riparian vegetation. BioScience 39:24–30.

Kadlec, J. A. 1987. Nutrient dynamics in wetlands. Pages 393–419 *in* K. R. Roddy and W. H. Smith, editors. Aquatic plants for water treatment and recovery. Proceedings of the Conference on Applications of Aquatic Plants for Water Treatment and Resource Recovery, Orlando, Fla.

Mason, C. F. 1976. Decomposition. The Institute of Biology's Studies in Biology 74. 58 pp.

Merritt, R. W., and K. W. Cummins. 1984. An introduction to the aquatic insects of North America. Kendall/Hunt Publishing Company, Dubuque, Iowa. 441 pp.

Murkin, H. R. 1989. The basis for food chains in prairie wetlands. Pages 316–338 *in* A. G. van der Valk, editor. Northern prairie wetlands. Iowa State University Press, Ames.

Polunin, N. V. C. 1984. The decomposition of emergent macrophytes in freshwater. Advances in Ecological Research 14:115–166.

Webster, J. R., and E. F. Benfield. 1986. Vascular plant breakdown in freshwater ecosystems. Annual Review of Ecology and Systematics 17:567–594.

Appendix. *Common and Scientific Names of the Plants and Animals Named in the Text.*

Plants	
Red maple	*Acer rubrum*
Watershield	*Brasenia schreberi*
American lotus	*Nelumbo lutea*
Water tupelo	*Nyssa aquatica*
Common reed	*Phragmites australis*
Pin oak	*Quercus palustris*
Black willow	*Salix nigra*
Bulrushes	*Scirpus* spp.
Burreeds	*Sparganium* spp.
Baldcypress	*Taxodium distichum*
Cattails	*Typha* spp.
Invertebrates (by function)	
Shredders	
Aquatic sowbug	Asellidae
Crayfish (omnivore)	Cambariidae
Freshwater scud	Gammaridae
Collectors	
Mayfly (gatherer)	Baetidae
Midge (gatherer)	Chironoraidae
Water flea (filterer)	Daphnidae
Fingernail clam (filterer)	Sphaeriidae
Grazers	
Pond snail	Physidae
Orb snail	Planorbidae
Predator	
Dragonfly	Aeshnidae
Vertebrates	
Northern shoveler	*Anas clypeata*
Least sandpiper	*Calidris minutilla*
Great egret	*Casmerodius albus*
Snapping turtle	*Chelydra serpentina*
Snow goose	*Chen caerulescens*
Common carp	*Cyprinus carpio*
Hooded merganser	*Lophodytes cucullatus*
River otter	*Lutra canadensis*
Nutria	*Myocastor coypus*
Muskrat	*Ondatra zibethicus*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
Fish and Wildlife Leaflet 13
Washington, D.C. • 1993

13.4.1. Considerations of Community Characteristics for Sampling Vegetation

Leigh H. Fredrickson and Frederic A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri–Columbia
Puxico, MO 63960

Wetland managers often monitor marsh vegetation to determine if management goals have been met and expenditures justified. Vegetation can be monitored using indices that identify plant composition, trends in vegetative changes, or rough estimates of food production. Development of vegetation sampling protocol requires careful assessment of management goals in relation to benefits received from sampling efforts. Assessing the results of manipulations has direct management implications, whereas detailed studies that emphasize plant life histories or basic ecological investigations have less direct value. Information on plant community characteristics that will enable managers to match sampling techniques with refuge needs and the constraints imposed by time, expertise, number of personnel, and program funds is provided.

Identification of Goals

The initial consideration in any collection of management data is: "How will this information assist in meeting refuge objectives?" Information on variables other than plants are important. Records on the hydrological regime, timing and type of manipulations, and the wildlife response to management must be maintained. Only then can the results of management be assessed.

The next step is to identify the type of vegetative information required (Table 1). Detailed changes in composition or densities and exact measurements of biomass usually have limited value for refuge needs, whereas more general changes in composition or densities and gross measurements of foods produced are essential in monitoring the effectiveness of management investments. Qualitative approaches or general quantitative approaches often are adequate. Thorough comparisons of techniques on different sites, as well as seasonal or long-term variation in vegetation, require refined quantitative methodologies and time-consuming collection methods. Little is gained from long-term sampling if data are not summarized regularly and subjected to analysis.

Costs of data collection, analysis, time, and personnel are generally greater for quantitative approaches. When time, personnel, and funds are limited, costly sampling systems that provide information with little value in meeting refuge objectives should not be implemented.

Expertise

Effective sampling requires some knowledge of plant taxonomy. Recognition of plants during all life phases (e.g., germination, flowering, seeding) is essential. Use of scientific names is required because common names are not used consistently across the country. In addition, differences between life histories of plants within a genus or between plants with the same common name may have important implications for management.

Table 1. *Use of information from vegetation sampling.*

Type of sample		Use of Information
Aboveground	Vegetative composition	
	Qualitative	
	Cover maps	Monitor general changes
	Photos	
	Ground stations	Monitor general changes
	Aerial	Monitor general changes
	Quantitative	
	Line intercept	Comparisons among years, sites, techniques, etc.
	Point count	Comparisons among years, sites, techniques, etc.
	Aerial photos	Potential to identify certain plant communities, monitor changes among seasons or years
	Vegetative density	Precise comparisons/unit area
	Vegetative structure	
	Qualitative	
	Photos	Monitor general condition or changes
	Visual estimates	Monitor general condition or changes
	Quantitative	
	Cover boards	General description, comparisons among years, sites, techniques, etc.
	Sampling devices	Quantify structure, comparisons among years, sites, management techniques, etc.
	Canopy photos	Quantify degree of closure
Biomass	Seeds	Estimate foods produced
	Vegetative parts	Estimate litter production—browse, etc.
	Percent cover	Estimate cover available on openings for wildlife
Belowground	Composition	Monitor changes among years, sites, techniques, etc.
	Density	Precise comparisons/unit area
	Biomass	Precise comparisons/unit area

Plant Community Characteristics

Plant distribution. Plant communities often have characteristics that make sampling difficult. Typically, a few plant species are common and occur regularly in whatever sampling scheme is used (Fig. 1). In contrast, a large number of plant species will be represented by only a few scattered individuals in most communities. This distribution results in high variability regardless of sampling technique, and dictates that large sample sizes are required if statistical testing and predictive sampling are desired.

Plant structure. The structure of different plants is an important consideration in sampling vegetation. Certain techniques will identify tall, robust vegetation but will overlook smaller or prostrate vegetation.

Growth form. The growth form of plants must be considered before data collection is undertaken. For example, some plants grow in clumps or have

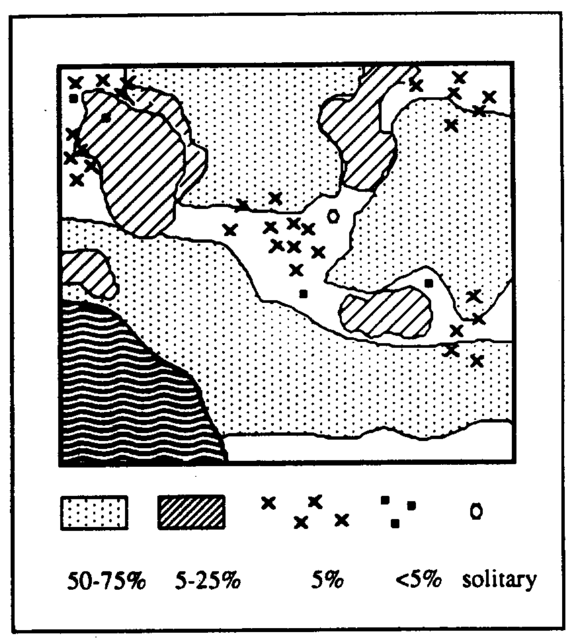


Figure 1. Plant distribution map showing dominance of a few species.

multiple leaves that are all attached to a single rhizome or root system. The distinction between a leaf and a stem becomes critical when data are compared between sites or among years. The chronology of plant growth requires that sampling be properly timed. Otherwise, some species will be overlooked or sampling will not be representative. Animal response to vegetation structure also affects the timing of data collection. Rapid growth of some plants dictates that sampling for structure cannot be delayed for the convenience of the investigator. For example, vegetative structure at the time of nest initiation cannot be identified after nesting is completed. Finally, the maturation pattern of seeds or production of underground parts is a critical consideration in scheduling collection of samples.

Sampling Techniques

The effectiveness of sampling techniques must be considered in relation to their costs in time and personnel (Table 2). Detailed approaches to sampling will be provided in specific techniques chapters in this handbook.

Plant composition. For general long-term trends, aerial or ground photos provide good records. When different vegetation can be distin-

Table 2. *Techniques commonly used to monitor vegetation.*

Information needed/ Technique used	Disadvantages	Advantages
Plant composition		
Line intercept	Time-consuming, requires large sample	Minimal equipment, can monitor size of openings in vegetation
Point count	Time-consuming, requires large sample	Minimal equipment, can monitor size of openings in vegetation
Quadrats	Time-consuming, require large sample	Minimal equipment
Cover maps	Only identify general plant communities	Quick, especially if aerial photos or other base maps are available
Aerial photos (LANDSAT)	Only identify general plant communities Expensive unless photos can be borrowed May require special equipment	Accurate potential for establishing a continuous record of changes
Photo stations	Only identify gross changes	Permanent record of major changes, economical
Plant density–herbaceous		
Quadrat	Time-consuming, needs large sample	Minimal equipment
Ocular	Visual estimates vary among individuals	Quick, minimal equipment
Plant density–woody		
Prism	Only an estimate, not effective for seedings or saplings	Quick, minimal equipment
Seeds		
Catch pans	Time-consuming, animals eat samples, costly to make pans, estimate only of fallen seeds because gradually maturing species drop seeds over an extended period	Can monitor gradual seed production
Quadrat	Time-consuming	
Vertical cover		
Cover board	Burdensome device in some habitats	Quick estimate of vertical cover
Horizontal cover		
Sampling device	Burdensome device in some habitats	Accurate estimate
Belowground biomass		
Quadrat	Time-consuming, difficult to obtain in deep habitats	Accurate estimate

guished from photographs, the potential to document changes exists. Cover maps developed from field inspections (e.g., pacing on ice) and aerial photos are often adequate and more economical than sampling with intercepts or quadrats. Color 35-mm slides are often available from Agricultural Stabilization and Conservation Service (ASCS) offices. Many of these low-level photographs clearly delineate wetland vegetation, and digitized planimeter analysis can yield estimates of the area of different vegetation zones. Comparisons among years must be made with photographs of the same similar season. Since slides can normally be borrowed from ASCS offices, the construction of composite photographs of a wetland from 35-mm slides is economical. Thus, the cost of color reproductions and time to construct maps can be far less than the expenses of aerial photography and large-format photographs. ASCS offices generally do not retain slides of a particular year for more than 2–3 years; therefore, data must be obtained within 2–3 years after the photograph was taken. Long-term photographs may be available within certain periods, but not specific years.

Plant densities. Visual estimates of the percent cover of important species on management units usually provide an adequate index to changes among years. Stem counts within quadrats are very time consuming. Monitoring all plants species within quadrats often has little importance in management and is both costly and time consuming.

Seeds, tubers, etc. No quick method has been developed to monitor seed or tuber production. General estimates of production usually meet management needs and require only information on plant composition and the relative estimates of production for each species. Estimates of belowground biomass are particularly expensive because plant samples must be separated from a large volume of soil. Such activities are generally beyond the capabilities of refuge staff or budgets. Sampling techniques that have low resolution, yet clearly document changes related to management, changes among years, and differences related to habitat use by wildlife, often meet the needs of refuge managers. Consistent record keeping among years using data sheets, photography stations, or ASCS photography provides long-term perspectives as refuge staffs change, modifications in hydrology occur, or as land-use practices influence plant composition on refuges.

Suggested Reading

Fredrickson, L.H., and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildl. Serv., Resour. Publ. 148. 29 pp.

Harper, J.L. 1977. Population biology of plants. Academic Press, N.Y. 892 pp.

Mueller-Dombois, D., and H. Ellenberg. 1974. Aims and methods of vegetation ecology. John Wiley & Sons, N.Y. 547 pp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.4.2. Economic and Legal Incentives for Waterfowl Management on Private Lands

Richard D. Schultz
U.S. Fish and Wildlife Service
Federal Building, Fort Snelling
Twin Cities, MN 55111

Introduction

Waterfowl management on public lands in the United States began about 1870 with the establishment of Lake Merritt, a State-owned refuge near Oakland, California. In 1924 the United States established the Upper Mississippi River Wild Life and Fish Refuge, a complex of waterfowl habitats extending from Wabasha, Minnesota, to Rock Island, Illinois. Over the next 50 years, more than 80 million acres of county, State, and Federal lands were acquired across the United States to provide waterfowl production, migration, and wintering habitats. Because of these early (and continuing) efforts, a significant portion of North America's remaining valuable wetland complexes exists on public lands.

Despite the success of governments in acquiring, restoring, and managing public lands for waterfowl and other species, many wildlife populations have declined to the lowest levels ever recorded. This is due, in part, to the historic and ongoing conversion of important wetlands and grasslands to croplands. Between 1950 and 1985 it is estimated that more than 450,000 acres of wetlands were converted each year; at least 87% of those conversions were for agricultural purposes. Today, 74% of the remaining wetlands are on private lands and are vulnerable to destruction.

In recent years, public and private conservation organizations have initiated programs designed to provide economic incentives for wildlife management on private lands. Other programs, whose primary objectives are other than waterfowl management, also improve and preserve waterfowl habitat on private lands. These programs range from tax incentives and wetland easements to direct financial assistance to landowners. In this chapter, legal and economic incentives for waterfowl management on private lands are summarized under the following categories: Federal programs, State and local programs, and private conservation organization programs.

In most instances, government programs and those of private conservation organizations complement one another and often provide the private landowner many alternatives from which to choose. Likewise, governmental and private organizations have recently expressed a strong desire to form partnerships to better manage waterfowl. This is one of the most important concepts in the North American Waterfowl Management Plan. No single entity has the capability to address the waterfowl needs of the future through unrelated and independent actions. Through combined efforts, however, we have a much better chance to achieve waterfowl management objectives.

The major purpose of this chapter is to discuss an array of economic and legal incentives for waterfowl management, although it is not a complete list. I am hopeful that the information contained here will stimulate the reader to investigate specific programs that are available for waterfowl management on private lands at the local level.

Federal Programs

One of the most significant pieces of legislation affecting natural resource management on private lands was the Food Security Act (Farm Bill) of 1985. This legislation was unique in that it began to integrate natural resource management with U.S. agricultural policy. Throughout the United States, waterfowl production, migration, and wintering habitats are affected by the programs designed to implement this legislation. The following is a discussion of these programs and other Federal programs that encourage waterfowl management on private lands.

Conservation Reserve Program (CRP)

One of the primary purposes of the CRP is to reduce soil erosion by retiring highly erodible croplands from production. These retired croplands provide excellent cover for upland-nesting waterfowl and other wildlife. Beginning in January 1989, CRP rules were modified to allow enrollment of certain wetlands into the program. With this change, private landowners were able to restore or enhance wetlands on their property, improving waterfowl production and migration habitats. Wintering waterfowl habitat on private lands was also improved through the restoration of bottomland hardwoods on qualifying CRP lands in the lower Mississippi valley.

Under the CRP, the Agricultural Stabilization and Conservation Service (ASCS) had the authority to share up to 50% of the cost of establishing conservation practices, including permanent vegetative cover, tree planting, wetland restoration and enhancement, and other erosion control practices. In many areas, private conservation organizations and State and Federal agencies will assume all or part of the landowner's cost for the restoration of wetlands on CRP lands.

Agricultural Conservation Program (ACP)

Through the ACP, cost-sharing up to 75% is available for private landowners willing to undertake conservation practices such as restoring drained wetlands or creating new ones. Unlike CRP, however, annual land rental payments are not paid to landowners under this program. The ACP is administered by the ASCS. Technical assistance for the ACP is provided by the Soil Conservation Service.

Water Bank Program

Wetlands and adjacent uplands in some States, including some states in the prairie pothole region and the lower Mississippi valley, are eligible for enrollment in the Water Bank Program. This U.S. Department of Agriculture program allows enrollment of wetlands and associated uplands into 10-year contracts where the landowner receives annual payments. Land parcels are reviewed for their wildlife values; no more than 4 acres of upland for every acre of wetland can be enrolled in the program. Since its inception, the program has not been fully funded; hence, only limited funding is available for enrollment of new lands. The Water Bank Program is administered by ASCS with technical assistance from the Soil Conservation Service.

Acres Conservation Reserve (ACR) Programs

Farmers participating in price support programs (commonly known as set-aside programs) of the U.S. Department of Agriculture have been required to set aside a certain percentage of their base acreage in most years. Conservation measures are required to provide soil erosion protection, water quality enhancement, wildlife production, and natural beauty. Millions of acres of cropland are retired each year as a result of this program.

Multiyear set-aside contracts have been available for program participants for program years 1986–90. Under these multiyear contracts, landowners may seed retired lands to permanent vegetative cover. Where this option has been used, high-quality upland nesting cover for waterfowl and other species has been established. However, multi-year set-aside is rarely used and relatively few acres are established in permanent cover.

The next logical step in this program is to promote the enrollment of restorable wetlands into annual and multiyear set-aside contracts throughout the United States. If this occurs, additional financial incentives for the landowner would likely become available from other government agencies and private conservation organizations.

Stewardship 2000: Partners for Wildlife on Private Lands

Recently, the U.S. Fish and Wildlife Service initiated Stewardship 2000, a program that will improve wildlife habitat on private lands. This program is designed to complement, and not compete with, similar programs administered by other agencies and organizations. Stewardship 2000 will concentrate on wetlands and their associated fish and wildlife values. The restoration of wetlands on CRP lands has been expanded through this new program to include wetland restoration on other private lands as well. Other improvements to waterfowl habitats have been completed through deferred haying and grazing, creation of waterfowl nesting structures, and in some instances, construction of waterfowl nesting islands.

In the lower Mississippi valley, Stewardship 2000 has increased and improved waterfowl wintering habitat. Under this program, the U.S. Fish and Wildlife Service enters into annual lease agreements with landowners for flooding of harvested rice paddies and for the establishment of bottomland hardwoods. Additional information about these private lands management programs can be obtained from the nearest U.S. Fish and Wildlife Service field office.

Small Wetlands Acquisition Program

Under this program, administered by the U.S. Fish and Wildlife Service, high-quality waterfowl production habitat in the prairie pothole region is purchased outright or by perpetual easements. Existing and restorable wetlands are eligible for these programs. Under the easement program, the landowner retains all property rights except the right to burn, drain, fill, or level-ditch the wetlands in question. Basically, the easement is designed to protect the wetland in perpetuity. Landowners in the prairie pothole region who are interested in selling their property in fee simple or in selling a waterfowl production easement should contact the nearest U.S. Fish and Wildlife Service office.

Federal Income Tax Incentives

Expenses for many conservation practices undertaken by private landowners are tax-deductible. Conservation practices designed to reduce soil erosion and improve water quality qualify, and expenses related to the restoration of wetlands for water quality and wildlife purposes are typically tax-deductible. Landowners who lease their property to others for hunting or similar purposes may qualify for investment-credit tax treatment for those conservation practices that benefit both recreational activities and wildlife.

Gifts of conservation easements made to charitable organizations may qualify for tax deductions. The conservation easements must be enforceable and perpetual, and they must be donated exclusively for conservation purposes to units of government or tax-exempt private entities. Additional information concerning tax incentives for waterfowl management on private lands can be obtained from a qualified tax preparer.

State and Local Programs

Many programs that improve waterfowl management on private lands are administered by State and local governments. These programs include short-term and perpetual land-retirement programs, property tax incentives, and direct financial assistance to private landowners. Examples of these programs are discussed below.

Reinvest in Minnesota (RIM)

In 1986 the Minnesota State legislature passed innovative legislation known as the Reinvest in Minnesota Resources Act of 1986. The purpose of this act is to retire marginal cropland from production through the use of conservation easements. In most instances, the program consists of perpetual easements, in which a lump-sum payment equal to 70% of the average market value of the agricultural land is made to the landowner. Both restorable wetlands and highly erodible croplands are eligible for the program. Perennial vegetative cover must be established on the uplands to reduce soil erosion, improve water quality, and improve fish and wildlife habitat. The program is administered by the Minnesota Board of Water and Soil Resources and the Minnesota Department of Natural Resources.

Critical Habitat Matching Program

As part of the RIM program, private landowners and individuals may contribute cash, land, easements, or pledges for acquisition or development of wildlife habitat. All contributions are tax-deductible and are matched, dollar for dollar, by State-appropriated funds.

Donated land is appraised at market value. If lands qualify, they are managed as a wildlife management area, scientific and natural area, fisheries area, or other appropriate State unit. Donated lands that do not qualify as critical habitat are sold, and the proceeds are deposited into the Critical Habitat Matching Account. Private landowners and others interested in participating in this program should contact the Minnesota Department of Natural Resources.

State Private Lands Management Programs

Many State natural resource departments have developed wildlife management programs for private lands. State biologists are often available to provide landowners with technical assistance in the development of their lands for waterfowl and other wildlife species. These biologists frequently serve as "brokers" and are also familiar with programs of other agencies that may meet the objectives of the individual landowner. In some instances, these State-administered programs provide cost-sharing assistance to help finance wildlife management projects.

State Tax Credit and Exemption Programs

Several States have statutes that provide property tax relief for those landowners who are interested in preserving habitat that can benefit waterfowl and other wildlife resources. In the Midwest, for example, Iowa, North Dakota, and Minnesota exempt certain wetlands from taxation. Additional information about these programs can be obtained from county tax assessors.

Indiana Classified Wildlife Habitat Act

The purpose of this legislation, passed in 1979, is to reduce habitat loss by encouraging landowners to develop or save existing wildlife habitat. The incentives for landowner participation are a reduction of the assessed value of classified lands to $1 per acre for tax purposes, and free technical advice and assistance from the Indiana Division of Fish and Wildlife. Lands eligible for this program include grasslands, shrublands, and wetlands. The owner of the classified wildlife habitat does not relinquish ownership or control of the property.

Minnesota State Cost-share Program

The Minnesota Board of Water and Soil Resources offers cost-share assistance to local Soil and Water Conservation Districts for construction costs of water quality projects. Frequently, these projects identify the need to restore wetlands and retire highly erodible croplands on private lands. Likewise, Watershed Management Districts, particularly in western Minnesota, have contributed cost-share grants for flood control purposes. Restoration of drained wetlands and enhancement of existing wetlands are projects eligible for this program, depending on flood control benefits. Private landowners located in watersheds for which a need exists to improve water quality or control flood waters should contact their local Soil and Water Conservation District for additional information.

Private Conservation Organization Programs

In recent years, private conservation organizations have been instrumental in promoting wildlife habitat improvement projects on private lands. Several of these organizations are national or international in scope, while others are regional or local. Collectively, these conservation organizations are a great source of financial and technical assistance for the private landowner who wishes to improve lands for waterfowl.

Ducks Unlimited—U.S. Habitat Program

Since 1983 Ducks Unlimited has financed the improvement of waterfowl habitat in several States of the upper Midwest. Most of these projects were on public lands. Recently, however, Ducks Unlimited has expanded its program and assists in wetland restoration projects on private lands, including those lands enrolled in the Conservation Reserve Program. In cooperation with the U.S. Fish and Wildlife Service, Ducks Unlimited has assisted in restoring several hundred wetlands in North Dakota and western Minnesota.

Ducks Unlimited Canada—Prairie Care Program

Beginning in June 1989, farmers in selected areas of Canada's prairie Provinces were offered incentives and technical assistance to adopt conservation land-management practices or to convert marginal croplands to pastures or hayland. Annual rental payments are also used to maintain grass cover for several years. Additional information about this program can be obtained from Ducks Unlimited Canada, 1190 Waverly Street, Winnipeg, Manitoba R3T 2E2.

Pheasants Forever

Activities undertaken by Pheasants Forever include the restoration of upland nesting and wintering cover for pheasants. Many Pheasants Forever projects also improve habitat for waterfowl; particularly where the organization finances the restoration of wetlands that provide excellent winter cover for pheasants in the upper Midwest. Local chapters also purchase or lease lands containing valuable habitats. Members of Pheasants Forever also work with private landowners, other private organizations, and government agencies to improve wildlife habitat.

The Nature Conservancy

The Nature Conservancy is an international organization, organized in the United States by State chapters; its purpose is to preserve rare and endangered plant and animal communities through land purchases and the acquisition of conservation easements. The Nature Conservancy also assists governments and other conservation organizations with land acquisitions, manages a worldwide system of nature preserves, and promotes legislation for the protection of ecological diversity.

Wetlands for Iowa

The Iowa Natural Heritage Foundation is a nonprofit organization whose purpose is to restore and preserve important resources within the State of Iowa. One such program is Wetlands for Iowa, which is designed to preserve existing wetlands and restore others. These wetlands may exist on private lands, and conservation easements can be acquired for their continued protection.

State Waterfowl Associations

These organizations assist in the restoration of wetlands located on CRP or public lands. Waterfowl associations and private duck-hunting clubs also purchase high-quality waterfowl habitat in fee title or protect important habitat through acquisition of perpetual conservation easements.

Local Hunting, Fishing, and Conservation Clubs

Local hunting, fishing, and conservation organizations are willing to assist private landowners with waterfowl habitat improvement projects. Many of these organizations have substantial financial resources that are often dedicated to wildlife habitat improvement projects on both public and private lands.

Summary

As indicated by the previous examples, a number of incentives exist for private landowners within certain areas to improve waterfowl management on their lands. Additional programs exist in Canada. Land managers and landowners interested in using these programs are encouraged to familiarize themselves with programs in their area. If no incentives exist for wildlife habitat protection of private lands, those interested are urged to promote the implementation of such programs through their local, State, and Federal governments. This participation is critical as we approach the next century, where the future of waterfowl in North America will depend on innovative programs to encourage resource conservation on private lands.

Suggested Reading

Henderson, F. R. 1984. Guidelines for increasing wildlife on farms and ranches. Kansas State University Cooperative Extension Service, Manhattan. 572 pp.

Messmer, T. 1989. North Dakota wildlife conservation programs. North Dakota State University Extension Service, Fargo. Pub. WL-942 revised. 16 pp.

Steward, D., D. DeFrates, and K. Peper. 1988. Nonregulatory wetland protection options. Minnesota Board of Water and Soil Resources, St. Paul. 17 pp.

Ward, J. R., F. K. Benfield, and A. E. Kinsinger. 1989. Reaping the revenue code. Natural Resources Defense Council, New York. 142 pp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.4.3. Managing Agricultural Foods for Waterfowl

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Road
Fort Collins, CO 80526

Agriculture, more than any other human activity, has had a profound influence on North American waterfowl. Most agricultural effects have been detrimental, such as the conversion of grassland nesting cover to cropland, the widespread drainage of wetlands, and the use of pesticides that may poison waterfowl or their food. However, some by-products of agriculture have been beneficial, particularly grain or other foods left as residue after harvest. Many waterfowl are opportunistic feeders, and some species such as Canada geese (*Branta canadensis*), snow geese (*Chen caerulescens*), mallard (*Anas platyrhynchos*), northern pintails (*A. acuta*), and green-winged teal (*A. crecca*) have learned to capitalize on the abundant foods produced by agriculture. During the last century, migration routes and wintering areas have changed in response to these foods. Some species have developed such strong traditions to northern wintering areas that many populations are now dependent on agricultural foods for their winter survival.

Their relatively large body size enables waterfowl to store fat, protein, and minerals for later use. These reserves can then be mobilized for egg formation, migration, molt, or in times of food shortage. Although strategies for depositing and using nutrient reserves differ among species, and are necessarily dependent upon seasonal availability of foods, waste grains are among the most extensively exploited food resources. Arctic-nesting snow geese, for example, feed extensively in agricultural fields during their northward migration. Their ability to exploit croplands has been largely responsible for dramatic population increases in this species. Clutch size and perhaps nesting dates of mallards and other early-nesting ducks are thought to be directly related to the amount of reserves obtained on their wintering grounds.

During breeding and molting periods, waterfowl require a balanced diet with a high protein content. Agricultural foods, most of which are neither nutritionally balanced nor high in protein, are seldom used during these periods. However, during fall, winter, and early spring, when vegetative foods make up a large part of the diet, agricultural foods are preferred forage except in arctic and subarctic environments. Waterfowl management during these periods is often directed at small grain and row crops. Corn, wheat, rice, barley, oats, peas, sorghum, rye, millet, soybeans, and buckwheat are commonly planted as waterfowl foods. The species and varieties suitable for a particular area, as well as the seeding and cultivation techniques necessary for a good yield, are dependent on soil conditions, growing season, moisture regimes, irrigation, the availability of farm implements, and other considerations. My purpose is therefore not to recommend crops or describe planting techniques, because these are site-specific considerations. Instead, I present guidelines that discuss the quality and quantity of agricultural foods needed by waterfowl, and techniques to enhance the availability of these foods.

Food Quality of Grains

Waste grain is a locally abundant, high-energy food that can be quickly consumed by waterfowl. The best indication of the nutritional quality of foods is given by an analysis of their chemical composition. The amount of gross energy, crude protein, fat, ash, fiber, and digestible carbohydrates (NFE) are indices to food value. However, since waterfowl use grains primarily as a high-energy food and supplement their diet with natural foods to compensate for nutritional deficiencies, the energy content of grains is the most commonly used basis for comparison. Unfortunately, energy content varies among varieties of the same grain, as well as by soil and environmental conditions. Moreover, waterfowl cannot digest different grains with similar efficiencies. In recognition of this digestive efficiency, metabolizable energy, which is indicative of the energy actually derived from a food, is a better comparative measure than gross energy content.

Agricultural foods (with the exception of soybeans) provide high levels of metabolizable energy (Table 1). Energy values, while indicative of fresh seeds, are not representative of grains underwater or exposed outdoors for an extended period. Under these conditions, energy value may decline rapidly. For example, rice will lose only 19% of its energy value after 90 days of flooding, but milo and corn will lose 42 and 50%, respectively, and soybeans will lose 86% of their energy content. Such losses underscore the need for well-timed harvests and manipulations to maintain food quality. Harvesting fields at intervals will help ensure a constant supply of fresh feed. When fields are flooded, water should be applied gradually so that a "flooding front" is created that progressively inundates new grain. Soybeans should be avoided as a waterfowl food crop. They not only decompose rapidly in water, but may also cause food impaction in the esophagus, which can be fatal. Additionally, legumes such as soybeans are undesirable because they often contain digestive inhibitors that reduce the availability of protein and other nutrients.

How Much to Plant?

Even though modern implements harvest about 95% of a ripened grain crop, most harvested fields still contain 50–310 pounds/acre of residual grain (Table 2). Waterfowl are efficient feeders, and will continue to use agricultural foods long after residual food density has been reduced. Waste corn, at typical postharvest densities of 100–500 pounds/acre, has to be reduced to a density of 90 pounds/acre before mallard feeding rates begin to decrease. Generally, waterfowl feeding on land will reduce densities to 13 pounds/acre before switching to alternate food sites, whereas waterfowl using foods underwater may abandon fields after densities decline to 45 pounds/acre. Daily food consumption varies among species, individuals within species, and with energetic demands related to behavior and thermoregulation. As a rule of thumb, average-sized geese will consume about 150–200 g/day, whereas large ducks need about half this amount. Although waterfowl will fly 20 miles or more to obtain grain, it is best to provide food no farther than a 10-mile radius from waterfowl concentrations.

Cost is always a consideration when planting food crops. Species that can be grown without irrigation will always be less expensive than water-demanding grains. Some crops, such as millets, are closely related to wild plants used by waterfowl. Millets are advantageous because they can be either

Table 1. *Energy content and chemical composition of common agriculture foods planted for waterfowl.*

	Metabolizable energy[a]		Percent (dry weight)				
Crop	Mallard	Canada goose	Protein	Fiber	NFE[c]	Fat	Ash
Barley	2.98[b]	3.32	14	5	—	2	2
Milo	—	3.85	12	3	80	3	2
Rice	3.34	—	9	1	—	2	1
Rye	3.14	2.74	14	4	68	2	2
Soybeans	2.65	3.20	42	6	28	19	5
Wheat	3.32[b]	3.35	26	19	34	4	17
Yellow corn	3.60	4.01	10	5	80	5	2

[a] Apparent metabolizable energy in kcal/g.
[b] Estimated as 6% less than the true metabolizable energy value.
[c] Nitrogen-free extract.

Table 2. *Average preharvest and postharvest densities of common agricultural crops planted for waterfowl.*

Crop	Density (pounds/acre) Preharvest	Postharvest	Location
Barley	2,613	105	Colorado
Corn (for grain)	5,580	320	Iowa, Illinois, Nebraska, Texas
Grain sorghum	3,678	258	Texas
Japanese millet	2,227	89	Colorado
Rice	5,205	160	Mississippi Valley
Soybeans	1,093	53	Mississippi Valley
Wheat	1,768	106	Colorado

drilled or broadcast, are inexpensive, grow quickly, and are less susceptible to wildlife depredations than other crops. Japanese millet tolerates shallow flooding and saturated soils, and produces high yields of seed. Other species, such as white proso millet, achieve a low growth form with no loss in seed production if grown under low moisture conditions. Carefully planned crop rotations may eliminate the need for inorganic nitrogen or insecticide applications, thereby reducing costs. One common rotation used in midwestern States is a mixture of sweet clover and oats the first year, followed by corn in the second year and soybeans in the third year. Winter wheat is planted in the fall of the third year, with clover and oats repeated in the summer of the fourth year.

Enhancing Food Availability

Before grain crops are selected, managers should consider not only the energy value of grains but also the physical characteristics of the seed head. Large seeds, such as corn kernels, are more quickly located and consumed by waterfowl than smaller seeds. Seed head structure is also important. For example, even though barley has a lower metabolizable energy, it is preferred over hard spring wheat because ducks are able to remove seeds more quickly from the heads.

Abundant grain crops are worthless if they are not presented in a manner that makes them available to birds. The amount of residual food remaining after harvest is affected by harvester efficiency and operation, slope of the field, insects, disease, cultivar, and moisture content of the grain. Reductions in surface grain density result from all postharvest, cultivation treatments (Table 3). In some instances, postharvest treatments may be beneficial, even if aboveground residues are decreased, because reduced ground litter increases the foraging efficiency of waterfowl. However, such benefits are often difficult to quantify; therefore, the best strategy is to present unharvested or freshly harvested crops in ways that have proven attractive to waterfowl (Table 4). Such practices regulate secondary availability, or the accessibility of grain residues after harvest.

In mild winter climates, precipitation or flooding from runoff usually enhances grain availability by making food more available to waterfowl. In cold

Table 3. *Estimated waste corn residues resulting from different tillage systems. See text for other variables affecting harvest residues.*

Tillage system	Grain density (pounds/acre) Middle range	Lower range
Untilled	320	76
Disk (tandem)	233	56
Chisel (straight shank)	148	35
Chisel (twisted shank)	27	5
Chisel (straight shank—disk (tandem)	22	4
Chisel (straight shank)—disk (offset)	8	1
Chisel (twisted shank)—disk (tandem)	5	<1
Chisel (twisted shank)—disk (offset)	3	0
Moldboard plow	2	0

Table 4. *Recommended treatments to enhance food availability for waterfowl.*

Crop	Treatment
Barley, wheat	Leave low-growing varieties standing, since their seed heads are easily fed upon by ducks and geese.
Corn, milo	Harvest when grain moisture is <21%. Burn corn stubble, then leave field dry—do not flood. Graze cattle if snow cover is persistent.
Soybeans	Do not flood fields. Beware of potential impaction problems if dry beans are consumed by birds.
Millets	Best if unharvested. Flood gradually to a depth of 8 inches.
Rice	Disk harvested fields to loosen and mix soil with grain and straw, or roll with a water-filled drum to create openings in stubble. Flood to a depth of 8 inches.

climates, however, food usually becomes less available after precipitation. In these regions, snowfall and cattle grazing are the most important components of secondary availability. After heavy snowfall, mallard and other ducks often use standing grain crops, since these are the only foods above snow. Cattle, turned loose to graze in harvested cornfields, create openings in the snow and break up corn ears, thereby increasing kernel availability.

The physical layout of fields may also affect food availability. In severe winter climates, wide swaths of harvested crops should be separated by several rows of unharvested plants, thereby providing a "snow fence" to enhance the availability of grain on the ground as well as provide a reserve of food that will remain above even the deepest snow. It may be advantageous to plant crops in blocks of rows running perpendicular to one another. This helps ensure that the tops of some rows will be exposed by the prevailing winds during heavy snow.

Suggested Reading

Alisauskas, R. T., C. D. Ankney, and E. E. Klaas. 1988. Winter diets and nutrition of midcontinental lesser snow geese. J. Wildl. Manage. 52:403–414.

Baldassarre, G. A., R. J. Whyte, E. E. Quinlin, and E. G. Bolen. 1983. Dynamics and quality of waste corn available to postbreeding waterfowl in Texas. Wildl. Soc. Bull. 11:25–31.

Clark, R. G., H. Greenwood, and L. G. Sugden. 1986. Influence of grain characteristics on optimal diet of field–feeding mallards. J. Appl. Ecol. 23:763–771.

McFarland, L. Z., and H. George. 1966. Preference of selected grains by geese. J. Wildl. Manage. 30:9–13.

Reinecke, K. J., R. M. Kaminski, D. J. Moorhead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi alluvial valley. Pages 203–247 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, eds. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Ringelman, J. K., W. R. Eddleman, and H. W. Miller. 1989. High plains reservoirs and sloughs. Pages 311–340 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, eds. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Sugden, L. G. 1971. Metabolizable energy of small grains for mallards. J. Wildl. Manage. 35:781–785.

Warner, R. E., and S. P. Havera. 1985. Effects of autumn tillage systems on corn and soybean harvest residues in Illinois. J. Wildl. Manage. 49:185–190.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.4.4. Habitat Management for Molting Waterfowl

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Street
Fort Collins, CO 80526

The ecology, behavior, and life history strategies of waterfowl are inseparably linked to that unique avian attribute, feathers. Waterfowl rely on flight capabilities to migrate, to fully exploit the resources of wetland and upland communities, and to escape life-threatening events. The insulation provided by contour and down feathers allows waterfowl to use a wide range of habitats and protects them from temperature extremes. Plumage is important not only for species recognition during courtship, but also for cryptic coloration of females during incubation. However, feathers become worn and must be periodically replaced. The process of feather renewal, or molt, is a critical event in the lives of birds. Despite the obvious importance of the molt, relatively little attention has been devoted to managing waterfowl during this period.

Unlike most birds, ducks, geese, and swans share the unusual trait of a complete, simultaneous wing molt that renders them flightless for 3 to 5 weeks during the postbreeding period. Concurrently, these waterfowl also renew their tail and body feathers. In addition to this postbreeding molt, ducks undergo a second yearly molt to renew all but their flight feathers. Here, I describe the nutrition, energetics, and management of molting adult ducks and geese, with emphasis on the period of molt when birds are flightless.

Nutrition and Energetics

Dry waterfowl feathers are about 86% protein. Large amounts of sulfur amino acids, mainly cystine, are required for the production of keratin, the protein constituent of feathers. In addition, the net energetic efficiency of feather synthesis is only 6.4%. This combination of low conversion efficiency, overall high protein demand, and specific amino acid requirements causes molt to be nutritionally and energetically costly.

The source of protein used in feather synthesis has important implications for habitat management. Most waterfowl lose weight during the flightless period and also experience changes in digestive organ and muscle masses. Such changes are attributable to diet and conversion of muscle protein to amino acids used in feather synthesis. It is now believed that waterfowl use a mixed strategy of muscle protein reserves and high protein foods for feather synthesis. Although there is a primary dependence on foods, internal reserves provide a buffer against periods of high protein demand or food shortage. Proper habitat management for molting waterfowl must therefore focus on providing sufficient high-protein, green forage for geese and herbivorous ducks, as well as providing aquatic invertebrates for most dabbling and diving ducks.

Molting Habitat: When and Where?

Molt chronology varies among species (Fig. 1) and is ultimately regulated by the number of daylight hours and hormonal changes. Geese and

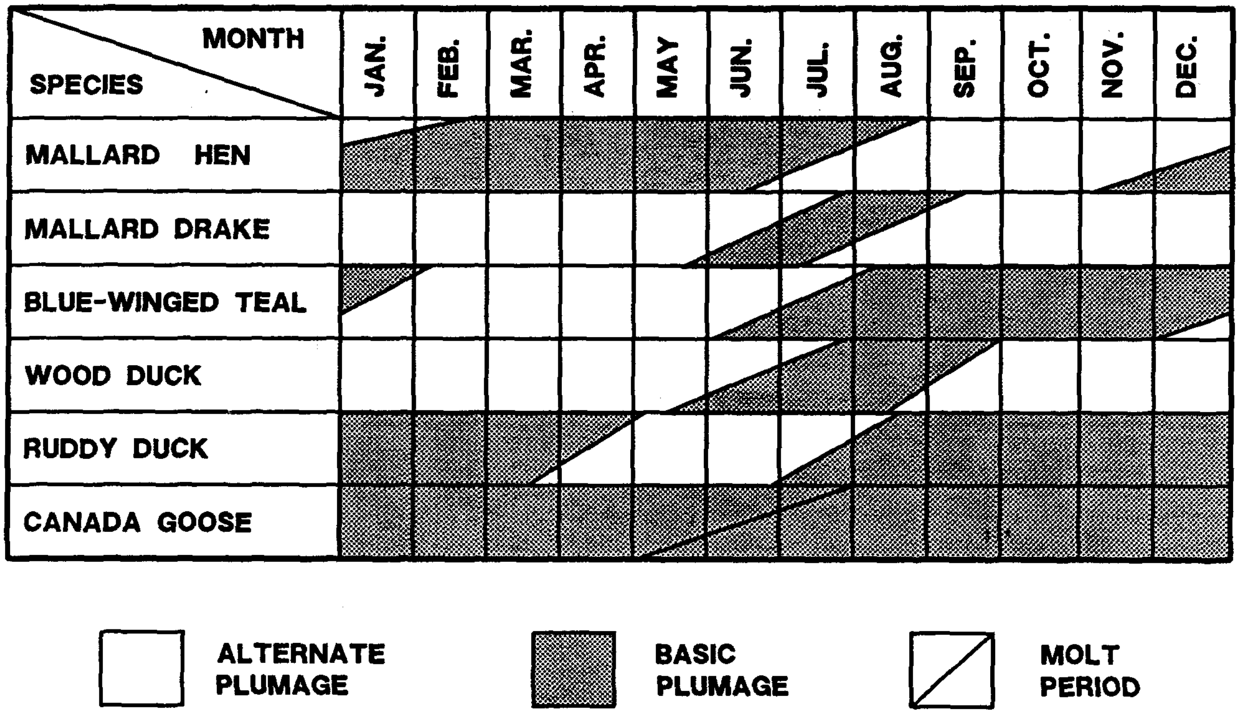


Fig. 1. Annual molt chronology of representative North American waterfowl (after Weller 1976). Molt patterns are for adult male waterfowl unless otherwise noted.

swans undergo a single, complete molt during the postbreeding period. Yearling birds and unsuccessful nesters make up the initial molting groups, followed shortly thereafter by adults with broods. Adults regain flight capabilities about the time goslings fledge. Duck plumages and molts are more complex than those of geese. Males acquire bright breeding ("alternate") plumage in fall and retain this plumage until after the breeding season. Thereafter, males molt into "basic" or "eclipse" plumage that is retained from midsummer into early fall. Most females begin postbreeding molt on northern breeding grounds and may complete this molt during migration or on wintering grounds. This plumage is worn until late winter or early spring, when they molt into basic plumage that is retained throughout the nesting period. The total duration of each molt is 6 to 7 weeks.

The timing of the flightless period for ducks depends on when a species nests and, for males, the length of time they remain with their hen before joining molting groups (Fig. 2). As with geese and swans, nonbreeding individuals or females that nested unsuccessfully molt early. Hens that nest successfully, or that unsuccessfully attempt to renest molt later. Unlike most males, late-molting females often do not join large molting groups but instead prefer to molt singly or in small groups. They also tend to use smaller wetlands near their breeding habitat. Thus, molt chronology and habitat use are partially regulated by phenological considerations such as an early spring versus a late spring, wetland abundance and permanency, and other conditions that influence nest success. Similarly, nutrient reserves and perhaps pairing status can affect the timing of prebasic molt on wintering grounds.

Individual ducks and geese often undergo postbreeding molt on wetlands used in previous years. Some of this traditional use may result from homing to nesting areas and subsequent use of nearby wetlands for molting. However, many waterfowl migrate hundreds of miles to traditional molting sites, suggesting that such wetlands possess unique attributes that make them ideal for molting birds. Although these attributes are largely unknown, some unique features are apparent, and generalized food and habitat requirements of some species have been described (Table). The common needs of all molting waterfowl are wetlands, adequate food resources, and security from predators and disturbance.

Geese and most ducks tend to concentrate on large, semipermanent or permanent wetlands during molt. These wetlands often provide large ex-

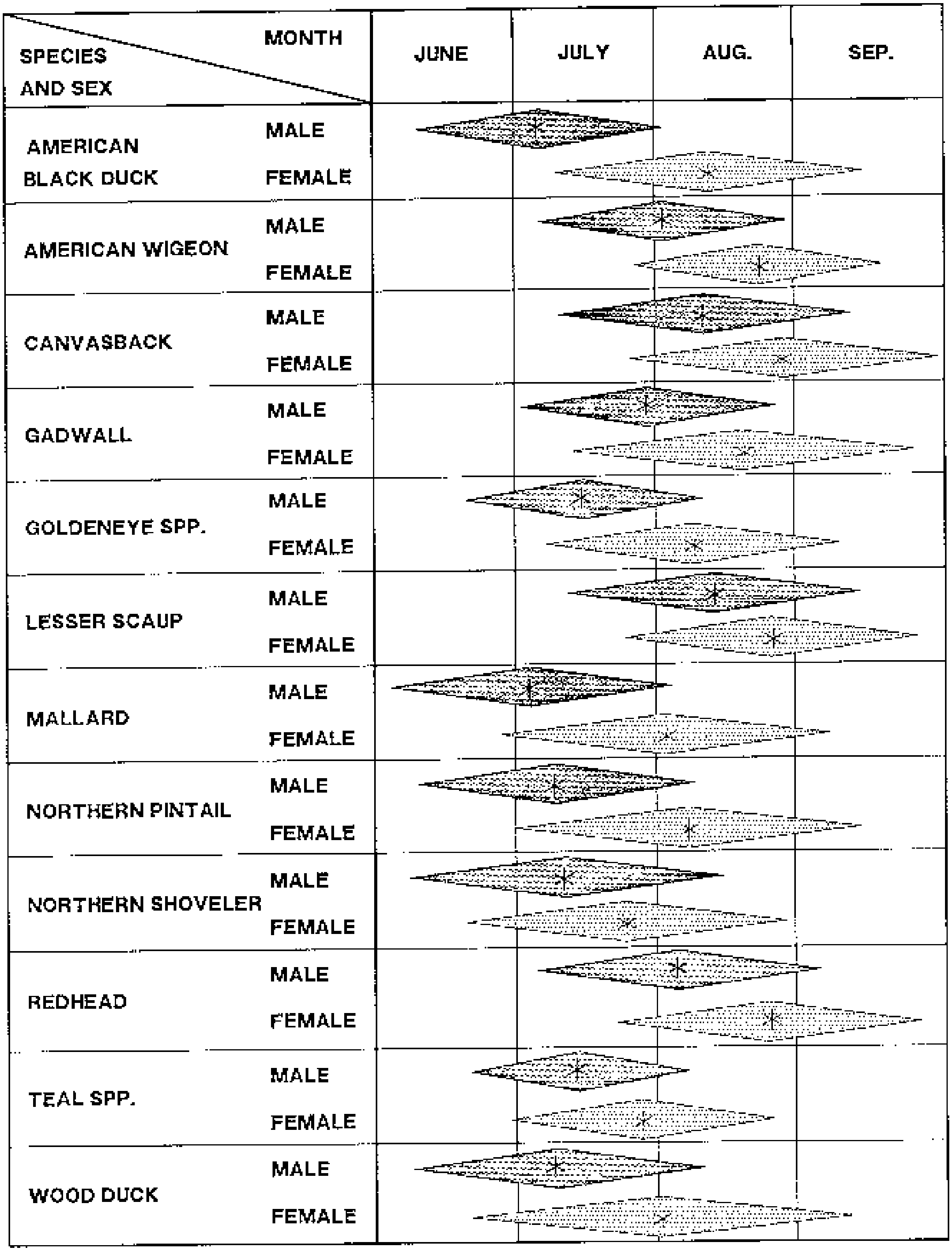


Fig. 2. Timing and duration of the flightless period for some North American ducks. Chronology is representative of individuals breeding at 45° north latitude and may vary according to location, phenology, and local nesting conditions. *Asterisks* denote the approximate time at which most birds are flightless.

Table. *Generalized habitat use, behavior, and food habits of selected duck species during the flightless period.*

Species	General habitat use and behavior	Food habits
American black duck	Flooded shrubs and emergents in inland habitats; tidal marshes and estuaries in coastal habitats. Rarely observed when flightless on inland areas	Omnivorous
American wigeon	Open water of large or medium-sized wetlands. Feeds in open water on submergent plants; loafs on shorelines	Herbivorous
Blue-winged teal	Extensive beds of cattail, bulrush, and other emergents	Omnivorous
Canvasback	Open-water portions of large lakes. Attracted to Sago pondweed. Seeks resting sites and security in open water	Omnivorous
Common goldeneye	Open water of large lakes	Mostly carnivorous
Gadwall	Same as American wigeon	Herbivorous
Lesser scaup	Same as canvasback	Mostly carnivorous
Mallard	Marshes with concealing cover, such as cattail, bulrush, or shrubs. Rarely observed during flightless period	Omnivorous
Northern pintail	Same as mallard. Often occurs in association with mallards	Omnivorous
Northern shoveler	Similar to teal and other dabbling ducks	Carnivorous—zooplankton
Redhead	Open-water portions of large lakes. Seeks resting sites and security in open water	Herbivorous—submergent vegetation
Wood duck	Swamps, wooded ponds, and marshes with abundant, dense cover	Omnivorous

panses of open water as well as emergent vegetation such as cattail and bulrush. Although open water and vegetative cover would seem to address different habitat needs, both may provide molting waterfowl with a sense of security. When rendered flightless, diving ducks seek escape from predators in open water. Geese, which traditionally prefer open nesting sites that enable them to quickly detect predators, may select open-water molting areas for the same reason. Mallards and most other carnivorous or omnivorous dabbling ducks seem to prefer thick, emergent vegetation for hiding. Wetlands used for molting also commonly possess islands or shorelines devoid of vegetation. Such areas enable waterfowl to rest out of water, yet provide open visibility to detect approaching predators.

Vegetation Management

Aquatic vegetation provides shelter, habitat for aquatic invertebrates, and green forage for molting waterfowl. Flooded, robust emergent species such as cattail, bulrush, or tall sedges are most desirable; however, any patch of flooded emergent vegetation may be used by molting birds. Most permanent wetlands contain bands of emergents around their periphery or in patches in shallow areas. Because seed banks usually contain an abundance of emergent plant seeds, spring and summer drawdowns may be used to encourage germination of robust emergents and moist-soil plants. If drawdowns are not possible and water depth exceeds 3 feet, fill may be added to create shallow areas necessary to establish and propagate emergent plants. In some instances, fish may compete with molting waterfowl for aquatic invertebrate foods, or rough fish such as carp may increase water turbidity, thereby reducing the abundance of submerged vegetation. Control of fish populations may be needed to correct such conditions.

Large wetlands often contain flooded emergents that occupy too much of the wetland basin. In such cases, control measures should be initiated to increase the open water to vegetation ratio to between 50:50 and 70:30, which are proportions attractive to many molting waterfowl. Canada geese are attracted to wetlands that have an open water to vegetation ratio of 90:10 or higher. Vegetation control is often achieved by drawdowns, followed by cutting or other mechanical or chemical control of vegetation, then subsequent reflooding during the growing season.

Many aquatic invertebrates are dependent on the microscopic organisms (periphyton) that attach to underwater substrates. To thrive, periphyton must have a rich nutrient base. Periodic drawdowns, every 3–5 years in most wetland systems, delay natural wetland succession, release nutrients through aerobic decay, allow seed germination, and promote the establishment of emergent vegetation by compacting the bottom substrate. Periphyton and allied invertebrate populations often increase markedly after drawdowns, thereby increasing the availability of high protein foods needed by many molting ducks.

Sedges, rushes, grasses, and other herbaceous plants all provide natural green forage for molting geese. Increasingly, geese also rely on Kentucky bluegrass, alfalfa, and other cultivated plants as a source of protein. Because geese extract only the readily soluble compounds from green forage, and often feed selectively on new shoots or other highly nutritious parts of plants, large quantities of forage are needed to provide the nutrients necessary for feather synthesis. Moreover, molting adults and goslings often compete for the same food resources, further increasing the demand for forage. Insufficient forage may result in gosling mortality, because young birds are at a disadvantage when competing with adults. Food plots of alfalfa, wheat, rye, or other forage should be established in instances where wetlands used for molting do not have sufficient forage within 200 yards.

Controlling Disturbance

Postbreeding Molt

Tolerance to human disturbance varies by species and exposure to human activities. Although no species of waterfowl is oblivious to disturbance, molting Canada geese can coexist with people provided that close approaches and direct harassment are avoided. Molting ducks, however, are less tolerant. Boaters and anglers may be particularly disruptive, causing birds to become more alert and evasive, thereby reducing foraging time and efficiency while increasing energy devoted to swimming and escape. Disturbance may also relegate flocks to suboptimal habitats where they are less secure from predators. Fortunately, many waterfowl seem to confine their activities to portions of large wetlands during the flightless period. Once such areas are delineated through field observations, human effects can be minimized through area closures that are delineated by buoy markers or landmarks. The behavior of molting birds and annual trends in molting populations are good measures of the success of such closures. Excessive alert or avoidance behavior, or annual declines in the population of molting birds are indications of adverse reactions to disturbance.

The timing of protection from disturbance depends partly on the time needed to grow new flight feathers. The growth rate of flight feathers increases with body size, generally at a rate of 0.08 inches per day per pound of body weight. However, because wing length increases with body mass, the duration of the flightless period ranges from 25 to 32 days for all waterfowl. Most waterfowl are able to fly when their primary feathers are 75 to 85% of their final length. However, because species and sexes molt asynchronously, protection from disturbance should extend from the time that the earliest species begins incubation (assuming that breeding birds molt locally) until 3 weeks after the young of the latest-nesting species begin flying (Fig. 2). When geese and ducks are present in a mixed population, this period of protection would extend over 3.5 months.

Prebasic Molt

Unlike northern wintering populations, in which species such as mallards undergo prebasic molt during January–March, ducks in southern populations begin molt in early winter, with paired birds appearing to molt earlier than unpaired individuals. When habitat conditions are favorable and food resources plentiful, prebasic molt occurs in early winter. Disturbance to ducks during prebasic molt has caused some southern States to consider restructuring hunting seasons to reduce the effects on paired and molting birds. The concern, which has not been substantiated, is that hunting disturbance may disrupt the formation of pairs, retard molt, and reduce foraging efficiency. In turn, these effects may delay the acquisition of nutrient reserves needed for migration and reproduction, and generally retard the biological timetable of affected individuals. In addition to manipulating hunting seasons and area closures, the strategies for minimizing disturbance during prebasic molt are similar to those described for the postbreeding molt.

The Need for Habitat Preservation

Knowledge of the habitat requirements and nutritional demands of molting waterfowl is far from complete. We do recognize that during the flightless period, waterfowl are completely dependent on the resources of a single wetland for about 1 month. The fact that some waterfowl undertake molt migrations of hundreds of miles, while bypassing myriad other seemingly “suitable” wetlands along the way, suggests that wetlands used by molting waterfowl possess unique qualities that we do not yet recognize. Until we better understand the features that make such areas suitable for molting birds, such habitats should be protected or managed with care.

Suggested Reading

Bailey, R. O., and R. D. Titman. 1984. Habitat use and feeding ecology of postbreeding redheads. J. Wildl. Manage. 48:1144–1155.

Dubowy, P. J. 1985. Feeding ecology and behavior of postbreeding male blue-winged teal and northern shovelers. Can. J. Zool. 63:1292–1297.

Gilmer, D. S., R. E. Kirby, I. J. Ball, and J. H. Reichmann. 1977. Post-breeding activities of mallards and wood ducks in north-central Minnesota. J. Wildl. Manage. 41:345–359.

Heitmeyer, M. E. 1988. Body composition of female mallards in winter in relation to annual cycle events. Condor 90:669–680.

Heitmeyer, M. E. 1988. Protein costs of the prebasic molt of female mallards. Condor 90:263–266.

Oring, L. W. 1964. Behavior and ecology of certain ducks during the postbreeding period. J. Wildl. Manage. 28:223–233.

Salomonsen, F. 1968. The moult migration. Wildfowl 19:5–24.

Weller, M. W. 1976. Molts and plumages of waterfowl. Pages 34–38 *in* F. C. Bellrose, ed. Ducks, geese, and swans of North America. Stackpole Books, Harrisburg, Pa.

Zicus, M. C. 1981. Molt migration of Canada geese from Crex Meadows, Wisconsin. J. Wildl. Manage. 45:54–63

Appendix. List of Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Sedges	*Carex* spp.
Rushes	*Juncus* spp.
Alfalfa	*Medicago sativa*
Kentucky bluegrass	*Poa pratensis*
Sago pondweed	*Potamogeton pectinatus*
Bulrush	*Scirpus* spp.
Rye	*Secale cereale*
Wheat	*Triticum* spp.
Cattail	*Typha* spp.
Animals	
Wood duck	*Aix sponsa*
Northern pintail	*Anas acuta*
American wigeon	*Anas americana*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Mallard	*Anas platyrhynchos*
American black duck	*Anas rubripes*
Gadwall	*Anas strepera*
Lesser scaup	*Aythya affinis*
Redhead	*Aythya americana*
Canvasback	*Aythya valisineria*
Canada goose	*Branta canadensis*
Common goldeneye	*Bucephala clangula*
Ruddy duck	*Oxyura jamaicensis*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1990

13.4.5. A Technique for Estimating Seed Production of Common Moist-soil Plants

Murray Laubhan
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri—Columbia
Puxico, MO 63960

Seeds of native herbaceous vegetation adapted to germination in hydric soils (i.e., moist-soil plants) provide waterfowl with nutritional resources including essential amino acids, vitamins, and minerals that occur only in small amounts or are absent in other foods. These elements are essential for waterfowl to successfully complete aspects of the annual cycle such as molt and reproduction. Moist-soil vegetation also has the advantages of consistent production of foods across years with varying water availability, low management costs, high tolerance to diverse environmental conditions, and low deterioration rates of seeds after flooding.

The amount of seed produced differs among plant species and varies annually depending on environmental conditions and management practices. Further, many moist-soil impoundments contain diverse vegetation, and seed production by a particular plant species usually is not uniform across an entire unit. Consequently, estimating total seed production within an impoundment is extremely difficult.

The chemical composition of seeds also varies among plant species. For example, beggartick seeds contain high amounts of protein but only an intermediate amount of minerals. In contrast, barnyardgrass is a good source of minerals but is low in protein. Because of these differences, it is necessary to know the amount of seed produced by each plant species if the nutritional resources provided in an impoundment are to be estimated.

The following technique for estimating seed production takes into account the variation resulting from different environmental conditions and management practices as well as differences in the amount of seed produced by various plant species. The technique was developed to provide resource managers with the ability to make quick and reliable estimates of seed production. Although on-site information must be collected, the amount of field time required is small (i.e., about 1 min per sample); sampling normally is accomplished on an area within a few days. Estimates of seed production derived with this technique are used, in combination with other available information, to determine the potential number of waterfowl use-days available and to evaluate the effects of various management strategies on a particular site.

Technique for Estimating Seed Production

To estimate seed production reliably, the method must account for variation in the average amount of seed produced by different moist-soil species. For example, the amount of seed produced by a single barnyardgrass plant outweighs the seed produced by an average panic grass plant. Such differences prevent the use of a generic method to determine seed production because many species normally occur in a sampling unit.

My technique consists of a series of regression equations designed specifically for single plant species or groups of two plant species closely related with regard to seed head structure and plant height (Table 1). Each equation was developed from data collected on wetland areas in the Upper Mississippi alluvial and Rio Grande valleys. The regression equations should be applicable throughout the range of each species because the physical growth form of each species (i.e., seed head geometry) remains constant. As a result, differences in seed production occur because of changes in plant density, seed head size, and plant height, but not because of the general shape of the seed head. This argument is supported by the fact that the weight of seed samples collected in the Rio Grande and Upper Mississippi valleys could be estimated with the same equation.

Estimating seed production requires collecting the appropriate information for each plant species and applying the correct equations. The equations provide estimates in units of grams per 0.0625 m^2; however, estimates can readily be converted to pounds per acre by using a conversion factor of 142.74 (i.e., grams per 0.0625-$m^2 \times 142.74$ = pounds per acre). Computer software developed for this technique also converts grams per square meter to pounds per acre.

Collection of Field Data

Measurements Required

Plant species
Seed heads (number)
Average seed head height (cm)
Average seed head diameter (cm)
Average plant height (m)

Equipment Required

Meter stick
Square sampling frame (Fig. 1)
Clipboard with paper and pencil (or field computer)

Method of Sampling

1. Place sampling frame in position. Include only those plants that are rooted within the sampling frame.

Table 1. *Regression equations for estimating seed production of eleven common moist-soil plants.*

Measurement[a] group	Plant species	Regression equation[bc] (weight in grams per 0.0625 m^2)	Coefficient of determination (R^2)
Grass			
	Barnyardgrass[d]	(HT × 3.67855) + (0.000696 × VOL)[e]	0.89
	Crabgrass	(0.02798 × HEADS)	0.88
	Foxtail[f]	(0.03289 × VOL)[g]	0.93
	Fall panicum	(0.36369 × HT) + (0.01107 × HEADS)	0.93
	Rice cutgrass	(0.2814 × HEADS)	0.92
	Sprangletop	(1.4432 × HT) + (0.00027 × VOL)[e]	0.92
Sedge			
	Annual sedge	(2.00187 × HT) + (0.01456 × HEADS)	0.79
	Chufa	(0.00208 × VOL)[h]	0.86
	Redroot flatsedge	(3.08247 × HEADS) + (2.38866 × HD) – (3.40976 × HL)	0.89
Smartweed			
	Ladysthumb/water smartweed	(0.10673 × HEADS)	0.96
	Water pepper	(0.484328 × HT) + (0.0033 × VOL)[g]	0.96

[a] Refer to Fig. 3 for directions on measuring seed heads.
[b] HT = plant height (m); HEADS = number of seed heads in sample frame; HL = height of representative seed head (cm); HD = diameter of representative seed head (cm); VOL = volume (cm^3).
[c] Conversion factor to pounds per acre is: grams per 0.0625 $m^2 \times 142.74$.
[d] *Echinochloa crusgalli* and *E. muricata*.
[e] VOL (based on geometry of cone) calculated as: (HEADS) × ($\pi r^2 h/3$); $\pi = 3.1416$, r = HD/2, h = HL.
[f] *Setaria* spp.
[g] VOL (based on geometry of cylinder) calculated as: (HEADS) × ($\pi r^2 h$); $\pi = 3.1416$, r = HD/2, h = HL.
[h] VOL (based on geometry of half sphere) calculated as: (HEADS) × ($1.33\pi r^3/2$); $\pi = 3.1416$, r = HD/2.

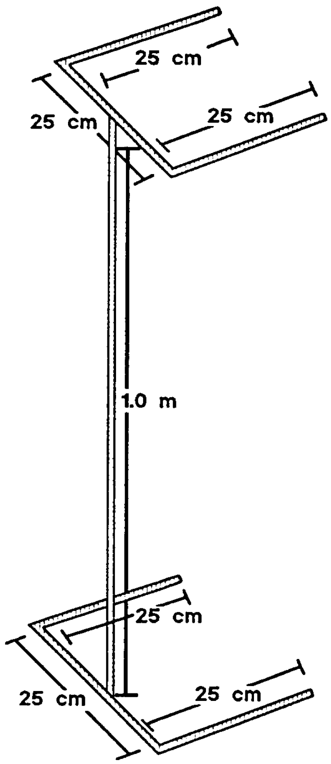


Fig. 1. Sampling frame design.

2. Record plant species present within sample frame on data form (Fig. 2).
3. For each plant species, record the number of seed heads within the sample frame. All seed heads occurring within an imaginary column formed by the sample frame should be counted.
4. For each plant species, select a single representative plant and measure
   a. the straightened height of the entire plant (from the ground to the top of the tallest plant structure) in meters,
   b. the number of seed heads within the sample frame,
   c. the height of the seed head in centimeters (measure along the rachis [i.e., main stem of flower] from the lowest rachilla [i.e., secondary stem of flower] to the top of the straightened seed head [Fig. 3].), and
   d. the diameter (a horizontal plane) of the seed head in centimeters (measure along the lowest seed-producing rachilla [Fig 3].).

Although average values calculated by measuring every plant within the sample frame would be more accurate, the time required to collect a sample would increase greatly. In contrast, obtaining measurements from a single representative plant allows a larger number of samples to be collected per unit time. This method also permits sampling across a greater portion of the unit, which provides results that are more representative of seed production in an entire unit.

Suggested Sampling Schemes

There are two basic approaches to estimating seed production within an impoundment. Both methods should supply similar results in most instances. The choice of method will depend largely on physical attributes of the impoundment and management strategies that determine the diversity and distribution of vegetation.

First approach: Sample across entire unit. The most direct procedure of estimating seed production is to collect samples across an entire unit using the centric systematic area sample design (Fig. 4). This method is recommended when vegetation types are distributed randomly across the entire impoundment (e.g., rice cutgrass and smartweed occur together across the entire

Plot Number	Plant species	Height (m)	Seed heads (no.)	Seed head height (cm)	Seed head diameter (cm)
1					
2					
3					
4					
5					
6					

Fig. 2. Sample data form for collecting information necessary to estimate seed production.

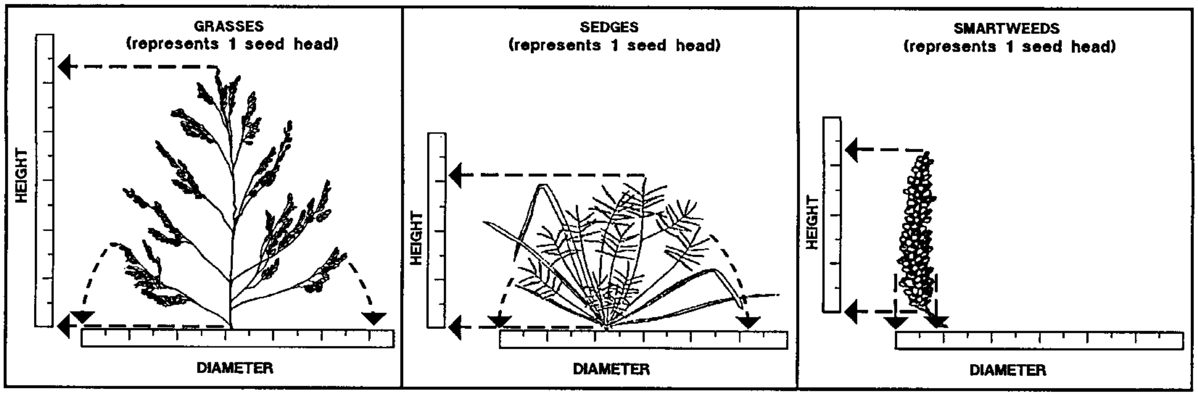


Fig. 3. Method of measuring dimensions of three seed head types.

impoundment; Fig. 5a). Divide an entire unit into blocks of equal dimension and establish a 0.0625-m^2 sample frame at the center of each block. In the field, this is accomplished by walking down the center of a row of such blocks and sampling at the measured interval. The precise number of samples necessary to provide a reliable estimate depends on the uniformity of each plant species within the impoundment and the desired accuracy of the estimate. The dimensions of the blocks are adjustable, but collect a minimum of one sample for every 2 acres of habitat. For example, a block size of 2 acres (i.e., 295 feet per side) results in 25 samples collected in a 50-acre moist-soil unit.

At each sampling station, measure and record each plant species of interest and the associated variables (i.e., plant height, number of seed heads, seed head height, and seed head diameter) necessary for estimating seed production of that species. If the same plant species occurs at two distinct heights (e.g., 0.4 m and 1.2 m), determine a seed estimate for plants at each height. If a plant species for which an estimate is desired does not occur within the sample frame, the plant species should still be recorded and variables assigned a value of zero. For example, if barnyardgrass seed production is to be estimated and the sample frame is randomly placed in an area where no barnyardgrass occurs, record a zero for plant height, number of seed heads, seed head height, and seed head diameter. This represents a valid sample and must be included in calculating the average seed production of barnyardgrass in the unit.

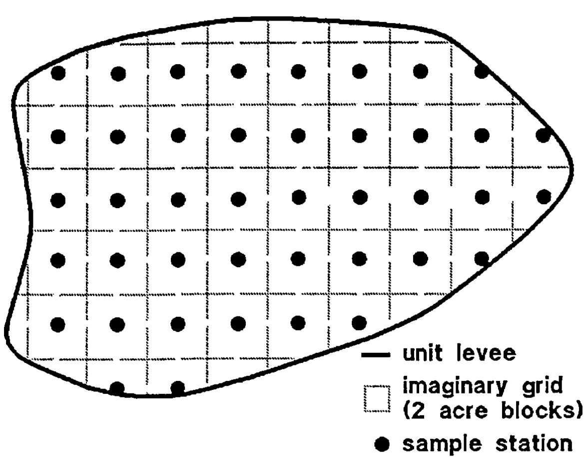


Fig. 4. Centric area sample method (unit = 84 acres)

Collect samples across the entire unit to ensure that a reliable estimate is calculated. Exercise care to sample only those areas that are capable of producing moist-soil vegetation. Borrow areas or areas of high elevation that do not produce moist-soil vegetation should not be sampled.

Estimate the weight of seed produced by each plant species in a sample with the appropriate regression equation (Table 1), or with the software developed for this purpose. Determine the average seed produced by each species in an impoundment by calculating the mean seed weight of all samples collected (if the species is absent from a sample, a zero is recorded and used in the computation of the mean) and multiplying the mean seed weight (grams per 0.0625m^2) by the total area of the unit. Determine total seed production by summing the average seed produced by each plant species sampled. Following collection of at least five samples, the accuracy of the estimate also can be

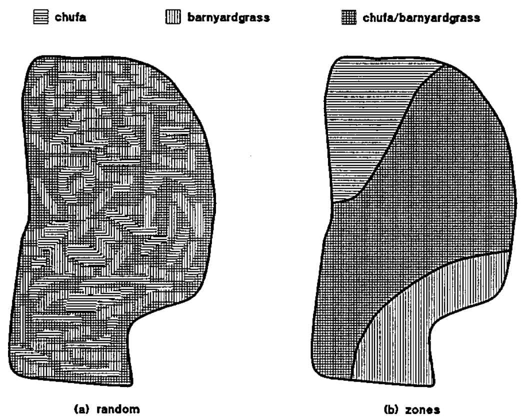


Fig. 5. Two general types of vegetation distribution.

determined. If higher accuracy is desired, collect additional samples by reducing the block size the appropriate amount or by randomly collecting additional samples.

Second approach: Sample within vegetation zones of a unit. This method is recommended for use in impoundments when species or groups of plants occur in distinct and nonoverlapping zones within a unit (e.g., smartweeds only occur at low elevations and barnyardgrass only occurs at higher elevations within the same unit; Fig. 5b). The same general methodology previously outlined for sampling an entire unit applies to this sampling scheme, except that

1. the centric area sampling method is applied separately to each vegetation zone within an impoundment,
2. seed production of an individual plant species over the entire unit is determined by multiplying the average seed production (based only on the samples collected within that zone) by the acreage of the zone sampled,
3. total seed production within a zone is calculated by summing the seed production estimates of each plant species occurring within that zone, and
4. total seed production across the entire impoundment is calculated by summing the seed production estimates of all zones composing the unit. If this sampling scheme is used, a cover map delineating vegetation zones is useful for calculating the acreage of zones sampled.

When to Collect Field Data

Samples must be collected when vegetation has matured and seed heads are fully formed because the regression equation for each plant species is based on seed head dimensions and plant height. Timing of sampling varies across latitudes because of differences in growing season length and maturation times of plant species. Information can be collected before the after-ripening of seeds (i.e., seed heads completely formed but seeds not mature) because seed head dimensions will not change appreciably. Information also can be collected following seed drop because seed head dimensions can be determined based on the geometry of the remaining flower parts (i.e., rachis and rachilla). This allows a greater time span for collecting information. If timed correctly, estimates for most moist-soil plants can be determined during the same sampling period.

Under certain conditions, two crops of moist-soil seeds can be produced within the same unit in a single year. Often, the second crop will be composed of plant species different from those composing the first crop. If this occurs, estimating total seed production requires sampling both first- and second-crop vegetation, even if the species composition of the second seed crop is similar to the first crop. Estimates based on the first crop cannot be applied to the second crop because seed head dimensions will be different.

Determining Required Sample Size

The number of samples necessary to estimate seed production will depend on the level of accuracy desired. Although as few as three samples will provide a mean value of seed production and an estimate of the variability within the unit, this type of estimate normally is unreliable. The most important factors influencing accuracy include the degree of uniformity in plant distribution and the species of plant sampled.

Plant distribution affects accuracy if the density of a plant species varies widely within the area sampled. Potential factors influencing changes in plant density include differential hydrology, use of spot mechanical treatments, and changes in soil type. Often, these factors can be controlled by selecting the appropriate sampling scheme. In addition, seed production by perennials that propagate by tubers tends to be more variable and, therefore, a larger number of samples may be required.

Following collection of at least five samples in a unit, the standard deviation (SD) can be calculated with the equation SD = $(s^2)^{1/2}$. The sample variance (s^2) is estimated with the formula $s^2 = (\sum_{i=1}^{n} x_i - \bar{x})^2 / n-1$, where x_i = seed estimate of sample i, $\bar{x}$ = average seed weight of all samples, and n = number of samples collected. The standard deviation indicates the degree of variation in seed weight and is, therefore, a measure of precision (see example)—the larger the SD, the lower the precision of the estimate.

The number of samples necessary to achieve a specified level of precision (95% confidence interval) can be calculated with the formula $n = 4s^2/L^2$, where s^2 = sample variance and L = allowable error (± pounds per acre). The sample variance (s^2) can be estimated from previous experience or calculated based on preliminary sampling. Because seed production varies among plant species and units, sample variance should be determined independently for individual plant species and units. Numerous environmental factors influence seed production on a particular site. Therefore, sample variance should be calculated annually for each site. A subjective decision must be made concerning how large an error (L) can be tolerated. This decision should be based on how the seed production estimate is to be used. For example, an L of ± 100 pounds per acre would be acceptable for determining the number of waterfowl use-days available. In other cases, a larger error might be acceptable. As the allowable error increases, the number of samples required decreases.

Estimating Seed Production

Although the technique is simple to use, several important factors must be considered to obtain accurate estimates of seed weight. The following example illustrates the process of making these decisions. In addition, the process of computing estimates using the regression equations demonstrates the correct manner of using field data to arrive at valid estimates.

1. *Unit considerations*—unit size is 10 acres. Vegetation consists of barnyardgrass distributed uniformly across the entire unit.
2. *Sampling strategy*—use a centric area sampling method with a maximum recommended block size of 2 acres to establish the location of five sample areas uniformly across the unit.
3. *Data collection*—at each plot, select a representative barnyardgrass plant within the sample frame and record the necessary information (Table 2).
4. *Estimate seed production*—for each sample, use the appropriate equation to determine the estimated seed weight. In this example, only the barnyardgrass equation is required (Table 3).
5. *Maximum allowable error*—in this example, an L of ± 100 pounds per acre is used for barnyardgrass. The standard deviation is then calculated to determine the precision of the estimate. If the standard deviation is less than the allowable error, no additional samples must be collected. However, if the standard deviation is greater than the allowable error, the estimated number of additional samples that must be collected is calculated.

- Allowable error = L = ± 100 pounds per acre
- Number of samples collected = n = 5
- Weight of individual samples (pounds per acre) = x_i = 982; 1,119; 871; 1,124; 1,237
- Average weight of samples (pounds per acre) = $\bar{x}$

  = 982 + 1,119 + 871 + 1,124 + 1,237 / 5
  = 5,333 / 5
  = 1,066.6 or 1,067
- Variance = $s^2 = \Sigma(x_i - \bar{x})^2/n-1$

  = $(982 - 1{,}067)^2 + (1{,}119 - 1{,}067)^2 + (871 - 1{,}067)^2$
  $+ (1{,}124 - 1{,}067)^2 + (1{,}237 - 1{,}067)^2 / 5 - 1$
  = $(-85)^2 + (52)^2 + (-196)^2 + (57)^2 + (170)^2 / 4$
  = 7,225 + 2,704 + 38,416 + 3,249 + 28,900 / 4
  = 80,494 / 4
  = 20,123.5 or 20,124 pounds per acre
- Standard deviation = $s = (s^2)^{1/2}$

  = $20{,}124^{1/2}$
  = 141.8 or 142 pounds per acre

Based on these computations, an estimated average weight of 1,067 ± 142 pounds per acre (i.e., 925–1,209 pounds per acre) of barnyardgrass seed was produced. However, the standard deviation (142 pounds per acre) is greater than the allowable error (100 pounds per acre), indicating that additional samples must be collected to obtain an average seed weight value that is within the acceptable limits of error.

Table 2. *Sample data sheet for estimating seed production.*

Plot	Plant species	Height (m)	Seed heads (number)	Seed head height (cm)	Seed head diameter (cm)
			Initial samples		
1	Barnyardgrass	1.1	12	16	9
2	Barnyardgrass	1.1	13	16	10
3	Barnyardgrass	1.1	11	16	8
4	Barnyardgrass	1.1	14	15	10
5	Barnyardgrass	1.2	9	18	12
			Additional samples		
6	Barnyardgrass	1.1	12	16	10
7	Barnyardgrass	0.9	15	17	9
8	Barnyardgrass	0.9	14	17	10

Table 3. *Estimating seed weight of individual samples.*

Plant species	Regression equation[a]	Plot	Estimated weight (grams per 0.0625-m^2)	Estimated weight (pounds per acre)
		Initial samples		
Barnyardgrass	(HT × 3.67855)	1	6.88[b]	982 [c]
	+ (0.000696 × VOL)	2	7.84	1,119
		3	6.10	871
		4	7.88	1,124
		5	8.67	1,237
		Additional samples		
		6	7.55	1,077
		7	7.08	1,010
		8	7.65	1,092

[a] HT = plant height (m); HEADS = number of seed heads in sample frame; HL = height of representative seed head (cm); HD = diameter of representative seed head (cm); VOL = volume (based on geometry of cone) calculated as: (HEADS) × (πr^2h/3); π = 3.1416, r = HD/2, h = HL.
[b] Weight (grams per 0.0625-m^2) = (HT × 3.67855) + (0.000696 × VOL) = (1.1 × 3.67855) + (0.000696 × 4081.6) = 4.0464 + 2.8408 = 6.88 VOL = (HEADS) × (πr^2h/3); π = 3.1416, r = 9/2 = 4.5, r^2 = 20.3, h = 16 = (12) × (3.1416 × 20.3 × 16/3) = (12) × (340.131) = 4081.6
[c] Conversion from grams per 0.0625-m^2 to pounds per acre: 6.88 × 142.74 = 982.

Total number of samples required = $4s^2/L^2$
= (4 × 20,124) / (100)^2
= 80,496 / 10,000
= 8
Additional samples required = total samples required – samples collected
= 8 – 5
= 3

Based on these calculations, three additional samples must be collected.

6. *Additional samples*—collect additional samples at random locations (Tables 3 and 4). Following collection of data, the average seed weight and standard deviation of samples must be recalculated using the equations in Step 5. If the accompanying software is used, these calculations are performed automatically. In this example, the revised estimate of average seed weight ($\bar{x}$) is 1,064 pounds per acre, and the standard deviation (s) is 110 pounds per acre.
7. *Estimating total seed production*—after collecting a sufficient number of samples of each species to obtain an average seed estimate with a standard deviation less than the maximum allowable error, estimate total seed production. An estimate of seed produced by each species is determined by computing the average seed weight of that species in all samples collected and multiplying this value by the area sampled. Total seed production is estimated by summing seed produced by each species. In this example only barnyardgrass was sampled. Therefore, total seed produced is equivalent to barnyardgrass seed produced.

Barnyardgrass seed produced = average seed weight × area sampled
= 1,064 (± 110) pounds per acre × 10 acres
= 10,640 ± 1,100 pounds in unit.

Computer Software

Computer software is available for performing the mathematical computations necessary to estimate seed weight. The program is written in Turbo Pascal and can be operated on computers with a minimum of 256K memory. The program computes the estimated seed weight of individual plant species collected at each sample location and displays this information following entry of each sample. In addition, a summary screen displays estimates of average and total seed produced in an impoundment as well as the standard deviation of the estimate. This information is automatically stored in a file that can be printed or saved on a disk. A copy of the program is available upon request. Instructions pertaining to the use of the program are obtained by accessing the README file on the program diskette.

Suggested Reading

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148, Washington, D.C. 29 pp.

Reinecke, K. J., R. M. Kaminski, D. J. Moorehead, J. D. Hodges, and J. R. Nassar. 1989. Mississippi alluvial valley. Pages 203–247 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, editors. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Appendix. Common and Scientific Names of Plants Named in Text.

Annual sedge	*Cyperus iria*
Barnyardgrass	*Echinochloa crusgalli*
Barnyardgrass	*Echinochloa muricata*
Beggarticks	*Bidens* spp.
Chufa	*Cyperus esculentus*
Crabgrass	*Digitaria* spp.
Fall panicum	*Panicum dichotomiflorum*
Foxtail	*Setaria* spp.
Ladysthumb smartweed	*Polygonum lapathifolium*
Redroot flatsedge	*Cyperus erythrorhizos*
Rice cutgrass	*Leersia oryzoides*
Sprangletop	*Leptochloa filiformis*
Water pepper	*Polygonum hydropiper*
Water smartweed	*Polygonum coccineum*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1992

13.4.6. Strategies for Water Level Manipulations in Moist-soil Systems

Leigh H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri–Columbia
Puxico, MO 63960

Water level manipulations are one of the most effective tools in wetland management, provided fluctuations are well-timed and controlled. Manipulations are most effective on sites with (1) a dependable water supply, (2) an elevation gradient that permits complete water coverage at desired depths over a majority of the site, and (3) the proper type of water control structures that enable water to be supplied, distributed, and discharged effectively at desired rates. The size and location of structures are important, but timing, speed, and duration of drawdowns and flooding also have important effects on plant composition, plant production, and avian use. When optimum conditions are not present, effective moist-soil management is still possible, but limitations must be recognized. Such situations present special problems and require particularly astute and timely water level manipulations. For example, sometimes complete drainage is not possible, yet water is usually available for fall flooding. In such situations, management can capitalize on evapotranspiration during most growing seasons to promote the germination of valuable moist-soil plants.

Timing of Drawdowns

Drawdowns often are described in general terms such as early, midseason, or late. Obviously, calendar dates for a drawdown classed as early differ with both latitude and altitude. Thus the terms early, midseason, and late should be considered within the context of the length of the local growing season. Information on frost-free days or the average length of the growing season usually is available from agricultural extension specialists. Horticulturists often use maps depicting different zones of growing conditions (Fig. 1). Although not specifically developed for wetland management, these maps provide general guidelines for estimating an average growing season at a particular site.

In portions of the United States that have a growing season longer than 160 days, drawdowns normally are described as early, midseason, or late. In contrast, when the growing season is shorter than 140 days, drawdown dates are better described as either early or late. Early drawdowns are those that occur during the first 45 days of the growing season, whereas late drawdowns occur in the latter 90 days of the growing season. For example, the growing season extends from mid-April to late October (200 days) in southeastern Missouri. In this area, early drawdowns occur until 15 May, midseason drawdowns occur between 15 May and 1 July, and late drawdowns occur after 1 July (Table 1). The

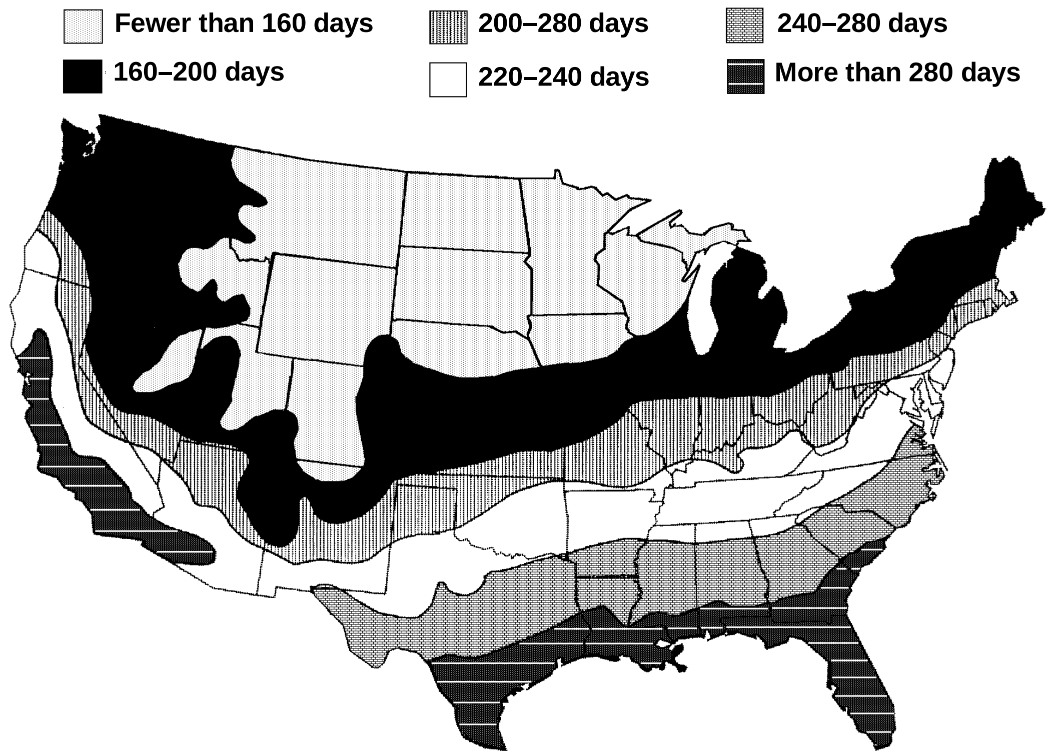


Fig. 1. Zones depicting general differences in the length of the growing season.

correct terminology for drawdown date can be determined for each area using these rules of thumb.

Moist-soil Vegetation

The timing of a drawdown has an important influence on the composition and production of moist-soil plants. Although the importance of specific factors resulting in these differences has not been well studied for moist-soil vegetation, factors such as seed banks, soil types, soil temperatures, soil moisture levels, soil–water salinities, day length, and residual herbicides undoubtedly influence the composition of developing vegetation.

Water manipulations will be effective and economical only if the site has been properly designed and developed (Table 2). Levees, type and dependability of water source (e.g., ground water, river, reservoir), type and placement of water control structures, water supply and drainage systems, and landform are among the most important elements that must be considered. Independent control and timing of water supply, distribution, depth, and discharge within and among units are essential (Table 2).

An independent water supply for each unit is required to optimize food production, maintain the potential to control problem vegetation, and make food resources available for wildlife (Table 2). Optimum management also requires that each unit have the capability of independent discharge. Stoplog water control structures that permit water level manipulations as small as 2 inches provide a level of fine tuning that facilitates control of problem vegetation or enhancement of desirable vegetation.

Table 1. *Environmental conditions associated with time of drawdown in southeastern Missouri.*

	Date	Temperature	Rainfall	Evapotranspiration
Early	1 April–15 May	Moderate	High	Low
Mid	15 May–1 July	Moderate–High	Moderate	Moderate
Late	1 July or later	High	Low	High

Table 2. *Important considerations in evaluating wetland management potential.*

Factors	Optimum condition
Water supply	Independent supply into each unit Water supply enters at highest elevation
Water discharge	Independent discharge from each unit Discharge at lowest elevation for complete drainage Floor of control structure set at correct elevation for complete drainage
Water control	Stoplog structure allowing 2-inch changes in water levels Adequate capacity to handle storm events
Optimum unit size	5 to 100 acres
Optimum number of units	At least 5 within a 10-mile radius of units

Wetland systems with high salinities can easily accumulate soil salts that affect plant vigor and species composition. Wetland unit configurations that allow flushing of salts by flowing sheet water across the gradient of a unit are essential in such areas. A fully functional discharge system is a necessity in arid environments to move water with high levels of dissolved salts away from intensively managed basins. Thus, successful management in arid environments requires units with an independent water supply and independent discharge as well as precise water-level control.

Scheduling Drawdowns

During most years, early and midseason drawdowns result in the greatest quantity of seeds produced (Table 3). However, there are exceptions, and in some cases, late drawdowns are very successful in stimulating seed production.

Table 3. *Response of common moist-soil plants to drawdown date.*

	Species		Drawdown date		
Family	Common name	Scientific name	Early[a]	Midseason[b]	Late[c]
Grass	Swamp timothy	*Heleochloa schoenoides*	+[d]	+++	+
	Rice cutgrass	*Leersia oryzoides*	+++	+	
	Sprangletop	*Leptochloa* sp.		+	+++
	Crabgrass	*Digitaria* sp.		+++	+++
	Panic grass	*Panicum* sp.		+++	++
	Wild millet	*Echinochloa crusgalli* var. *frumentacea*	+++	+	+
	Wild millet	*Echinochloa walteri*	+	+++	++
	Wild millet	*Echinochloa muricata*	+	+++	+
Sedge	Red-rooted sedge	*Cyperus erythrorhizos*		++	
	Chufa	*Cyperus esculentus*	+++	+	
	Spikerush	*Eleocharis* spp.	+++	+	+
Buckwheat	Pennsylvania smartweed	*Polygonum pensylvanicum*	+++		
	Curltop ladysthumb	*Polygonum lapathifolium*	+++		
	Dock	*Rumex* spp.		+++	+
Pea	Sweetclover	*Melilotus* sp.	+++		
	Sesbania	*Sesbania exalta*	+	++	
Composite	Cocklebur	*Xanthium strumarium*	++	+++	++
	Beggarticks	*Bidens* spp.	+	+++	+++
	Aster	*Aster* spp.	+++	++	+
Loosestrife	Purple loosestrife	*Lythrum salicaria*	++	++	+
	Toothcup	*Ammania coccinea*	+	++	++
Morning glory	Morning glory	*Ipomoea* spp.	++	++	
Goosefoot	Fat hen	*Atriplex* spp.	+++	++	

[a] Drawdown completed within the first 45 days of the growing season.
[b] Drawdown after first 45 days of growing season and before 1 July.
[c] Drawdown after 1 July.
[d] + = fair response; ++ = moderate response; +++ = excellent response.

In areas characterized by summer droughts, early drawdowns often result in good germination and newly established plants have time to establish adequate root systems before dry summer weather predominates. As a result, early drawdowns minimize plant mortality during the dry period. Growth is often slowed or halted during summer, but when typical late growing-season rains occur, plants often respond with renewed growth and good seed production. In contrast, midseason drawdowns conducted under similar environmental conditions often result in good germination, but poor root establishment. The ultimate result is high plant mortality or permanent stunting. If the capability for irrigation exists, the potential for good seed production following midseason or late drawdowns is enhanced.

Germination of each species or group of species is dependent on certain environmental conditions including soil temperature and moisture. These conditions change constantly and determine the timing and density of germination (Table 3). Smartweeds tend to respond best to early drawdowns, whereas sprangletop response is best following late drawdowns. Some species are capable of germination under a rather wide range of environmental conditions; thus, control of their establishment can be difficult. Classification of an entire genera into a certain germination response category often is misleading and inappropriate. For example, variation exists among members of the millet group (*Echinochloa* spp.). *Echinochloa frumentacea* germinates early, whereas *E. muricata* germinates late because of differences in soil temperature requirements. Such variation among members of the same genus indicates the need to identify plants to the species level.

Natural systems have flooding regimes that differ among seasons and years. Repetitive manipulations scheduled for specific calendar dates year after year often are associated with declining productivity. Management assuring good production over many years requires variability in drawdown and flooding dates among years. See *Fish and Wildlife Leaflet* 13.2.1 for an example of how drawdown dates might be varied among years.

Wildlife Use

Drawdowns serve as an important tool to attract a diversity of foraging birds to sites with abundant food resources. Drawdowns increase food availability by concentrating foods in smaller areas and at water depths within the foraging range of target wildlife. A general pattern commonly associated with drawdowns is an initial use by species adapted to exploiting resources in deeper water. As dewatering continues, these “deep water” species are gradually replaced by those that are adapted to exploit foods in

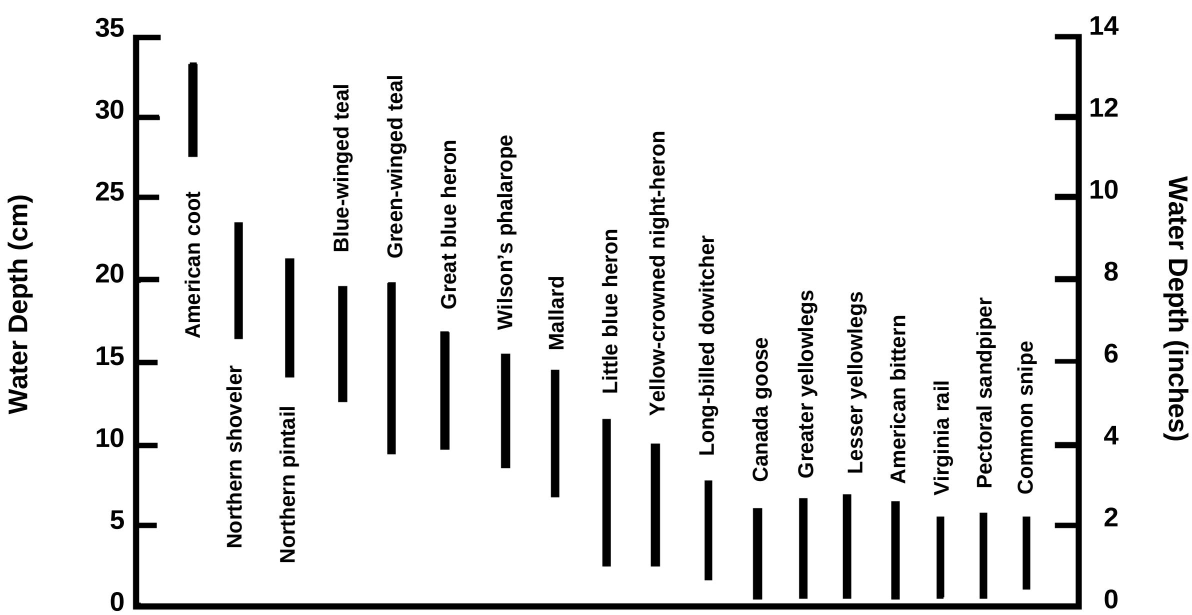


Fig. 2. Preferred water depths for wetland birds commonly associated with moist-soil habitats.

shallower water (Fig. 2). The most effective use of invertebrate foods by wetland birds occurs when drawdowns to promote plant growth are scheduled to match key periods of migratory movement in spring. By varying drawdown dates among units, the productivity of each unit can be maintained and resources can be provided for longer periods. Slow drawdowns also prolong use by a greater number and diversity of wetland wildlife.

Effects of Drawdown Rate

Moist-soil Plant Production

Fast Drawdowns

Sometimes fast drawdowns (1–3 days) are warranted, especially in systems with brackish or saline waters where the slow removal of water may increase the level of soil salts. However, in most locations fast drawdowns should only be scheduled early in the season or when flood irrigation is possible. Rapid drawdowns that coincide with conditions of high temperature and little rainfall during the growing season create soil moisture conditions that often result in poor moist-soil responses (Table 4). Some germination may occur, but generally development of root systems is inadequate to assure that these newly established plants survive during summer drought. Thus, at latitudes south of St. Louis, fast drawdowns are never recommended after 15 June if irrigation is not possible.

Slow Drawdowns

Slow drawdowns (2–3 weeks) usually are more desirable for plant establishment and wildlife use. The prolonged period of soil saturation associated with slow drawdowns creates conditions favorable for moist-soil plant germination and establishment (Table 4). For example, slow drawdowns late in the growing season can result in seed yields of 700 pounds per acre. Rapid drawdowns on adjacent units subject to identical weather conditions have resulted in 50 pounds per acre. Furthermore, slow drawdowns provide shallow water over a longer period, ensuring optimum foraging conditions for wildlife. If salinities tend to be high, slow drawdowns should only be scheduled during winter or early in the season when ambient temperatures and evapotranspiration are low.

Table 4. *Comparison of plant, invertebrate, bird, and abiotic responses to rate and date of drawdown among wet and dry years.*

	Drawdown rate	
	Fast[a]	Slow[b]
Plants		
Germination		
Period of ideal conditions	short	long
Root development		
Wet year	good	excellent
Dry year	poor	excellent
Seed production		
Early season	good	excellent
Mid–late season	not recommended	excellent
Wet year	good	good
Drought year	poor	good
Cocklebur production	great potential	reduced potential
Invertebrates		
Availability		
Early season	good	excellent
Mid–late season	poor	good
Period of availability	short	long
Bird use		
Early season	good	excellent
Mid–late season	poor	good
Nutrient export	high	low
Reducing soil salinities	good	poor

[a] Less than 4 days.
[b] Greater than 2 weeks.

Invertebrate Availability in Relation to Drawdowns

When water is discharged slowly from a unit, invertebrates are trapped and become readily available to foraging birds along the soil–water interface or in shallow water zones (Table 4). These invertebrates provide the critical protein-rich food resources required by pre-breeding and breeding female ducks, newly hatched waterfowl, molting ducks, and shorebirds. Shallow water for foraging is required by the vast majority of species; e.g., only 5 of 54 species that commonly use moist-soil impoundments in Missouri can forage effectively in water greater than 10 inches. Slow drawdowns lengthen the period for optimum foraging and put a large portion of the invertebrates within the foraging ranges of many species. See *Fish and Wildlife Leaflet* 13.3.3 for a description of common invertebrates in wetlands.

Spring Habitat Use by Birds

Slow drawdowns are always recommended to enhance the duration and diversity of bird use (Table 4). Creating a situation in which the optimum foraging depths are available for the longest period provides for the efficient use of food resources, particularly invertebrate resources supplying proteinaceous foods. Partial drawdowns well in advance of the growing season (late winter) tend to benefit early migrating waterfowl, especially mallards and pintails. Early-spring to mid-spring drawdowns provide resources for late migrants such as shovelers, teals, rails, and bitterns. Mid- and late-season drawdowns provide food for breeding waders and waterfowl broods. These later drawdowns should be timed to coincide with the peak hatch of water birds and should continue during the early growth of nestlings or early brood development.

Fall Flooding Strategies

Scheduling fall flooding should coincide with the arrival times and population size of fall migrants (Table 5). Sites with a severe disease history should not be flooded until temperatures

Table 5. *Water level scenario for target species on three moist-soil impoundments and associated waterbird response.*

	Unit A		Unit B		Unit C	
	Water level		Water level		Water level	
Period	Scenario	Response	Scenario	Response	Scenario	Response
Early fall	Dry	None	Dry	None	Gradual flooding starting 15 days before the peak of early fall migrants; water depth never over 4 inches	Good use immediately; high use by teal, pintails, and rails within 2 weeks
Mid fall	Dry	None	Flood in weekly 1–2-inch increments over a 4-week period	Excellent use by pintails, gadwalls, and wigeons	Continued flooding through September	Excellent use by rails and waterfowl
Late fall	Flood in weekly 2–4-inch increments over a 4–6-week period	Excellent use immediately by mallards and Canada geese	Continued flooding, but not to full functional capacity	Excellent use by mallards and Canada geese	Continued flooding to full functional capacity	Good use by mallards and Canada geese
Winter	Maintain flooding below full functional capacity	Good use by mallards and Canada geese when water is ice free	Maintain flooding below full functional capacity	Good use by mallards and Canada geese when water is ice free	Continued flooding to full pool	Good use by mallards and Canada geese when water is ice free
Late winter	Schedule slow drawdown to match northward movement of migrant waterfowl	Excellent use by mallards, pintails, wigeons, and Canada geese	Schedule slow drawdown to match northward movement of early migrating waterfowl	Excellent use by mallards, pintails, wigeons, and Canada geese	Schedule slow drawdown to match northward movement of waterfowl	Good use by mallards and Canada geese when water is ice free
Early spring	Continued slow drawdown to be completed by 1 May	Excellent use by teals, shovelers, shorebirds, and herons	Drawdown completed by 15 April	Excellent shorebird use	Drawdown completed by 15 April	Excellent shorebird use

moderate. When flooding is possible from sources other than rainfall, fall flooding should commence with shallow inundation on impoundments suited for blue-winged teals and pintails. Impoundments with mature but smaller seeds, such as panic grass and crabgrasses, that can be flooded inexpensively are ideal for these early migrating species. Flooding always should be gradual and should maximize the area with water depths no greater than 4 inches (Fig. 3). As fall progresses, additional units should be flooded to accommodate increasing waterfowl populations or other bird groups such as rails. A reasonable rule of thumb is to have 85% of the surface area of a management complex flooded to an optimum foraging depth at the peak of fall waterfowl migration.

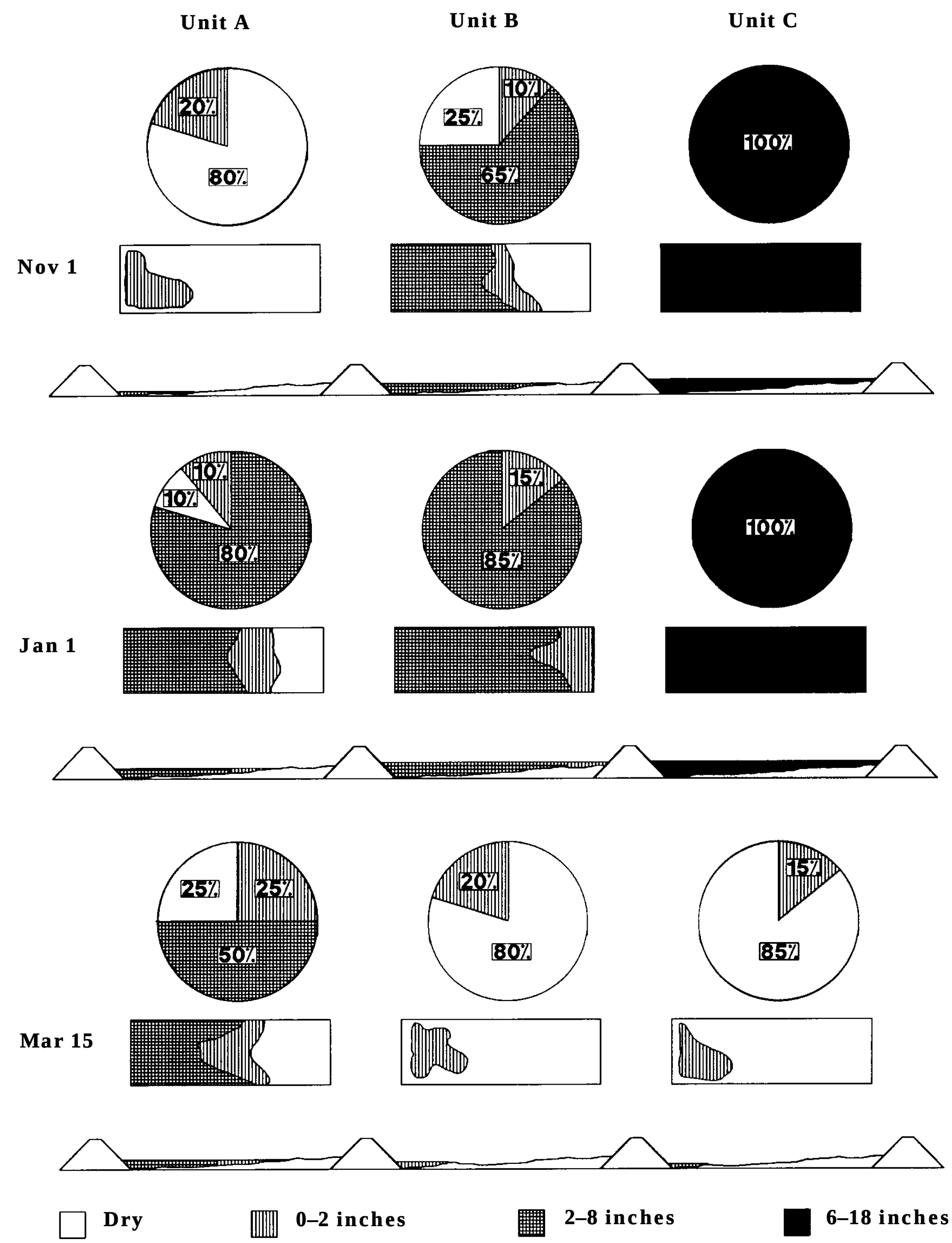


Fig. 3. Planned flooding strategies for three moist-soil units during one winter season. The initiation, depth, and duration of flooding are different for each unit. Note that two of the three units were never intentionally flooded to capacity. This does not mean that natural events would not flood the unit to capacity. Flooding strategies should be varied among years to enhance productivity.

Suggested Reading

Eldridge, J. 1990. Aquatic invertebrates important for waterfowl production. U.S. Fish Wildl. Leafl. 13.3.3. 7 pp.

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish Wildl. Serv., Resour. Publ. 148. 29 pp.

Fredrickson, L. H., and F. A. Reid. 1986. Wetland and riparian habitats: a nongame management overview. Pages 59–96 *in* J. B. Hale, L. B. Best, and R. L. Clawson, eds. Management of nongame wildlife in the Midwest: a developing art. Northcentral Section, The Wildlife Society, Madison, Wis.

Fredrickson, L. H. and F. A. Reid 1988. Waterfowl use of wetland complexes. U.S. Fish Wildl. Leafl. 13.2.1. 6 pp.

Reid, F. R., J. R. Kelley, Jr., T. S. Taylor, and L. H. Fredrickson. 1989. Upper Mississippi Valley wetlands—refuges and moist-soil impoundments. Pages 181–202 *in* L. Smith, R. Pederson, and R. Kaminski, eds. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Appendix. Common and Scientific Names of Birds Named in Text.

Pied-billed grebe	*Podilymbus podiceps*
American bittern	*Botaurus lentiginosus*
Great blue heron	*Ardea herodias*
Little blue heron	*Egretta caerulea*
Yellow-crowned night-heron	*Nycticorax violaceus*
Tundra swan	*Cygnus columbianus*
Snow goose	*Chen caerulescens*
Canada goose	*Branta canadensis*
Mallard	*Anas platyrhynchos*
Northern pintail	*Anas acuta*
Northern shoveler	*Anas clypeata*
Blue-winged teal	*Anas discors*
Canvasback	*Aythya valisineria*
Virginia rail	*Rallus limicola*
American coot	*Fulica americana*
Greater yellowlegs	*Tringa melanoleuca*
Lesser yellowlegs	*Tringa flavipes*
Pectoral sandpiper	*Calidris melanotos*
Long-billed dowitcher	*Limnodromus scolopaceus*
Wilson's phalarope	*Phalaropus tricolor*
Common snipe	*Capella gallinago*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1991

13.4.7. Managing Beaver to Benefit Waterfowl

James K. Ringelman
Colorado Division of Wildlife
317 West Prospect Road
Fort Collins, CO 80526

Aside from humans, no other organism has the capacity to modify its environment as much as the beaver. In doing so, beaver create wetlands that provide valuable waterfowl habitats. Because beavers are widely distributed in North America (Fig. 1), beaver ponds can benefit waterfowl during breeding, migrating, and wintering periods. Mismanaged beaver populations, however, can severely degrade riparian habitats and become a costly problem. The key to successfully managing beaver for waterfowl benefits is understanding the values of beaver ponds in meeting the seasonal needs of waterfowl. Beaver populations must then be managed to provide these benefits in a self-sustaining manner compatible with the carrying capacity of the habitat.

Before the arrival of Europeans, 60–400 million beavers occupied 5.8 million square miles of North America. But by 1900, beavers had been so severely over-exploited by trappers and hunters that they were almost extinct. Today, beaver populations are on the upswing: 6 million to 12 million animals occupy diverse habitats ranging from the boreal forests of Canada south to the Texas gulf coast, and from California's Central Valley east to the Atlantic seaboard. This recent population increase is a testament to the resiliency of beaver populations and their responsiveness to management techniques. I review some techniques useful for managing beaver populations and enhancing beaver habitats to benefit waterfowl, and explain the ecological relations and characteristics that make beaver ponds attractive waterfowl habitats.

Beaver Ponds as Breeding Habitats for Waterfowl

Ecological Relations

Most of the important habitats created by beaver and used by breeding waterfowl are north of 40° latitude in the mixed hardwoods–coniferous forests of the Northeast, in the montane habitats of the West, in parklands and the Precambrian Shield regions of southern Canada, and in the boreal and subarctic forests of northern Canada. Beaver ponds in these regions are attractive to most dabbling duck species, particularly American black ducks, mallards, and green-winged teal. Hooded mergansers, ring-necked ducks, common goldeneyes, and buffleheads are common diving duck species found on beaver ponds. Beaver ponds also provide important breeding habitat for wood ducks throughout their breeding range.

A beaver colony is defined as a group of beavers occupying a pond or stretch of stream, using a common food supply, and maintaining a common dam or dams. An average of one or two beaver colonies per mile occur along suitable streams and

Fig. 1. Range of the beaver in North America. Modified from Novak 1987.

rivers. Each colony usually contains four to eight beavers. Their activities, most notably the creation of ponds by flooding of riparian habitats and removal of woody vegetation, may influence 20 to 40% of the total length of second- to fourth-order streams and may remain as part of the landscape for centuries. Unexploited beaver populations can create as many as 26 ponds per mile of stream length in suitable habitats, but typically the number of ponds ranges from three to six per mile. Most stream sections used by beaver have valley slopes of 1 to 6%, and of the remaining use, one-quarter occurs along sections with 7 to 12% slope. Beavers generally do not occupy streams where valley slopes exceed 15%. Suitability of a site also increases with valley width. First-order streams usually are narrow with high gradients and an undependable water supply, and therefore receive little use. Conversely, many streams greater than fourth-order often flood in spring, destroying on-channel beaver dams. On these streams and rivers, beaver activities are mostly confined to banks, backwater wetlands, and floodplains. Beavers commonly occupy natural lakes and glacial depressions, such as kettle ponds, throughout their range.

Availability of food is the most important biotic constraint to beaver distribution. In northern regions, beavers annually cut at least a ton of forage. Usually, they take food resources closest to their lodge or bank dens first. Most food is gathered within 100 yards of their pond. Although they will consume a wide range of woody and herbaceous plants, beaver prefer quaking aspen, cottonwood, willow, alder, maple, birch, and cherry, supplemented by herbaceous emergents such as sedges and floating-leaved vegetation, including pondweeds and waterlilies. In agricultural areas, they consume a wide variety of crops such as corn and soybeans. Riparian zones dominated by deciduous tree species preferred by beaver may be virtually clear-cut. An important effect of removing this tree canopy is an increase in the density and height of the grass–forb–shrub layer, which enhances waterfowl nesting cover adjacent to ponds. Additionally, the deep channels created by beaver to help transport food within the pond provide travel lanes for breeding pairs and broods of waterfowl.

Beaver pond complexes create a wetland community with characteristics similar to waterfowl breeding habitats on the northern Great Plains. Most important among these characteristics is a wetland complex that is usually composed of several wetlands of varying sizes, shapes, depths, and successional stages. These diverse wetlands provide space for territorial birds to isolate themselves from individuals of the same species. Also, as in prairie habitats, such complexes enable breeding waterfowl to optimize their use of aquatic resources. For example, beaver colonies in highly desirable locations may persist for several decades, and wetlands may advance to late successional stages with vegetation and aquatic invertebrate communities functionally similar to semipermanent and permanent wetlands in the prairies. Other beaver ponds located on less suitable sites, or new ponds created by beavers dispersing from an established colony, may possess vegetative structure and invertebrate communities more similar to temporary or seasonal prairie wetlands. Wetland fertility, water permanency, and water temperature regimes also vary within a beaver pond complex.

In addition to increasing the quantity of wetlands available to waterfowl, beaver enhance wetland quality. Wetland fertility is increased because much of the sediment and organic matter that is normally carried downstream is retained behind beaver dams. Beavers also add new sources of organic matter in the form of fecal matter and the plant material they haul or fell into the pond and later use as food or building material. The net effect is an increase in the nutrient base for aquatic plants and invertebrates. Total invertebrate biomass and density in beaver ponds may be two to five times greater than in stream riffle sites, ranging from 1,000 to 6,800 organisms per square foot and from 0.1 to 1 gram per square foot, depending on the season. Moreover, the structure of invertebrate communities is changed as running-water taxa are replaced by pond taxa, which are more readily exploited by waterfowl. These aquatic invertebrates make up the protein food base so important to laying females and to growing ducklings.

The structural characteristics of beaver ponds also are attractive to breeding waterfowl. Habitat diversity increases as beaver flood lands and open forest canopies. The flooded area under the tree canopy and underlying shrub layer provides lateral and overhead cover sought by many dabbling duck pairs and broods. Later, northern flickers and other primary excavators may create waterfowl nesting cavities in the dead trees that remain standing in ponds. The “feathered edge,” typical of many beaver ponds, creates shallow-water foraging areas that warm quickly in early spring, and often provides sites where seeds and invertebrates can be obtained. Beaver lodges and dams afford loafing areas and nesting sites for geese, ducks, and sandhill cranes, depending on the degree of vegetative concealment on the structure.

Management Strategies

Beaver ponds provide a mosaic of environmental conditions, dependent on pond size and age, successional status, substrate, and hydrologic characteristics. Hydrologic characteristics are especially important to waterfowl managers. Controlling water levels in beaver ponds is an important but sometimes difficult proposition. As in any nesting habitat, water in early spring must be sufficient to attract and hold breeding pairs, and stable enough to sustain water through the brood-rearing period. Beaver ponds located in relatively small watersheds, off the main channel, or with dams in disrepair, may have inadequate water in early spring. Such wetlands do not provide optimal habitat for waterfowl. Conversely, beaver ponds located in montane habitats far below snowline may fill with water from snowmelt about the time early-nesting waterfowl species complete their clutches, flooding nests located around the pond margin.

Consider transplanting beaver to a site if water and food are adequate, but dams are in disrepair because beavers have abandoned the area. If water flow is inadequate, examine the feasibility of channeling water from a reliable source into the pond complex. One objective of managing beaver ponds as waterfowl breeding habitat should be to manage ponds for seasonally stable water levels.

Despite the benefits of stable water within the breeding season, this type of water regime reduces the productivity of beaver ponds when maintained over several years. The decline is primarily caused by anaerobic conditions, which bind nutrients to soil and organic matter, thereby making them unavailable to plants and animals. These anaerobic processes are exacerbated by the tranquil flow regimes and high organic loads typical of beaver ponds. Artificially increasing flow rates may help increase aerobic decay, but the best approach is to periodically drain or reduce the water levels in ponds to promote aerobic decay of organic matter and to reverse wetland succession. The interval between drawdowns is difficult to prescribe because the need for such action depends on the length of the warm season, water temperature, pond size and organic load, and water flow rates. In low latitudes, beaver pond productivity may decline in a few years, whereas ponds at high latitudes may take much longer to reach detrimental anaerobic conditions.

Drawing down a beaver pond is often easier said than done, because of the natural tendency of beavers to quickly plug any breach in their dam. Explosives or backhoes can be used to remove dams, but this often becomes an ongoing process because dams are quickly reconstructed. Better results are often achieved with beaver-resistant water control structures (Fig. 2), which are installed in the dam and are resistant to blockage by beaver. Only a fraction of the wetlands in a beaver pond complex should be dewatered during a given year to ensure adequate habitat for waterfowl and beaver in the remaining ponds. Ponds should not be drawn down during the brood-rearing period because young birds may become stranded or have to move, and become more exposed to predators.

Managing distribution of beaver can be a challenge equal to that of controlling water levels. Beaver that occupy sites adjacent to private lands, roads, or other human structures may impound water that causes timber or crop damage or creates a nuisance. Often, the only solution is to trap the offending beaver. If live-trapped, such individuals can often be successfully transplanted to suitable but unoccupied habitats. Supplemental feeding has

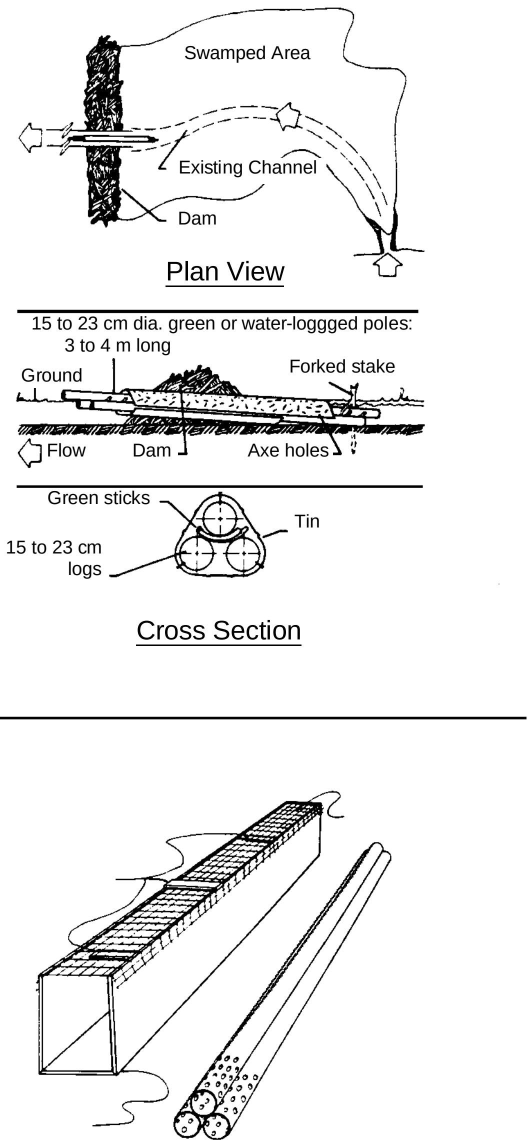


Fig. 2. Three designs for beaver-proof water control structures: three-log drain (*top*), box drain (*lower left*), and perforated plastic drainpipe (*lower right*). From Arner and Hepp 1989.

been used to "hold" transplanted beavers in new areas until they become established, but supporting a beaver population by artificial feeding is an intensive and costly approach that is not recommended. A woven-wire fence, stretched across a stream channel between steel posts may be installed (where legal) to encourage beavers to build dams at selected sites.

Unexploited beaver populations can create numerous wetlands. With the extirpation of the gray wolf, which was a primary predator of beaver, other factors such as trapping, food depletion, space, and disease have become the agents of population control. Before these agents intercede, however, beavers may severely degrade riparian and upland habitats. If unchecked, beaver populations and associated wetlands may oscillate from locally abundant to scarce. Populations exploited by trapping often remain at more constant levels commensurate with their food supply, their principal limitation. Field surveys are the most reliable means to determine the adequacy of remaining food resources. In good stands, 4 acres of quaking aspen, 12 acres of willow, or intermediate acreages of the two in combination are adequate to support an average colony of six animals. Such indices of adequate food supply are available for most regions of the United States. If managers control beaver by trapping, a general rule for maintaining stable populations at mid-latitudes (40–50°) is to remove about 25% of the fall population in willow habitat, 40% in quaking aspen habitat, and 70% in cottonwood habitat. This prescription reflects the progressive increase in reproductive rates of beaver with decreasing altitude and climatic severity, and increasing food quality and quantity.

In forested habitats, managing upland nesting cover around beaver ponds is usually impractical. Fortunately, the grass–forb–shrub cover that is common near beaver ponds often provides high quality, albeit limited, waterfowl nesting habitat. Nest success is often relatively high because many forested habitats have high habitat diversity, an abundance of buffer prey species, and predator populations that are more in balance with the habitat than are those on the northern Great Plains. Nevertheless, nests located along travel lanes such as dams and shorelines are more exposed to predators. Nests located on beaver lodges are often successful because such sites are secure from most mammalian predators. Trampling by livestock and flooding also cause nest failure, but flooding can be controlled by water-level management techniques, and fences often minimize damage by livestock.

Beaver Ponds as Migratory and Wintering Habitats

Ecological Relations

During spring and fall, beaver ponds are used by migrating waterfowl throughout North America. Open (ice-free) water, in which migrants can obtain aquatic invertebrates and plant seeds, tubers, winter buds and rhizomes, is the most important characteristic of these habitats. Beaver ponds, however, usually are not managed for migratory waterfowl except in the southeastern United States, where intensive management is sometimes used to attract fall migrants and wintering waterfowl for hunting. These areas are often associated with hardwood bottomlands or floodplain forests, where mallards and wood ducks are especially common.

Ecological relations described for beaver pond breeding habitats in northern regions are similar or identical to those in beaver ponds at southern latitudes. Successional patterns in beaver ponds in the South are similar to those in northern habitats, but occur more quickly. After beaver have created permanently flooded wetlands, trees die and the canopy opens, making conditions more suitable for growth of herbaceous plants or semi-aquatic vegetation. Sediments and organic matter are retained over time, thereby decreasing pond depth. Aquatic invertebrate communities develop and invertebrate biomass increases as the pond vegetation becomes established. Physical features of habitat created by beaver, such as dead, standing timber with a well-developed shrub layer, provide excellent habitats for wood ducks and other waterfowl to roost at night. Seed-producing annual plants associated with beaver ponds provide vegetative foods important to many dabbling ducks, particularly in years when mast crops such as acorns are unavailable. The wetland complex created by beaver provides diverse habitats that are readily exploited by waterfowl.

Management Strategies

Management strategies for migrating and wintering waterfowl must first consider important characteristics of beaver ponds: (1) those with few emergent plant species and shallow water areas, but with the potential for manipulating water level; (2) those with emergents and shallow water, where water levels can be manipulated; and (3) those with no possibilities for drainage. Ponds of the first type, which are common in the Southeast, are best managed by lowering the water level to allow germination of seed-producing, annual plants that are beneficial to waterfowl (Table). This technique, known as moist-soil management, relies on the timing and duration of drawdown to promote the germination and growth of seeds

Table. *List of desirable plants that occur in beaver ponds of the southeastern United States.*

Common name	Scientific name
Redroot flatsedge	*Cyperus erythrorhizos*
Millets	*Echinochloa* spp.
Pennywort	*Hydrocotyle ranunculoides*
Duckweed	*Lemna* spp.
Frogbit	*Limnobium spongia*
Water primrose	*Ludwigia leptocarpa*
Parrotfeather	*Myriophyllum brasilense*
Stout smartweed	*Polygonum densiflorum*
Nodding smartweed	*Polygonum lapathifolium*
Pondweeds	*Potamogeton* spp.
Beakrush	*Rhynchospora corniculata*
Burreed	*Sparganium chlorocarpum*
Watermeal	*Wolffia* spp.

already in the soil. In rare instances, when desirable aquatic vegetation is absent and the seed bank is inadequate, commercially available seed can be used. In Alabama, beaver ponds which were dewatered as described earlier, and then planted with Japanese millet, have yielded 1,400–2,400 pounds of seed per acre. Although moist-soil plants typically do not attain such high seed production, they do support high densities of aquatic invertebrates and provide seeds of a better nutritional balance than many commercially available plants.

Beaver ponds with an abundance of desirable emergent plants are best left undisturbed. If undesirable emergents are present, however, managers can alter the vegetative composition by water-level manipulations, mechanical disturbance, burning, or herbicide application. Water-level control is most easily achieved with beaver-proof control structures (Fig. 2). Mechanical disturbances and burning share the common objective of retarding vegetation succession and opening dense stands of vegetation. These management activities are usually conducted in late winter or early spring after water is drawn down. To effectively change plant composition, burning or mechanical treatments must damage roots of plants. Usually, this requires dry soil conditions, so that heavy mechanical equipment can be operated in the pond. If fire is used, heat must be sufficient to penetrate to root level. Herbicides such as Dalapon, Banvel, and Rodeo also can be used to control plants where such use is permitted. Managers should make certain that their herbicide of choice is approved for aquatic use and is applied at proper rates by a licensed applicator.

Impounded areas without drainage most commonly occur in cypress–tupelo wetlands where there is insufficient elevation change to use hidden drains. In these situations, managers may attempt to enhance the vegetative composition by introducing beneficial aquatic plants to the pond (Table). Floating-leaved plants such as duckweed and watermeal are beneficial species that are easy to introduce. If the overstory of trees provides too much shade to allow aquatic plants to establish, it may be beneficial to clear-cut small openings to help vegetation become established. By manipulating vegetative composition and interspersion, beaver ponds can provide attractive winter habitats for waterfowl.

Suggested Reading

Arner, D. H., and G. R. Hepp. 1989. Beaver pond wetlands: a southern perspective. Pages 117–128 *in* L. M. Smith, R. L. Pederson, and R. M. Kaminski, eds. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock.

Beard, E. B. 1953. The importance of beaver in waterfowl management at the Seney National Wildlife Refuge. J. Wildl. Manage. 17:398–436.

Johnson, R. C., J. W. Preacher, J. R. Gwaltney, and J. E. Kennamer. 1975. Evaluation of habitat manipulation for ducks in an Alabama beaver pond complex. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 29:512–518.

Longley, W. H., and J. B. Moyle. 1963. The beaver in Minnesota. Minn. Dep. Conserv., Tech. Bull. 6. 87 pp.

Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988. Alteration of North American streams by beaver. Bioscience 38:753–762.

Novak, M. 1987. Beaver. Pages 282–313 *in* M. Novak, J. A. Baker, M. E. Obbard, and B. Malloch, eds. Wild furbearer management and conservation in North America. Ministry of Natural Resources, Ontario, Canada.

Renouf, R. N. 1972. Waterfowl utilization of beaver ponds in New Brunswick. J. Wildl. Manage. 36:740–744.

Yeager, L. E., and W. H. Rutherford. 1957. An ecological basis for beaver management in the Rocky Mountain region. Trans. North Am. Wildl. Conf. 22:269–300.

Appendix. List of Common and Scientific Names of Plants and Animals Named in Text.

Animals

Wood duck	*Aix sponsa*
Green-winged teal	*Anas crecca*
Mallard	*Anas platyrhynchos*
American black duck	*Anas rubripes*
Ring-necked duck	*Aythya collaris*
Common goldeneye	*Bucephala clangula*
Bufflehead	*Bucephala albeola*
Gray wolf	*Canis lupus*
Beaver	*Castor canadensis*
Northern flicker	*Colaptes auratus*
Sandhill crane	*Grus canadensis*
Hooded merganser	*Lophodytes cucullatus*

Plants

Maple	*Acer* spp.
Alder	*Alnus* spp.
Birch	*Betula* spp.
Sedges	*Carex* spp.
Japanese millet	*Echinochloa crusgalli*
Rushes	*Juncus* spp.
Duckweed	*Lemna* spp.
Waterlily	*Nymphaea* spp.
Tupelo	*Nyssa aquatica*
Cottonwood	*Populus* spp.
Quaking aspen	*Populus tremuloides*
Pondweeds	*Potamogeton* spp.
Cherry	*Prunus* spp.
Willow	*Salix* spp.
Baldcypress	*Taxodium distichum*
Watermeal	*Wolffia* spp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1991

13.4.8. Options for Water-level Control in Developed Wetlands

J. R. Kelley, Jr.[1], M. K. Laubhan[2], F. A. Reid[3],
J. S. Wortham, and L. H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri
Puxico, Missouri 63960

Wetland habitats in the United States currently are lost at a rate of 260,000 acres/year (105,218 ha/year). Consequently, water birds concentrate in fewer and smaller areas. Such concentrations may deplete food supplies and influence behavior, physiology, and survival. Continued losses increase the importance of sound management of the remaining wetlands because water birds depend on them.

Human activities modified the natural hydrology of most remaining wetlands in the conterminous United States, and such hydrologic alterations frequently reduce wetland productivity. The restoration of original wetland functions and productivity often requires the development of water distribution and discharge systems to emulate natural hydrologic regimes.

[1] Present address: National Biological Survey, Office of Migratory Bird Management, Laurel, Maryland 20708.
[2] Present address: National Biological Survey, National Ecology Research Center, 4512 McMurry Avenue, Fort Collins, Colorado 80525.
[3] Present address: Ducks Unlimited, Inc., Western Regional Office, 9823 Old Winery Place, #16, Sacramento, California 95827.

Construction of levees and correct placement of control structures and water-delivery and water-discharge systems are necessary to (1) create soil and water conditions for the germination of desirable plants, (2) control nuisance vegetation, (3) promote the production of invertebrates, and (4) make foods available for wildlife that depends on wetlands (Leaflets 13.2.1 and 13.4.6). This paper provides basic guidelines for the design of wetlands that benefit wildlife. If biological considerations are not incorporated into such designs, the capability of managing wetlands for water birds is reduced and costs often are greater.

Although we address the development of palustrine wetlands in migration and wintering areas, many of the discussed principles are applicable to the development of other wetland types and in other locations.

Levees

Placement

A primary goal of the development and management of wetlands is the maximization of the amount of flooded habitat. Consequently, levees often are constructed to impound water across large areas with little regard for significant changes in elevation. Because the size and placement of levees were neglected, large portions may be flooded to depths that preclude foraging by some water birds.

Levee placement should be compatible with the natural topography. Contour levees facilitate an efficient and precise control of water in an entire impoundment. As a result, the composition of the vegetation can be controlled more reliably and foods can be made more readily available. Contour intervals on which to construct levees should be established by balancing construction costs, detrimental effects on existing habitats, and the extent and desirable depth of the flooded area. For example, levees on 8-inch (20.3 cm) contours may be appropriate for managing herbaceous vegetation. In contrast, levees for impounding water in forested habitats with similar topographic variation may have to be on a greater contour interval to reduce the number of trees that must be removed. Furthermore, development should not proceed where numerous contour levees in a small area are required.

Permanent Levees

Because they permit control of water levels and dictate the maximum water depth in an impoundment, permanent levees are an integral component of developed wetlands.[1] In addition, permanent levees often are used to form header ditches for the movement of water from sources to the impoundment. Although the dimensions of permanent levees vary by wetland type (permanent, semipermanent, seasonally flooded) and proposed function, the design must be based on engineering criteria.

Appropriate soils must be used for levees to ensure long-term integrity. Because soils have different physical and chemical properties (such as organic-matter content and texture) that affect their suitability as construction material, not all soils can be used to build levees. For example, because of their high susceptibility to water seepage and low erosion potential, coarse sandy soils are poorly suited for levee material. Similarly, soils of mostly organic materials often are unsuitable because of their high potential to shrink and swell. In general, clays or silty clay loams are best suited as levee material because they are highly compactible and have a low shrink-swell potential. Local Soil Conservation Service offices can provide assistance with obtaining recommended engineering specifications for levees with specific soil types.

Levees should be seeded with non-woody vegetation to help bind the soil and reduce wind and wave erosion. Mixtures of cool-season grasses, warm-season grasses, or both have been used successfully. Because the most appropriate species vary by location and management objectives, a list of desirable species should be obtained from a local extension specialist.

After engineering criteria are satisfied, management goals also should be considered before construction. Levees should be capable of supporting equipment (e.g., tractor, mower, disk) for their maintenance and the control of vegetation in the impoundment. The side slopes of levees should be gradual to allow easy, safe maintenance and deter potential damage by burrowing mammals such as nutria, muskrat, or beaver. Levees with 12-foot (3.7 m) crowns and minimum side slopes of 4:1 or 5:1 usually are satisfactory (Fig. 1). Levees with more gradual side slopes require a greater volume of material, increase construction costs, and destroy more wetland habitat but may be needed to satisfy engineering requirements for some soil types.

The width and height of levees also depend on the size of the impoundment and desirable depth of flooding. Large impoundments (>80 acres [>32 ha]) and impoundments that function as permanently flooded wetlands are subject to severe wave action that increases the risk of erosion. Consequently, large or deeply flooded impoundments require more substantial levees than smaller or seasonally flooded impoundments. As a general rule, the levee height should be at least 1.0 to 1.5 feet (0.3–0.5 m) above the maximum planned flooding depth. Based on these guidelines, levees of permanently and semipermanently flooded impoundments (4–5 foot [1.2–1.5 m] water depths) should have a minimum height of 6 feet (1.8 m), whereas the levee height of seasonally flooded impoundments (4–18 inch [10–46 cm] water depth) should be a minimum of 3 feet (0.9 m). Where unplanned severe flooding occurs regularly, as along rivers, a low levee that is submerged quickly and uniformly often is damaged less by flooding than a large protective levee that is partially overtopped. Where unplanned flood events are less severe or only infrequent, protected (e.g., rip-rapped) emergency spillways can be incorporated into the levee design to maintain the structural integrity.

[1] Federal, state and local permits may have to be obtained for the placement of dredge or fill material into wetlands.

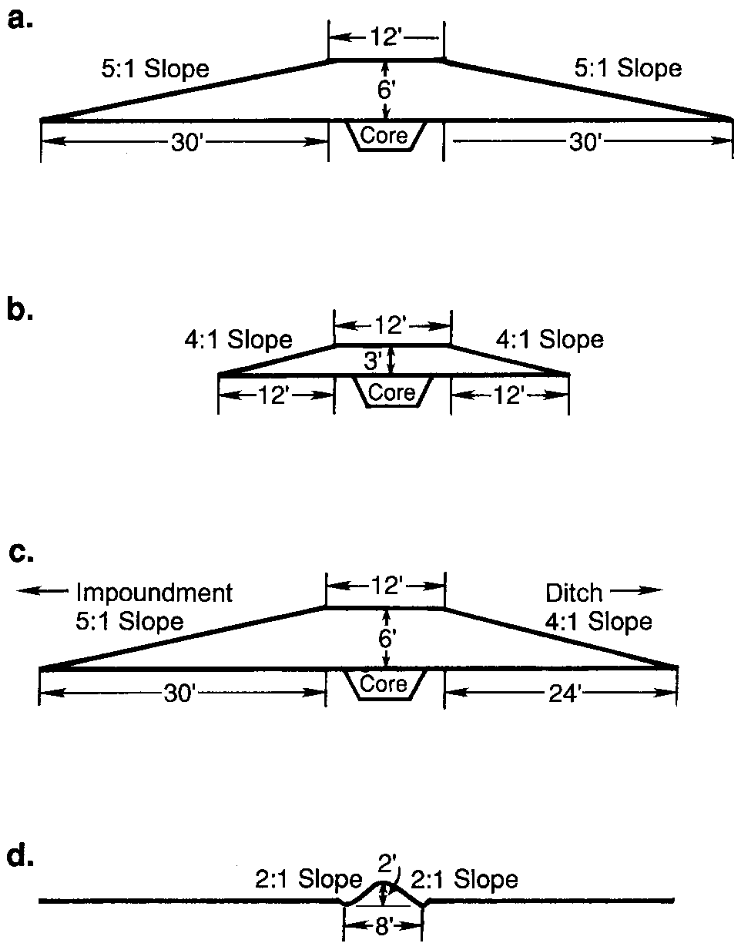


Fig. 1. Dimensions of levee for a permanent or semipermanent impoundment (a), levee for a seasonally flooded impoundment (b), header-ditch levee (c), and rice-dike levee (d).

Levees that form header ditches should be constructed according to many of the same criteria as impoundment levees (Fig. 1c). However, the height of header-ditch levees should be based on the quantity and rate of water that must be transferred from the water source to the impoundment. The levee height should be a minimum of 1.5 feet (0.5 m) above the maximum planned water capacity of the ditch.

Temporary Levees

Formerly, many impoundments were constructed without regard to natural topography, and elevation changes in excess of 3 feet (0.9 m) were common. Although small elevation changes promote plant diversity and provide a diversity of depths for foraging, the management of impoundments with large topographic variations can be impaired because water levels are difficult to manipulate. One method of improving the manipulation of water levels in such impoundments is the construction of temporary levees, often called rice dikes. The dimensions of completed rice dikes vary by soil type and equipment, but those constructed with a rice-dike plow typically have steep side slopes, a base width of about 8 feet (2.4 m), and a height of about 2 feet (0.6 m; Fig. 1d). Small levees also can be constructed with terrace plows, fire plows, bulldozers, and motor graders. These implements can be used to develop levees with more gradual side slopes and greater heights, but construction is more costly and the amount of manageable habitat in an impoundment is reduced. Regardless of the construction method, small levees should be built only on well-drained soils to assure a dry, impervious core. Because rice dikes gradually taper toward the top, they are very susceptible to erosion from wave action. Consequently, most rice dikes are effective only if constructed on contours which prevent water from overtopping and eroding the levee. Rice dikes usually have a life-span of less than 2 years.

Water-control Structures

Correct placement and type of water-control structures for precise manipulation of water levels are essential for the simulation of natural hydrologic regimes. Structures to regulate the water discharge should be placed at the lowest elevation in the impoundment and be large enough to permit complete, rapid dewatering. Stoplog structures have proven to be the most effective design because desired changes in water depth can be achieved with appropriately sized stoplogs and because water depths can be maintained with a minimum of monitoring (Fig. 2a). In contrast, screw gates are poorly suited as outlet structures because they require constant monitoring during drawdowns and do not enable precise manipulations (Fig. 2b). However, screw gates may be used to regulate the water flow into an impoundment. The number and size of water-control structures should be determined by topography and size of the impoundment. Structures should be placed where management activities cause little disturbance of wildlife.

Flooding Systems

A proper design of flooding systems is imperative to successful wetland management. If possible, each location for levees should be

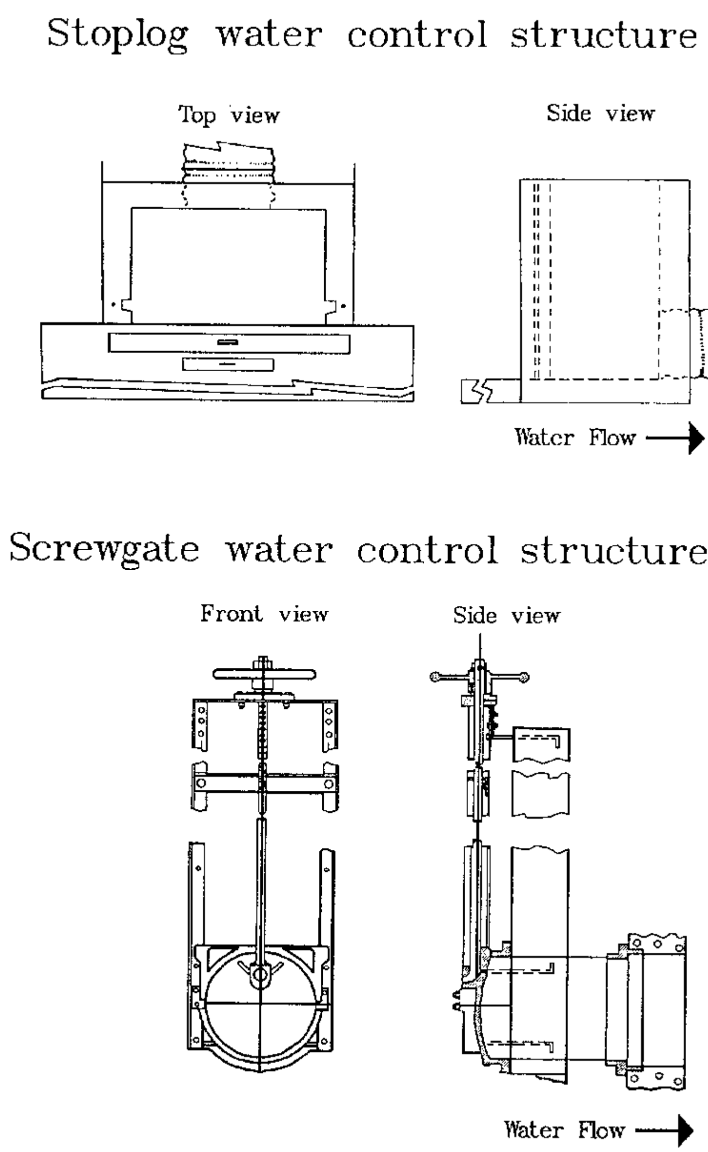


Fig. 2. Stoplog (a) and screw gate (b) water-control structures for manipulating water levels.

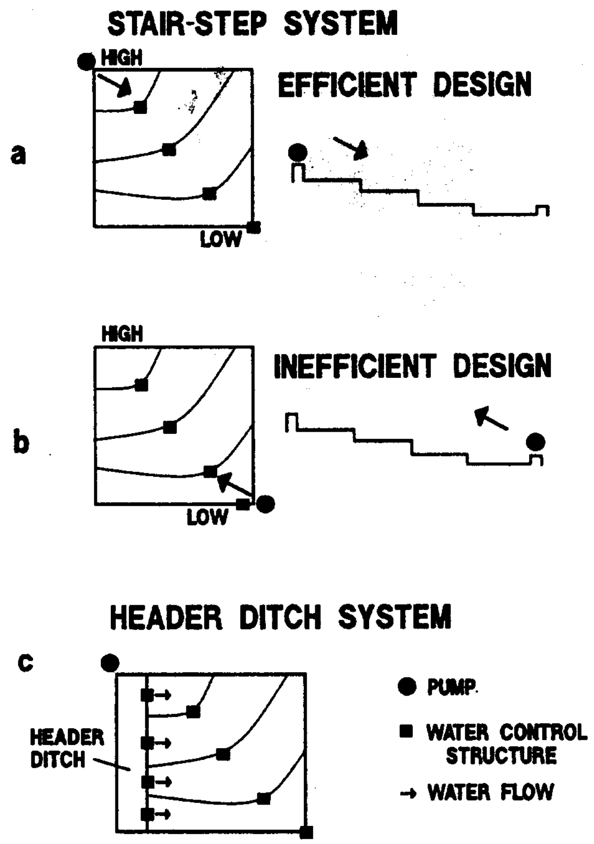


Fig. 3. Configuration of stair-step (a and b) and header-ditch (c) flooding systems.

developed to permit the independent control of the depth, duration, and time of flooding. Furthermore, a proper location of the pumping units is important for efficient water manipulation. Any of three methods generally are used to flood a complex of impoundments. The first is a stair-step overflow system (Fig. 3a and 3b). Ideally, the water enters at the highest elevation. When flooding commences, the area at the highest elevation is flooded first. Subsequent additions of water can be used to flood additional areas at lower elevations. Having the water enter at the highest elevation also ensures that it can flow through impoundments, making it possible to remove salts and to irrigate vegetation effectively. The second system requires the construction of a water transfer system adjacent to several areas with levees (Fig. 3c). Such a transfer system may consist of a header ditch or polyvinylchloride (PVC) pipe with water-control structures that independently regulate water flow into each impoundment. The use of a PVC pipe allows more efficient use of water than a header ditch and never requires control of vegetation. However, the PVC pipe should be buried to prevent deterioration. A hydrologist or engineer should be consulted prior to the installation of a permanent pipe system because the distance that water can be transferred through a pipe varies with pump type, pipe size, and elevation gradient. The third flooding system consists of a portable pump with sufficient hose or pipe to transport water from the source (e.g., pond, ditch) to each impoundment.

Dewatering Systems

The dewatering system is as important to successful wetland management as the flooding system. The discharge system should ensure the quick and complete removal of water from all impoundments. Thus, discharge ditches should be at least 2 feet (0.6 m) below the base elevation of an impoundment. Although the quantity of water that must be removed from impoundments determines the dimensions (i.e., base width, side slope) and the number of required discharge ditches, requirements for maintenance also should be considered. The ability to completely remove water from the discharge ditches prevents undesirable vegetation, such as American lotus or willows, from becoming established and reducing drainage capacity. If such problems develop, ditches with minimum side slopes of 4:1 permit equipment access to control vegetation and still promote efficient water removal.

Benefits of Proper Development

The value of a properly constructed wetland can best be evaluated by comparing the costs of construction and maintenance with the benefits for wildlife. To illustrate the long-term costs and benefits of contour levees, compare a 1,000 acre moist-soil impoundment with contour levees and one with a single straight levee bisecting the unit (Fig. 4). The initial cost of construction is 320% greater with contour levees (Table), but water levels over the entire area can be managed to establish vegetation and food resources for water birds. In contrast, optimum water levels can be achieved on only 45% of the area if a levee were constructed across the elevation gradient. The remaining 55% will either be too deep for water birds or will remain dry.

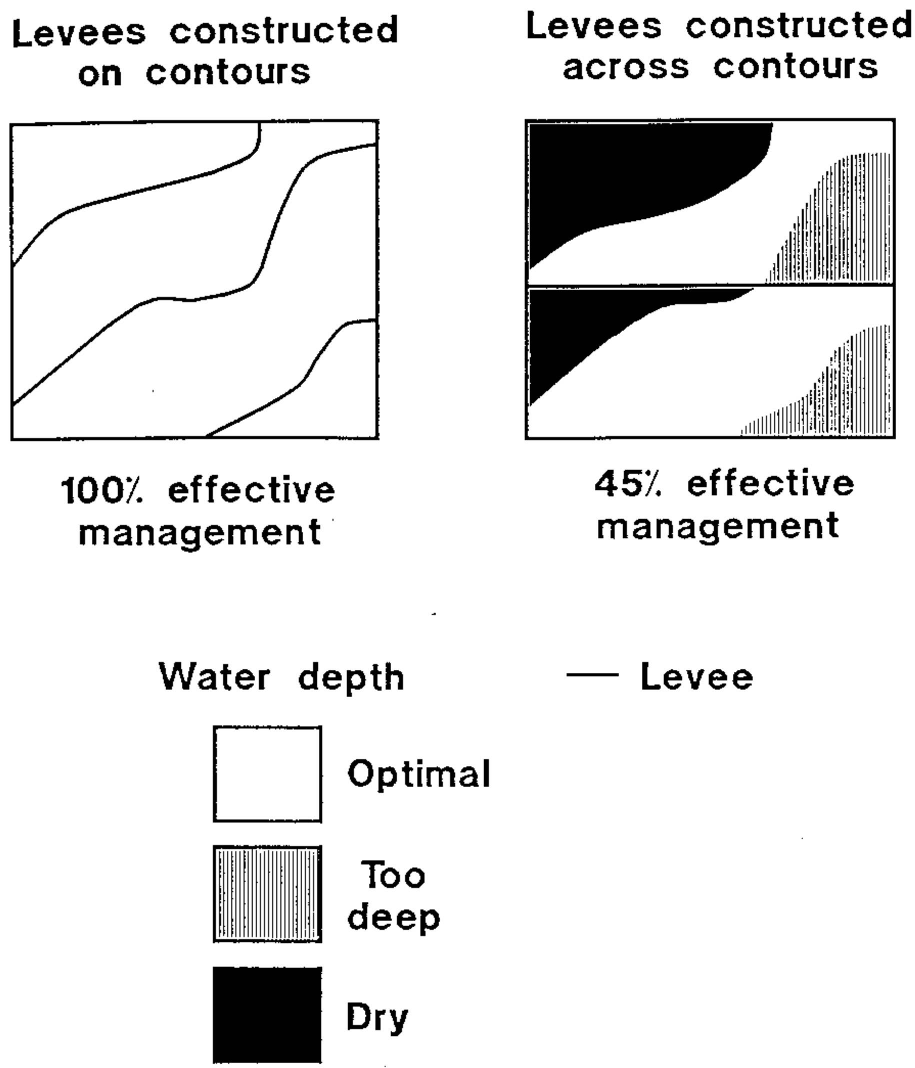


Fig. 4. Cost-benefit comparison of an impoundment with and without contour levees.

Table. Construction costs for hypothetical 1,000-acre impoundments with levees on contours and with levees not on contours.[a]

Item	Levees on contour	Levees off contour	Difference
Amount of fill material (yd^3)	51,371	16,054	35,317
Cost of interior levees ($0.88/$yd^3$)	45,206	14,127	31,079
Initial levee cost ($/acre)	45.21	14.13	31.08
Effectively managed area (%)	100	45	55
20 year cost ($/effective acre)	2.26	1.57	0.69
Effectively managed area in 20 years (acres)	20,000	9,000	11,000
Seed production in 20 years (million lbs)	30.0[b]	4.5[c]	25.5
Waterfowl use-days in 20 years (in millions; 0.2 lbs/day/bird)	150.0	22.5	127.5

[a] Conversions of measurements to metric units not given.
[b] Based on a seed-production rate of 1,500 lbs/acre/yr.
[c] Based on a seed-production rate of 500 lbs/acre/yr.

After 20 years, the impoundment with contour levees provides 11,000 more acres of managed habitat than the impoundment without contour levees. With the precise water-level control from proper levee placement, the annual moist-soil seed production may average 1,500 lbs/acre (275 kg/ha). In the impoundment without contour levees, the water-level control would be less precise and the annual seed production may average only 500 lbs/acre (92 kg/ha), of which a portion would be unavailable to birds because of deep water. The difference in the annual seed production would result in an additional 25.5 million pounds (about 11.6 million kg) of seed in the impoundment with contour levees during 20 years. This amount of food could support as many as 6.4 million additional waterfowl use-days/year.

Proper construction and placement of levees and water-control structures provide benefits not only for waterfowl. For example, of 80 water birds that commonly use wetlands in Missouri, more than 55 species use only shallowly flooded habitats (<10 inches [25.4 cm]). Many of these species are dependent on invertebrates, which also respond best to shallowly flooded environments. Other foods, including tubers and browse, also are more available to water birds if shallowly flooded. Thus, contour levees that permit shallow flooding over the entire impoundment are of great importance in meeting the needs of many wetland species. Including these factors in a cost-benefit analysis would make contour levees an even more attractive alternative.

Recommendations

In summary, recommended specifications for the development of managed wetlands are:

1. The simulation of natural hydrologic cycles.
2. Independent water delivery and water discharge for each impoundment.
3. Water delivery at the highest elevation.
4. Water discharge at the lowest elevation.
5. Stoplog structures as the most appropriate outlet structures.
6. Levees on contours.
7. Maximized flooded area to shallow depths (<10 inches [<25 cm]).
8. Water-control structures, pumps, and other structures placed where they and their maintenance cause the least disturbance to wildlife.

Suggested Reading

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish and Wildlife Service Resource Publication 148. 29 pp.

Payne, N. F. 1992. Techniques for wildlife habitat management of wetlands. McGraw-Hill Inc., New York, N.Y. 549 pp.

Smith, L. M., R. L. Pederson, and R. M. Kaminski, editors. 1989. Habitat management for migrating and wintering waterfowl in North America. Texas Tech University Press, Lubbock. 560 pp.

Appendix. Common and Scientific Names of the Plants and Animals Named in the Text.

Animals	
Beaver	*Castor canadensis*
Nutria	*Myocaster coypus*
Muskrat	*Ondatra zibethicus*
Plants	
American lotus	*Nelumbo lutea*
Willows	*Salix* spp.

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
NATIONAL BIOLOGICAL SURVEY
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

13.4.9. Preliminary Considerations for Manipulating Vegetation

Leigh H. Fredrickson and Frederic A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri—Columbia
Puxico, MO 63960

A wide diversity of plants has adapted to the dynamic nature of wetlands. The continually changing floral landscape is shaped by physical or abiotic components that include climate, fire, soil, and water. Water quantity, quality, and chemistry have a dominating influence on wetlands as do factors such as hydroperiod (period when soils are saturated) and hydrological regime. Other factors that may affect the abundance, structure, and species composition of macrophytes or robust emergents are natural grazing, disease, and interspecific plant competition.

Vegetation is important to waterfowl for producing seeds, tubers, and browse; providing nest sites; and serving as substrates for animal foods. For example, the emergent marsh stage with the greatest number and diversity of birds has been called the "hemimarsh." A maximum diversity and number of birds occur when vegetation cover and water interspersion in Type IV (semipermanent marsh) wetlands is at a 50:50 ratio. This wetland condition provides ideal nesting cover for waterbirds, as well as substrates and litter for invertebrate populations.

Emergent wetlands other than glacial marshes also require good interspersion of cover and water to attract waterfowl. Likewise, a diversity of wetland vegetation is much more desirable than a monoculture. As man expanded his activities in North America, the natural events producing mosaics of wetland vegetation were eliminated or altered. As an example, drainage or water diversion to enhance row crop production not only affects the immediate site, but often affects soil moisture conditions on adjacent areas as well.

This change in water availability influences plant species composition. Intensive cultivation for grains and forage, together with other human-related activities (water diversion projects, livestock grazing, and the elimination of natural fires) have modified the physical processes that influence the productivity of wetland systems. Managed areas throughout North America now must provide predictably good wetland habitat, despite modifications to water supplies, flooding regimes, and other physical factors.

Manipulation of wetland vegetation is a commonly employed tool. Although water-level manipulation is the traditional technique for modifing plant communities under intensively managed systems, other options include fire, grazing, and other physical and chemical disturbances. Values of vegetation structure and composition along with general concepts relating to manipulations are discussed.

Desirable or Undesirable?

Traditionally, plants in waterfowl wintering or migration corridors were considered desirable if they produced large amounts of seed for food, whereas on waterfowl breeding grounds cover for nesting, broods, and molting birds was the desired characteristic. The value of plants as food (in the form of tubers and browse) and cover has long been acknowledged. However, recent information indicates plants are vitally important to invertebrates as nutrient sources and substrates. Likewise, structural characteristics of vegetation may provide important habitat components when waterfowl court, molt, or require escape cover. Robust marsh vegetation serves as a nutrient pump within wetlands and can influence water chemistry and primary productivity. All of these functions are integral values of wetlands that are important considerations beyond the provision of seeds for waterfowl.

"Undesirable" plants are not simply "a group of plants whose seeds rarely occur in waterfowl gizzard samples." Rather, plants that quickly shift diverse floral systems toward monocultures, are difficult to reduce in abundance, have minimal values for wetland wildlife, or outcompete plants with greater value should be considered less desirable. When manipulation of undesirable plants is required, it should be timed so that the resultant decomposing vegetation can be used effectively by wetland invertebrates. If reflooding is shallow, these organisms with high protein content are readily available for consumption by waterfowl or shorebirds.

The Need For Disturbance

Vegetation within semipermanent and permanent wetlands can shift rapidly to a monoculture of robust plants. If water regimes remain constant or if muskrat populations are low, these monocultures may rapidly reduce associated waterfowl use. Manipulation of these monocultures by flooding or drying, fire, or chemical means can modify the structure and potentially increase plant and animal diversity. Disturbance tends to destroy monocultures and sets back succession. For instance, moist-soil wetlands that once were dominated by seed-producing annuals (Fig. 1), but have shifted to less desirable perennials after several years, may require mechanical mowing or discing.

"Undesired," especially exotic, plants may also plague managers. Problem plants often differ among regions. For example, purple loosestrife is a hardy perennial that causes management problems in the Northeast and Midwest, whereas American lotus with its elaborate tuber systems is a serious problem for managers in the Southeast and Midwest, where static water regimes occur. Invasions of young woody trees must be controlled in intensively managed marsh sites, because these same small sprouts can only be removed by very expensive bulldozer operations once sapling stages are reached. Problem woody and herbaceous growth forms are compared by region in Table 1.

Vegetation structure can also be modified with machinery to provide good interspersion. Mowing and rototilling have successfully produced the "hemimarsh" conditions under controlled experiments in Canadian prairies. Tracked vehicles are used to open dense stands of plants in Hawaii to improve habitat for endangered waterbirds, and duck-hunting clubs in California mow to create good interspersion for hunting. In summary, manipulation of vegetation may be desired to set back succession and reduce monocultures of robust plants, to diversify monotypic plant communities with undesirable characteristics, to reduce woody invasion in moist-soil areas, and to modify vegetation structure.

Initial Considerations in Development of Managed Wetlands

Careful considerations of potential vegetation problems and identification of anticipated, re-

	Year 1		Year 5		Year 6
Dominant vegetation	water smartweed		black willow		water smartweed
	common barnyardgrass	$\xrightarrow{*}$	aster	$\xrightarrow{**}$	straw-colored flatsedge
	sprangletop		swamp smartweed		common barnyardgrass

* Similar annual water regime/no physical disturbance.
** Physical disturbance (disc).

Figure 1. Successional shift of moist-soil plants.

Table 1. *Comparison of problem woody and herbaceous vegetation by region.*

Vegetation	West	Midwest/Southeast	Northeast
Woody	Salt cedar	Eastern cottonwood	Mountain alder
	Willow	Willow	
	Fremont cottonwood	Silver maple	
Herbaceous	Alkali bulrush	American lotus	Purple loosestrife
	Cattail	Cattail	
		Sesbania	
		Common cocklebur	
		Alligatorweed chafflower	

quired manipulations before construction can reduce management costs on intensively managed sites. Input by knowledgeable managers is essential as engineering plans are developed. Disturbance of unmodified or critical sites by development can negate any benefits of construction. Undoubtedly, any obstruction (such as a levee) will modify the previous hydrological regime. Typically, lands within levee systems become wetter because water is retained longer. Severe damage may be avoided by simply knowing where parking lots, drainage ditches, and roads can be placed. Initial considerations should include climatic, edaphic, and hydrologic information, as well as life history information for dominant flora (Table 2). An understanding of natural flooding regimes on a local scale should be developed in order to emulate natural conditions. Drainage patterns within a watershed indicate proper locations of levees and water-control structures. Improperly placed drainage structures preclude complete dewatering and reduce management options. Soil characteristics and potential to hold water affect seed germination and effectiveness of subsequent flooding. Placement of borrow ditches requires considerations such as costs of pumping water into or away from ditches and whether access to the site with equipment is required regularly. On areas where hunting is allowed, access across deep ditches is essential.

Costs associated with flooding, as well as providing as much area as possible with optimum water depths, make contour levees highly desirable. Optimum water control to enhance manipulation of plants and to promote proper flooding depths for most waterfowl requires levees on con-

Table 2. *A checklist of variables important in the development of management scenarios for wetland habitats critical to vegetation management.*

Management considerations
Climate
Precipitation cycle
Temperature ranges
Length of growing season
Soils
Structure/texture
Fertility
Topography
Residual herbicides
Water control potential
Water supply/source
Levees
Control structures
Pumps
Impoundments in complex
Number
Size
Juxtaposition
Plants
Species composition
Species life history
Structure and maturity
Seedbank
Exotic and problem species
Equipment for manipulations
Access
Repair capabilities
Other land uses
Grazing
Mineral development

tours at intervals of no more than 18 inches. Larger, more permanent levees that can withstand the weight of machinery and have a slope of 4:1 are desirable. On undeveloped areas, smaller levees built with road graders or specially designed equipment such as rice-levee plows offer management potential. These smaller levees, however, are less permanent and are difficult to repair if damage occurs during flooding.

Improvements in previously developed areas should stress fine tuning of water control or relocation of water-control structures. Major renovations may include establishment of contour levees, decreased intervals between levees, or reconfiguration of the area. Individual water control on each management parcel enhances management potential. For example, the addition of a header ditch with appropriate control structures may provide independent control on each management unit. Although initial development costs may be great, the area of high-quality habitat may increase dramatically. Installation of stoplogs that give finer control of water levels may be a minor but important improvement. Because plants readily respond to water level changes of as little as 1 in., the full potential of manipulations can only be met when the structure allows control at this level of precision. A mix of stoplogs of different dimensions, rather than only 4 in. or more in thickness, assures this potential. In dry regions, design of levees, ditches, and other control structures should be developed to make maximum use of available waters and reduce evapotranspiration.

Requirements of Vegetation Management

Manipulation of managed wetland areas often is better described as a learned craft or art, rather than strictly as applied science. Many differences exist among wetlands in different regions, areas, and sites. By recognizing the unique characteristics of their particular management area and of sites within each area, managers may enhance the ecological processes to emulate a more natural dynamic system. Preliminary assessments should include the following considerations:

Location—The site is of prime importance. Saline or alkaline areas have different problems from freshwater systems. Latitude is also important because of length of growing season and types of resources normally required by migrants or residents at that location.

Topography—An understanding of the subtle elevational differences within specific wetland sites is essential for predicting vegetation response. Further, the topography may influence management options such as rate of drawdown or appropriateness of management options (e.g., wet and dry sites for common snipe).

Water levels—A systematic record of water level changes is critical when assessing vegetation response to dewatering and when determining availability of optimum foraging depths (less than 10 inches)for dabbling ducks. A monitoring program should be designed with respect to the flooding source (i.e., rainfall or pumping), or important fluctuations may be overlooked.

Water quality—In some locations water sources should be monitored for the presence of toxic substances to alert managers to potential problems.

Site inspections and monitoring—Vegetation and wildlife responses should be monitored to evaluate site use and to identify manipulations needed to enhance or prevent certain vegetative conditions. Time of day, weather conditions, visibility, disturbance, and time in season are important considerations when observing wildlife use in a specific vegetation zone. Some species (e.g., migrants) may use specific wetland sites for only short periods of time, but these sites may be critical at those times. Monitoring schedules may vary depending on management objectives, but weekly or biweekly inspections or surveys during periods of peak use are more desirable than surveys at longer intervals. Records should be maintained for each unit rather than pooling all information for the area.

Plant identification—Plants must be identified at all stages, including the young seedling stage, to ensure proper timing and type of manipulation. For undesirable plants, effective control requires action at the young seedling stage and before seed maturation. Unfortunately, most taxonomic texts do not include adequate information for identification of seeds or seedlings.

Burrowing animals—Furbearers (such as muskrat and beaver) and other mammals (such as groundhogs) are important components of a dense wetland system, but control of these mammals is essential to maintain levee integrity in some situations.

Rough fish—Carp and some other fish create high turbidity that influences the establishment and growth of submergents. Tilapia cause problems by competing with waterbirds for food and by forming nest bowls that are difficult to drain. Control of such fish is an integral part of effective vegetation management.

Equipment—Equipment availability is essential for well-timed manipulations. Expensive dewatering activities may be wasted if equipment is unavailable or unreliable. Quick repair of equipment is often necessary when suitable conditions for manipulations may be restricted to a few weeks annually. Likewise, ineffective manipulations may occur with the most knowledgeable managers if inexperienced or overly enthusiastic equipment operators manipulate more than is necessary or modify the wrong vegetation.

Timing—Manipulations are most effective if implemented at critical times. Management strategies that are designed for convenience or are conducted routinely may be ineffective because they do not match floral phenology or chronology of wildlife activities. Proper timing of manipulations enhances the potential for maximum production of foods and may increase the use of foods produced. Manipulations to modify vegetation require careful considerations because of costs, structural changes, diverse wildlife requirements, and long-term implications.

Suggested Reading

Fredrickson, L.H., and T.S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish Wildl. Serv., Resour. Publ. 148. 29 pp.

Kaminski, R.M., H.R. Murkin, and C.E. Smith. 1985. Control of cattail and bulrush by cutting and flooding. Pages 253–262 in Coastal Wetlands. Lewis Publishers, Inc., Chelsea, Mich. 286 pp.

Kantrud, H.A. 1986. Effects of vegetation manipulation on breeding waterfowl in prairie wetlands—A literature review. U.S. Fish Wildl. Serv., Spec. Sci. Rep. -Wildl. 3, 15 pp.

Linde, A.F. 1985. Vegetation management in water impoundments: Alternatives and supplements to water-level control. Pages 51–60 *in* M.D. Kighton, ed. Water Impoundments for Wildlife: A Habitat Management Workshop. U.S. Dep. Agri. For Serv. St. Paul, Minn. 136 pp.

Murkin, H.R., R.M. Kaminski and R.D. Titman. 1982. Responses by dabbling ducks and aquatic invertebrates to an experimentally manipulated cattail marsh. Can. J. Zool. 60: 2324–2332.

Rundle, W.D. 1981. Habitat selection by fall migrant snipe in southeastern Missouri. Proc. Annu. Conf. Southeast Assoc. Fish Wildl. Agencies 35:20–26.

Smith, L.M., and J.A. Kadlec. 1985. Fire and herbivory in a Great Salt Lake marsh. Ecology 66:259–265.

Weller, M.W., and L.H. Fredrickson. 1973. Avian ecology of a managed glacial marsh. Living Bird 12:269–691.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants

Silver maple	*Acer saccharinum*
Mountain alder or speckled alder	*Alnus incana*
Alligatorweed chafflower	*Alternathera philoxeroides*
Straw-colored flatsedge	*Cyperus strigosus*
Common barnyardgrass	*Echinochloa crusgalli*
Sprangletop	*Leptochloa* spp.
Purple loosestrife	*Lythrum salicaria*
American lotus	*Nelumbo lutea*
Common reed	*Phragmites australis*
Marsh knotwood or water smartweed	*Polygonum coccineum*
Swamp smartweed	*Polygonum hydropiperoides*
Eastern cottonwood	*Populus deltoides*
Fremont cottonwood	*Populus fremontii*
Willow	*Salix* spp.
Black willow	*Salix nigra*
Saltmarsh bulrush or alkali bulrush	*Scirpus robustus*
Sesbania	*Sesbania* spp.
Saltcedar tamarisk or salt cedar	*Tamarix pentandra*
Cattail	*Typha* spp.
Common cocklebur	*Xanthium strumarium*

Birds, mammals, and fish

Common snipe	*Gallinago gallinago*
Beaver	*Castor canadensis*
Groundhog or woodchuck	*Marmota monax*
Nutria	*Myocastor coypus*
Muskrat	*Ondatra zibethicus*
Common carp	*Cyprinus carpio*
Tilapia	*Tilapia* spp.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.4.10. Control of Willow and Cottonwood Seedlings in Herbaceous Wetlands

Leigh H. Fredrickson and Frederic A. Reid
Gaylord Memorial Laboratory
School of Forestry, Fisheries and Wildlife
University of Missouri-Columbia
Puxico, MO 68960

Willow and cottonwood are common species in forested wetlands and occur throughout most riparian and floodplain habitats of North America. These woody species are especially common in early successional stands where seasonal flooding occurs regularly. Cottonwood and willow are often considered problem plants, because they rapidly invade wetlands dominated by herbaceous flora and can form dense, extensive stands. The shade created by these species eliminates herbaceous undergrowth, and once the sapling stage is reached, cottonwoods and willows are difficult to eradicate. Control of these species can be costly and varies considerably with latitude.

Willow and cottonwood growth may be undesirable where intensive management of seasonally flooded impoundments is encouraging herbaceous growth or where levee structures could be compromised because of root intrusion. If woody plant control is a priority, life history responses within specific regions must be identified before attempting specific management manipulations. For instance, at more northern sites, seedlings and saplings that have been mowed can be controlled by shallow flooding. However, summer flooding at more southern sites is difficult because of evapotranspiration and can, in fact, accelerate growth. Control in these southern areas may best be achieved by taking advantage of summer droughts. A complete drawdown of an impoundment during the hottest days of summer prevents development of extensive root systems in newly established seedlings. Shallow discing at this time ensures destruction of newly established seedlings and disrupts the root systems of older plants. Drawdowns that expose expanses of mudflats before seed dispersal may enhance germination of woody species adapted to wet sites at southern latitudes, whereas drawdowns after seed dispersal reduce establishment of woody growth and confine it to narrower mudflat zones. Deep flooding that covers all aboveground growth can eliminate young seedlings.

Techniques for physical disturbance include several options. Shallow discing is a traditional technique that destroys both above- and belowground growth, yet is economical. A double cross-disc is most effective in dense stands. Discing twice, or even three times, in a growing season may be most effective for controlling young woody growth. Drought conditions may allow more opportunities for discing. When sapling size reaches approximately a 3-in. stem diameter, discing becomes ineffective. Mowing with a bushhog is an option even after discing is infeasible, but root systems are not modified. Additionally, multiple shoots will develop from most severed trunks. Fall mowing, followed by flooding throughout the next growing season, may effectively control willow saplings. When stem diameters reach 4 in. or greater, bulldozers may be the only realistic option for control. Large earthmoving equipment is not always an option because it

- is expensive
- requires experienced operators

- requires dry impoundments
- removes some of the topsoil
- destroys natural swales
- deepens ditches and swales, thus increasing volume of water retained and
- compacts the soil.

Chain saws may be used on large trees, especially if only a few trees present problems. This technique is time consuming and leaves stumps that may rapidly sprout unless treated with herbicides.

Herbicides are a chemical option, but chemicals and application are usually costly. Furthermore, chemical use is often restricted in aquatic systems and on public lands. Although chemicals are expensive, their use may be more economical than control with heavy equipment in some situations. Some chemicals may have residual effects on desired vegetation and future plant growth. Use of chemical control must be carefully balanced with other options before implementation. Chemicals may play a particularly important role on some sites that are inaccessible or cannot be disced because of vegetative structure or flood debris.

Control of woody species requires major management costs in labor, fuel, and machinery. Costs for control by discing willow seedlings or early sapling growth at the Ted Shanks Wildlife Management Area, Missouri, are $3,000/year or more on the 2,470-acre (1,000-ha) tract managed for moist-soil and agricultural crops. Control of older woody stands with bulldozers may require expenditures in excess of $10,000. On sites suitable for agricultural crops, alternating years of cultivation offers good short-term control.

Managers should be cautious when modifying natural sites that are dominated by willow and cottonwood. This habitat should be viewed as an integral component of a wetland complex that provides somewhat different sources of food and cover than other wetland types. Although extensive stands of these woody species may seldom be used, creating openings or increasing the amount of edge may be less costly and may provide needed resources for some species. Recent evidence suggests that leaf litter may be especially important in maintaining crustacean populations, which are critical food sources for hooded mergansers, mallards, wood ducks, yellow-crowned night-herons, and others. The structure of older trees may also provide important cover and nest sites for colonial waterbirds and passerines such as willow flycatchers and yellow warblers. Beaver impoundments throughout the continent are often dominated by willow and cottonwood. Such natural areas can only be degraded by the control of woody plants. Cottonwood and willow are usually least desirable when they occur as extensive monocultures. A mixture of these species with others usually provides desired food and cover in wetlands. Thus, management planning should consider woody species in long-term habitat objectives.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Eastern cottonwood	*Populus deltoides*
Fremont cottonwood	*Populus fremontii*
Willow	*Salix* spp.
Birds and mammals	
Wood duck	*Aix sponsa*
Mallard	*Anas platyrhynchos*
Willow flycatcher	*Empidonax traillii*
Yellow warbler	*Dendroica petechia*
Hooded merganser	*Lophodytes cucullatus*
Yellow-crowned night-heron	*Nycticorax violaceus*
Beaver	*Castor canadensis*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1988

13.4.11. Control of Purple Loosestrife

Daniel Q. Thompson
623 Del Norte Place
Fort Collins, CO 80521

Purple loosestrife is an herbaceous perennial weed that is native to Eurasia and probably arrived in eastern North America with early maritime traffic. The spread of this alien by 1900 (Fig. 1) was closely associated with canal and waterway traffic. By 1985 (Fig. 2), this aggressive weed had spread into all of the contiguous States north of the 35th parallel except Montana; similarly, all of the southern provinces of Canada had been invaded. In the last 20 years, loosestrife has become well established in reclamation projects and riparian wetlands in the West and Northwest. It has also invaded estuarine marshes in British Columbia.

The impact of this weed on North American wetland habitats has been disastrous. In many areas, purple loosestrife makes up more than 50% of the biomass of emergent vegetation. Moreover, these displacements are seemingly permanent, as seen in the Northeast, where many purple loosestrife stands have maintained themselves for more than 20 years. The effects of these changes have not been well studied but biologists believe that serious reductions in productivity of waterbirds and aquatic furbearers have resulted. Platformnesting species cannot use the stiff loosestrife stems for nest construction, nor are stems or rootstocks palatable to muskrats. In addition, dense, closely-spaced clumps do not provide brood cover or foraging areas. Although white-tailed deer and livestock will readily graze on young, succulent plants, palatability declines by late June and the forage value of wetland pastures that have been invaded by purple loosestrife is seriously reduced.

Field Identification

Purple loosestrife is most readily identified by its tall, showy spikes of pink-red flowers that bloom from late June to early September. Mature plants can have 30 or more stems arising 6 feet above a perennial rootstock (Fig. 3). With the onset of fall frost, leaves turn red for about 2 weeks; shortly thereafter, they fade and gradually fall. The sturdy, rigid stems remain standing through winter and spring—well into the following growing season. Each stem supports dense, spiralling rows of dark-brown seed capsules that will remain attached to the floral stalks through the winter, creating a distinctive silhouette that is useful in field recognition. From overhead, the brownish tone of each clump of dead stems could make a useful signature in aerial photography.

Adaptations

Most serious weeds are of foreign origin and have evolved competitive mechanisms in their native habitats that preadapt them to be successful on new continents that they may invade. Purple loosestrife is no exception; its affinity for freshwater marshes, open stream margins, and alluvial floodplains in Europe is closely paralled by its invasion of similar sites in North America. Moreover, its most common plant associates in American habitats

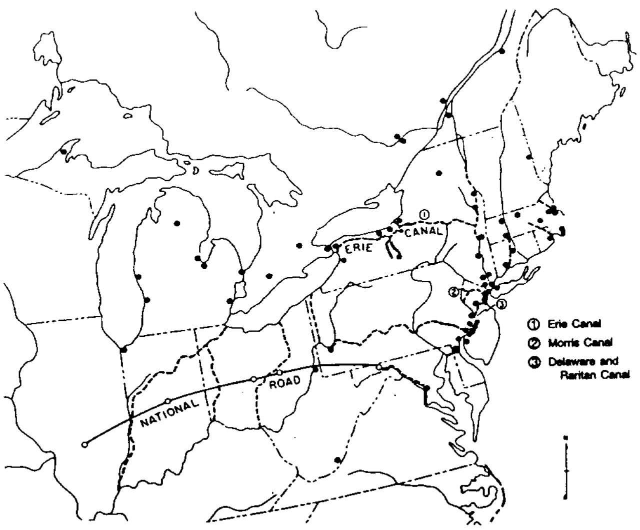


Fig. 1. Spread of purple loosestrife as of 1900.

(cattails, reed canarygrass, sedges, and rushes) are highly similar to its associates in Europe.

The outstanding success of loosestrife in invading American wetlands is supported by a remarkable list of weedy attributes. Purple loosestrife has demonstrated a high degree of resistance to chemical control, indicating that the genetic makeup of our American population is robust. Vigorous and varied modes of reproduction also characterize a successful weed. These traits are demonstrated in prolific seed production that issues from the dense whorls of capsules that are borne on each floral stalk; 3-year-old plants can produce in excess of 1 million seeds. Vegetative reproduction is another competitive advantage; loosestrife can withstand clipping, crushing, or shallow burial by sending up new shoots from adventitious buds arising from stems or rootcrowns (Fig. 4). Purple loosestrife also has a wide scope of seed dispersal mechanisms. The flat, thin-walled seeds are small enough to be carried in the plumage of migrant waterbirds or the fur of aquatic mammals; they have also been recovered from mud caked on the feet of shorebirds. Similarly, seeds trapped in mud on footgear, vehicle treads, or in the cooling systems of outboard motors could account for local and long-distance jumps in the distribution of this weed. Drift in flowing water or by wind on the surface of open water are the most likely means of local spread.

Purple loosestrife has an added advantage over most weeds in that it is cultivated and sold as horticultural stock across the northern United States

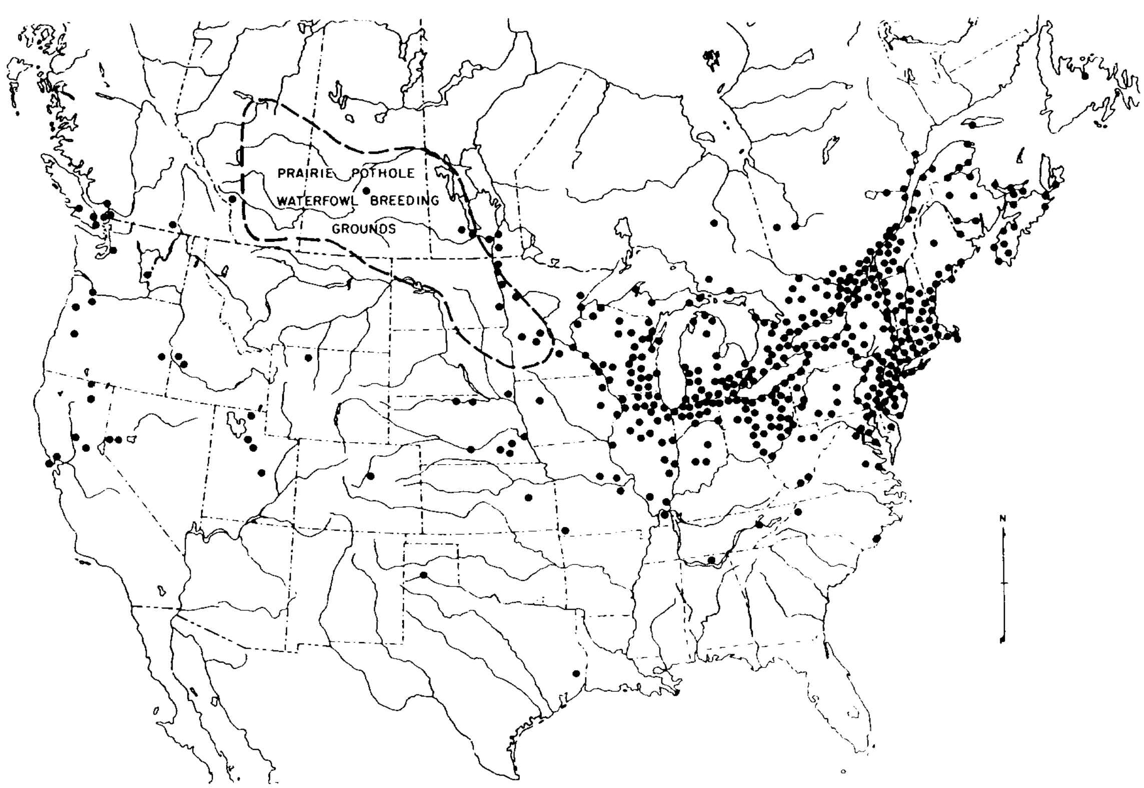


Fig. 2. Distribution of purple loosestrife as of 1985.

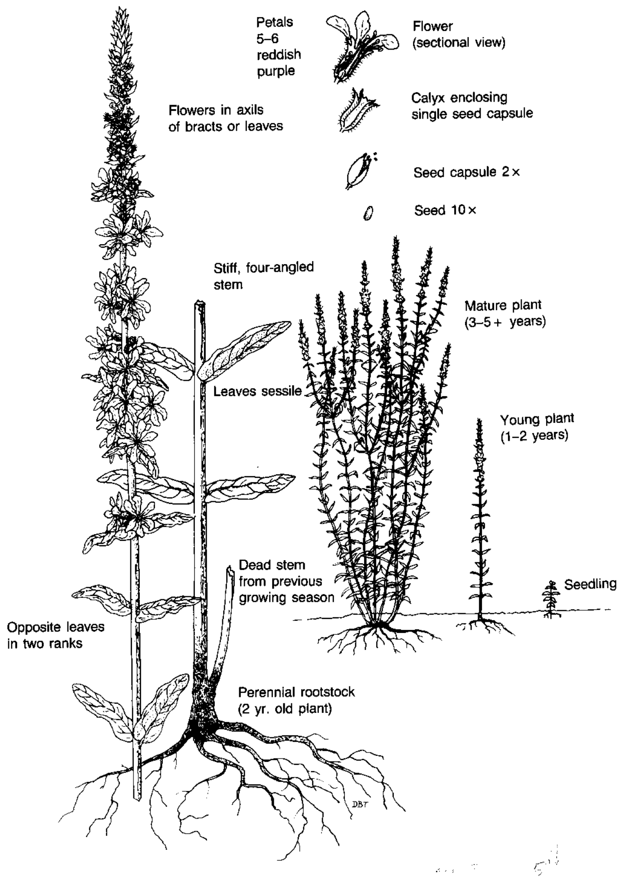


Fig. 3. Structure, growth forms, and field identification of purple loosestrife.

Fig. 4. Adventitious shoots of purple loosestrife arising from stems that have lodged onto a mat of duckweed (*Lemna* spp.) in a deepwater marsh near Rome, Wisconsin.

and southern Canada. Most of these stocks are infertile hybrids; however, some local sources include fertile plants that could escape into downstream wetlands. Beekeepers have also been responsible for the spread of purple loosestrife into uninfested wetlands. They value the plant as a source for nectar and pollen and have scattered seed in several midwestern waterways. With growing awareness of the impact of loosestrife on wildlife habitats, this practice is declining.

Another source of escapes arose from a growing interest in the restoration of native vegetation on country acreage. More than 150 private seed companies offer seed mixes of "wildflowers" and native prairie vegetation. A recent survey indicated that about 25% of the lists of seed mixes from these suppliers contained alien species; 10% of the lists containing aliens included purple loosestrife. Anyone attempting to restore a marsh or wet prairie with the faulty mixes would be inviting disaster. Within the past 10 years, Idaho, Illinois, Ohio, Minnesota, and Wisconsin have enacted legislation to check the spread of purple loosestrife through seed supplies or horticultural stocks.

Habitat Vulnerability

To protect their resource, wetland managers need to develop a sensitivity to the vulnerability of habitats to purple loosestrife invasion. Since loosestrife spreads primarily by floating seeds or propagules, a marsh basin or pothole that is isolated from surrounding drainage channels is relatively secure from infestation. The configuration and continuity of a river or waterway determines its vulnerability. Mountain or high plateau streams with steep gradients and narrow canyons are relatively invulnerable to loosestrife colonization and spread. In contrast, streams with low gradients and broad floodplains have shallow cross-sections and slow, winding channels that offer many opportunities for colonization by drifting seeds or propagules. Streambank cover is also an important determinant of vulnerability to invasion by an emergent perennial weed. The presence of cattails, grasses, sedges, or rushes (purple loosestrife's most frequent associates in North America) identifies a habitat that is susceptible to invasion. In contrast, streams that are bordered by woody vegetation (riverbottom hardwoods in the East; spruce, willow, and alder in the West) have well-shaded banks where the high light requirement of purple loose-strife precludes seedling development.

Recent Control Efforts

Chemical—Although early efforts to control purple loosestrife with chemicals were discouraging, the advent of glyphosate (Roundup:N-[phosphonomethyl] glycine) brought new promise of success. Designed as a postemergence spray for the control of agricultural weeds, this broad-spectrum herbicide was authorized for field tests on purple loosestrife in upstate New York in 1979. These experiments showed no significant differences among three rates (1.7, 3.4, and 6.7 kg/ha) of application but revealed sharp differences in responses to timing of application; treatments in the 2nd week of August at late flowering stage obtained nearly 100% shoot reduction. This work also showed that seedling survival was affected by the timing of application; the plots sprayed in June became reinfested with seedlings whereas the plots sprayed in July and August were free of seedlings.

In 1982, a new formulation of glyphosate (Rodeo-EPA Reg. No. 524-343) was approved for use over water, thereby clearing glyphosate for field use against purple loosestrife. Rodeo has subsequently been used for loosestrife control in the Northeast and Midwest with some success. Nevertheless, several problems confront the use of glyphosate in natural habitats. First, single applications seldom result in complete control; each summer, a small percentage of purple loosestrife crowns fail to send up shoots and thus avoid mortality. Second, the movement of ATV spray rigs in wetland habitats can cause more damage to the community than control of weed clumps will relieve. Last, although aerial spraying will avoid physical damage to the habitat, the widespread use of a broad-spectrum herbicide on complex wetland communities will have unknown effects on nontarget native species. Field studies in a wide range of habitats have shown that herbicides can affect breeding birds by altering the structure, foliage diversity, and species composition of vegetation treated. The wise use of chemical control in natural habitats hinges on the care with which the treatment is delivered. The delivery system should be as gentle and as target-specific as possible.

Water manipulation—Awareness of the effects of soil and water levels on purple loosestrife is one of the wetland manager's most useful means of coping with the weed. Experimental work in Ohio on the effects of flooding on loosestrife seedlings showed that duration of flooding was more important than depth; mortality in 8-inch seedlings covered by 12 or more inches of water increased sharply after 2 weeks, reached 95% mortality by 4 weeks, and 100% by 5 weeks. Seedlings with terminal growths extending above the water surface grew vigorously and survived flooding.

Mowing and tillage—Along irrigation canal banks or other rights-of-way where tractors can operate, repeated mowing or clipping will greatly reduce the vigor of purple loosestrife. A combination of spraying with a broad-leaf herbicide and subsequent repeated mowing will encourage monocot competitors; with grasses reestablished, the cover can be more easily maintained. These efforts will also suppress a potential source of loosestrife seeds from migrating down the canal. Loosestrife's woody rootstock is the key to its vulnerability to tillage. As an herbaceous perennial, it stores energy in its root crown which lies in the upper 6 inches of the soil. Tillage with disc or harrow is an effective means of grubbing loosestrife rootstalks from fallow fields or open borders where disturbance to the soil or plant community is acceptable. To suppress adventitious shoots arising from broken rootstocks, spot spraying with an herbicide will probably be needed—followed by seeding with native grasses or reed canarygrass.

Other measures—Another way to suppress loosestrife seedlings is to sow Japanese millet on muck beds exposed by an early drawdown. In addition to suppressing loosestrife seedlings, mature emergent millet stands can provide high-quality waterfowl food. This technique would be particularly useful on small areas that are accessible for hand seeding, e.g., waterbird display pools; it would be less useful during drawdowns on large impoundments with scattered emergent stands and many remote muck flats that would be difficult to reach. Plant competition can be used by the wetland manager to slow or even stop the spread of local infestations. Loosestrife seedlings cannot establish or survive in the shade of willow or alder thickets, nor under the canopies of wetland hardwoods. Wetland managers threatened with the invasion of purple loosestrife should be careful not to stress or disturb shrub or tree communities under their care.

Biological Control

Field studies in North America and Europe have identified purple loosestrife as an excellent candidate for biological control. Since 1987, interagency (USDA and USFWS) efforts have been underway for the biological control of purple loosestrife. Thus far, several promising candidate insect control agents have been identified; search and screening for additional agents continue in Europe. Meanwhile, rigorous host specificity tests on a list of cultivated and native plants from North America have begun in Europe on three insect species. Additional screening tests will be performed in quarantine in North America.

Containment

At present, containing the spread of existing infestations is our best strategy. The rate of spread of purple loosestrife between 1940 and 1980 has been estimated to be 1,160 km^2/year (381 mi^2/year). This relatively slow rate of expansion can be further reduced with several countermeasures.

Early detection—Purple loosestrife has several characteristics that can be exploited to slow its spread and impact. First, its tall floral stalks immediately identify an established plant. Second, it is difficult for loosestrife propagules to gain foothold in undisturbed wetland habitat; they need a patch of moist soil that is open to sunlight to establish themselves as seedlings. Last, if an isolated plant somehow becomes established in an otherwise healthy wetland, its seeds will remain dormant and suppressed by surrounding native vegetation—thus giving an alert wetland manager time to eradicate the invader. Managers whose units are within the limits of loosestrife distribution should include an annual search for purple loosestrife in their work schedules. The search need not be highly organized or exclusively pursued, but it is important that it remain among each summer's plans. Annual lowlevel aerial photography can be helpful in maintaining surveillance of loosestrife infestations; scientists in Ohio have constructed infestation maps from 35-mm color transparencies obtained from county Agricultural Stabilization and Conservation Service files.

Local eradication—Wetland managers who are alert to the first appearance of purple loosestrife can successfully follow a program of local eradication. If the infestation occurs as scattered, young plants in soft, organic soil, hand pulling or digging is often feasible; however, since fragments of stem or root crown can regenerate new plants, all pulled material must be carried out of the wetland basin. Wisconsin wetland managers have found that small areas (less than 50 plants), isolated colonies can be eradicated with herbicides delivered from hand-carried sprayers. The herbicide should be applied directly on the weed's foliage. When using glyphosate, great care should be taken to avoid drift onto the weed's nearest neighbors; these plants are needed to close in the space occupied by the dying loosestrife clump. Spraying with glyphosate can be done any time after loosestrife foliage is well developed; however, best results will be obtained with late summer applications. Broadleaf herbicides (2,4-D) are also effective on purple loosestrife; moreover, they offer the advantage of not harming monocots which are loosestrife's most frequent neighbors. Although best results with 2,4-D come from applications in early growth stages (late May to early June), the absence of flower spikes increases the chances that spray crews will overlook some plants. Whatever herbicide is used, the infestation sites should be revisited later in the season, and in subsequent years, to be sure that all loosestrife survivors are eradicated.

Minimum impact management—Until a biological control program can be implemented, the key to coping with established purple loosestrife is to avoid any manipulations or actions that might stress the native vegetation and allow loosestrife seedlings to spring up from dormant seed stocks. The standard waterfowl management practice of early drawdown to encourage smartweed and millet seedlings on shallow impoundment margins is an open invitation to purple loosestrife dominance. Shallow reflooding to provide dabbling duck foraging will often not be sufficiently deep to suppress young loosestrife seedlings. If a drawdown cannot be avoided (for example, a water control structure needs repair), the work should be delayed until mid-July. By this time, the peak of the growing season will have passed and loosestrife seedlings will not have sufficient time to grow to a size that would survive reflooding and overwinter dormancy.

Suggested Reading

Balogh, G. R., and T. A. Bookhout. 1989. Remote detection and measurement of purple loosestrife stands. Wildl. Soc. Bull. 17:66–67.

Henderson, R. 1987. Status and control of purple loosestrife in Wisconsin. Wis. Dep. Nat. Resour., Res. Manage. Findings 4 (July). 4 pp.

Malecki, R. A., and T. J. Rawinski. 1985. New methods for controlling purple loosestrife. N.Y. Fish Game J. 32:9–19.

Rawinski, T. J., and R. A. Malecki. 1984. Ecological relationships among purple loosestrife, cattail and wildlife at the Montezuma National Wildlife Refuge. N.Y. Fish Game J. 31:81–87.

Thompson, D. Q., R. L. Stuckey, and E. B. Thompson. 1987. Spread, impact, and control of purple loosestrife (*Lythrum salicaria*) in North American wetlands. U.S. Fish Wildl. Serv., Fish Wildl. Res. 2. 65 pp.

Wilcox, D. A. 1989. Migration and control of purple loosestrife (*Lythrum salicaria* L.) along highway corridors. Environ. Manage. 13:(in press).

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Alder	*Alnus* sp.
Sedge	*Carex* sp.
Japanese millet	*Echinochloa crusgalli*
Rush	*Juncus* sp.
Duckweed	*Lemna* sp.
Purple loosestrife	*Lythrum salicaria*
Reed canarygrass	*Phalaris arundinacea*
Spruce	*Picea* sp.
Smartweed	*Polygonum* sp.
Willow	*Salix* sp.
Cattail	*Typha* sp.
Animals	
White-tailed deer	*Odocoileus virginianus*
Muskrat	*Ondatra zibethicus*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1989

13.4.12. Control of Phragmites or Common Reed

Diana H. Cross and Karen L. Fleming
Office of Information Transfer
U.S. Fish and Wildlife Service
1025 Pennock Place, Suite 212
Ft. Collins, CO 80524

Phragmites, or common reed, is a perennial grass often associated with wetlands. When phragmites is interspersed with open water or with other vegetation, waterbirds and small mammals find cover among the stems. Its dense root systems strengthen dikes and roads. On many sites, however, this robust emergent forms monotypic, impenetrable stands having little value for waterfowl. Ducks occasionally nest on the edges of large stands, but avoid the dense interior.

Phragmites is native to North America and is found worldwide, primarily in lowland temperate regions. Phragmites can occupy upland sites with seeps, or grow in brackish or fresh water several feet deep. Large monocultures are usually associated with impounded areas and resultant stabilized water regimes. Such sites, having levees or water-control structures that keep large areas moist for long periods, create ideal situations for phragmites to become a problem. The plants are less competitive when there is variation in water levels among wet and dry seasons and years. Growth is often stunted where soil fertility is extremely high or low or where salinity is high. Phragmites usually establishes itself on dry borders of marshes, but frequently invades shallow water foraging sites by outcompeting and subsequently replacing more desirable emergent plants.

Because waterfowl benefit from interspersion of phragmites with other plant species and water, we do not recommend eradication of this plant from wetlands. Instead, phragmites should be controlled only to the degree necessary to achieve management objectives. By understanding the ecology and life history of phragmites, such control is more easily achieved.

Ecology and Life History

Phragmites has a thick stalk that can reach 13 ft (4 m) under optimal conditions. This height is usually not seen until 5–8 years after establishment. The long, flat leaves spread out widely from the stem and are relatively broad, gradually narrowing to a fine tip (Figure). The very high transpiration rate of phragmites is achieved primarily through these leaves. The terminal flower cluster consists of numerous perfect flowers. These flowers, purplish at first, gain long, white silky hairs around them by maturity, creating the large, plumelike flower cluster that persists through winter.

Phragmites most often spreads vegetatively by stout, creeping rhizomes. Fragments of these rhizomes are viable if they have at least two or three nodes and are 8 in. (20 cm) long. All stands have horizontal and vertical rhizomes, and young stands also have long surface runners that aid rapid expansion of the colony. Mature clones normally have a balance of vertical and horizontal rhizomes, while colonizing clones have predominantly horizontal rhizomes. Although these rhizomes are usually 8–39 in. (20–100 cm) below the substrate surface, they can penetrate to twice that distance. Thick

Figure. *Phragmites australis* plant (× ⅓), spikelet and floret (× 3), and rhizome. *Illustration from Hitchcock (1950).*

mud roots with small lateral roots that reach down 3 ft (1 m) or more grow from the horizontal rhizomes.

Vertical rhizomes arise from buds at nodes of horizontal rhizomes. Each upright rhizome bears only one shoot the first year, up to six the second year, and more thereafter. Vertical rhizomes also bear roots that branch and form dense mats.

Although germination from seed does occur, it is not common. Seedling survival is low because sites must remain wet, but not flooded, until seedlings are well established. Furthermore, until rhizomes develop, seedlings are highly susceptible to frost.

Mature stands of phragmites are normally composed of about 8–20 shoots per square foot (80–200 shoots per square meter). In Utah, shoot growth occurs from April to June with little growth occurring in undisturbed plants after June. Stems usually tassel in late summer but may begin to flower as early as mid-July. Plants begin flowering at 3–4 years; in most mature stands, about half of the shoots will bear flower clusters. Shoots die after flowering but most remain standing throughout winter. Seeds generally ripen in late September.

The horizontal rhizomes, which are responsible for the perpetuation of the stand, are where most of the nutrient reserves and plant hormones are stored. Rhizomes grow most rapidly from late summer to early winter. Buds are formed in fall and normally remain dormant in winter. These first buds that emerge, formed when food was abundant the previous summer, are large. The average size of emerging buds decreases through the spring emergent period, which lasts 1–3 months. Buds are also very vulnerable to frost damage. Other spring-formed buds remain below the soil surface, ready to emerge as a replacement crop. These are generally smaller and will form a shorter, denser crop of stems. During the growing season, buds will emerge within a month of any activity that breaks the internal dormancy. Fire and discing are examples of activities that may break this dormancy and stimulate new shoot growth.

Control

Control of phragmites is more easily achieved in areas where growing seasons are short and plant growth is less vigorous. The period of vulnerability will vary with the site and treatment. Control treatments may include spraying herbicides, mowing, discing, bulldozing, crushing, shading, dredging, flooding, draining, burning, and grazing. In many areas, a combination of treatments is most effective. Managers should consider control objectives (i.e., containment, reduction, or elimination) and then choose the most suitable treatment.

After successful treatment other plants will become established in areas formerly dominated by phragmites. These may include many plants attractive as waterfowl food, such as wild millet, smartweeds, rice cutgrass, and wild rice.

Chemical Control

Several herbicides have been used on phragmites with varying degrees of effectiveness. Local conditions and regulations will influence the choice

Table. *Reduction of phragmites effected by three herbicides (data obtained from the literature; citations available upon request).*[a]

Herbicide[b]	Dosage	Time of application	Comments
Amitrole	12 lb/a	summer	increase dosage on wet sites
Amitrole and dalapon	2 lb and 10 lb/a	summer	increase dosage on wet sites
Dalapon	15-30 lb/a	throughout growing season	burned 7–19 weeks before treatment, longer interval more effective
Dalapon	20 lb/a	throughout growing season	most effective in August and September
Dalapon	22.3 lb/a and 10.7 lb/a	September and following May	
Dalapon	12 lb/a and 12 lb/a	May and June	effective through two growing seasons
Dalapon	15 lb/a and 15 lb/a	May and June	effective to third growing season
Glyphosate	4-6 lb/a	June	equally effective applied at 2 lb/a 2 successive years
Glyphosate (Rodeo)	4-6 lb/a	September	lower dosage equally effective
Glyphosate (Rodeo)	4 lb/a	September	applied by helicopter
Glyphosate	10.7 lb/a	late fall	

[a] All treatments considered successful by investigators. Percent reductions are not provided because post-treatment evaluations were not performed at comparable intervals.
[b] Mention of trade names does not imply U.S. Government endorsement.

of herbicides. Systemic herbicides are most effective if applied to actively growing plants, when sugars are being translocated from the leaves to the rhizomes. On moderately wet sites, the period of optimal control occurs from full growth to early fruiting. Aerial application of chemicals should never be undertaken until after waterfowl have completed nesting activities because of possible overdrift. In areas with long, hot summers, spraying may be done as late as mid-September.

Chemical control of phragmites has been achieved most frequently with amitrole, dalapon, and glyphosate (Table). These herbicides are absorbed by the foliage and are translocated to the rhizomes. If the dosage is too concentrated, top kill may occur before the herbicide can be translocated to the rhizome and treatment will not be effective. Care should be taken not to break stems during treatment, as this would also prevent the herbicide from reaching the rhizomes.

Amitrole may be used to effectively control phragmites on flooded and dry sites. Neither dalapon nor glyphosate (as Rodeo, the formulation approved in most States for use in wetlands) are as effective on flooded sites, but they will produce results on moist or dry sites. Rodeo can also be effective when sprayed on senescing shoots during late fall. Several researchers have found that split applications (at 1/2 the dosage) work better than a single, full-strength application. This treatment method is likely to be less stressful to the environment, as well. The second dose should be applied 15–30 days after the first.

Size, accessibility, and proximity of phragmites stands to other vegetation or wetlands dictates the most appropriate application technique. Regardless of method, herbicides must be applied at the dosage prescribed on the label for maximum effectiveness. On smaller beds, backpack spray equipment is sufficient. If areas are very large or are inaccessible from the ground, aerial spraying by an experienced helicopter pilot is suggested. A marker system should be in place before flying transects to maintain a reference point when the tank is refilled. For best results, the same area should be sprayed in 2 successive years, then spot-treated as necessary thereafter. Infrared photographs of treated areas are helpful in locating any missed spots. Equipment used for aerial spraying must be free of leaks and have complete cut-off capabilities to prevent treatment of nontarget areas. The cost of aerial spraying in the late 1980's varied from $30 to $50 per acre; some refuges have taken advantage of State cost-sharing programs or made agreements with the highway department to reduce costs.

Mechanical Control

Mechanical control is difficult, but possible on sites that are flooded or consistently moist. A "cookie cutter" or rotary ditch digger can be used in flooded areas to chop through rhizome-packed substrates, creating openings in dense stands. On drier sites, bulldozers, brushcutters, discs, rototillers, mowers, crushers, and plows can be practical and effective. On unflooded areas, discing is often the most practical method, but crushing repeatedly with rollers also may contribute significantly to phragmites control. Dredging is effective in some situations, but potential effects on wetlands and aesthetic considerations limit its use.

On areas that are dry in late summer, phragmites may be mowed with sicklebar mowers or rotary brush cutters. After 3 consecutive years of summer mowing in Canada, phragmites was replaced by short grass-sedge-sowthistle meadow. Phragmites stands mowed in spring will recover with shorter but more dense growth than the original crop, and will almost always develop fully within the same season. Thus, mowing is most effective in August and September. When beds are too large for annual mowing, wide strips cut through the stands create more edge and make stands more attractive to waterfowl.

Discing in summer or fall reduces stem density, but discing from late winter to midsummer stimulates bud production and results in stands with greater stem density. Discing is more effective than plowing because the chopped rhizome pieces that result are too small to be viable. The most effective time for cutting rhizomes is late in the growing season. Furthermore, in dry areas, rhizome fragments remaining above ground may dry out or freeze, while fragments buried deeply will deplete energy sources before buds reach the surface. Like discing, bulldozing is destructive to phragmites under certain conditions. A latesummer treatment may expose rhizomes to killing winter frosts, provided the area remains unflooded. Dredging removes phragmites from flooded areas, but unless the horizontal rhizomes are removed or the area remains deeply flooded (more than 5 ft or 1.5 m) following dredging, regrowth will almost certainly occur.

Water-level manipulation, where it can be used, is a useful tool for controlling phragmites. Flooding will not alter established stands, but if water levels greater than 12 in. (30 cm) are maintained, colonies will not expand. At these depths, runners are unable to anchor and will float to the surface. Seedlings are easily killed by raising water levels, but timing of water-level manipulations must be carefully determined to be effective and to avoid conflicts with other management objectives.

Draining water from established stands often reduces plant vigor and allows more desirable species to compete, but drying may require several years to degrade a stand. The potential benefits of severe frosts are more likely to be achieved on drained areas. On many wetland areas, however, drainage is neither practical nor desirable.

Abrupt alteration of salinity (e.g., by allowing salt-water intrusion into a coastal impoundment) can be effective if used before stands are well established. However, because phragmites is more salt-tolerant than many other emergents, the saltwater challenge is more likely to hurt competing plants and the freshwater biota than it will phragmites.

Fire used alone as a control measure has variable results depending on intensity of the burn, but is generally most effective in late summer. Generally, winter burning affords no control and often increases densities of spring crops unless a latespring freeze kills new buds. Spring burning without other control treatments is ineffective because the original stand is simply replaced with a more vigorous growth. In fact, burning in spring removes all dead stems and litter and scorches buds, stimulating multiple buds to develop and emerge. Early to midsummer burns are also ineffective because regrowth still replaces the original stand. Burning phragmites late in the growing season reduces stand vigor temporarily because few replacement buds are available. Furthermore, reserve energy is in the rhizomes by then and cannot be used for winter bud production. In dry, peaty areas, late-summer burns kill phragmites roots and rhizomes, creating depressions that may subsequently fill with spring run-off water and be useful to waterfowl.

Biological Control

Biological control is rarely a practical option for controlling phragmites because those organisms known to feed on this plant (moth larvae, aphids, leaf miners, gall midges, rodents, and birds) cause only incidental damage, with a few rare exceptions. American coots consume young shoots in the immediate area of their nests. Considerable damage to phragmites shoots occurs locally by such species as muskrats and nutria, but like coot grazing, this is not an activity under the manager's control.

Controlled grazing has little effect on shoot density, but rhizomes that are repeatedly trampled will bear few shoots and recover slowly when grazing has ceased. If phragmites stands are grazed for 2 years or more, vigor is reduced considerably. Because the amount of grazing required to reduce these stands would be detrimental to desirable plant species as well, grazing is not a recommended control measure on wildlife management areas.

Combining Treatments

On many areas, control of phragmites is achieved most effectively if control treatments are combined. For example, after an area is drained, chemical or mechanical treatments are more easily applied. If an area is drained and then plowed, the resultant short growth is easily treated with chemical sprays. Stands that are drained and then either cut or treated with chemicals may again be flooded to prevent survival of the replacement buds.

Some of the more labor-intensive treatment combinations are even more effective for control. Stands that are mowed, burned, and then disced at least twice will be almost completely removed. The green material from the new growth can be turned under with a heavy disc (32-in. blade) using a 400-hp tractor. This treatment method would likely cost about $35 per acre. The spread of phragmites can be contained by burning in mid- to late summer and then treating the second growth with chemicals. Herbicides must be translocated to the rhizomes to achieve more than a partial kill; therefore, the longer the interval between burning and spraying, the more effective the application.

Phragmites can be controlled, but expansion of stands and vigor returning to treated sites must be monitored closely. Repeated treatments over several years will be necessary. In some situations, it may be more reasonable to prevent stand expansion rather than expect to achieve complete control. Effective control requires an understanding of the plant's growth cycle and the local growing season in order to schedule effective treatments.

Suggested Reading

Haslam, S. M. 1970. The performance of *Phragmites communis* Trin. in relation to water supply. Ann. Bot. 34:867–877.

Haslam, S. M. 1971. Community regulation in *Phragmites communis* Trin. I. Monodominant stands. J. Ecol. 59:65–73.

Hitchcock, A. S. 1950. Manual of the grasses of the United States. 2nd rev. ed. U.S. Dep. Agric. Misc. Publ. 200. Pages 190–191.

Shay, J. M., and C. T. Shay. 1986. Prairie marshes in western Canada, with specific reference to the ecology of five emergent macrophytes. Can. J. Bot. 64:443–454.

van der Toorn, J., and J. H. Mook. 1982. The influence of environmental factors and management on stands of *Phragmites australis*. I. Effects of burning, frost, and insect damage on shoot density and shoot size. J. Appl. Ecol. 19:477–499.

Appendix. Common and Scientific Names of Plants and Animals Named in Text.

Plants	
Sedge	*Carex* sp.
Coast barnyard grasss or wild millet	*Echinochloa walteri*
Rice cutgrass	*Leersia oryzoides*
Phragmites or common reed	*Phragmites australis* (syn *P. communis*)
Smartweed	*Polygonum* sp.
Sowthistle	*Sonchus* sp.
Wild rice	*Zizania aquatica*
Birds and Mammals	
American coot	*Fulica americana*
Nutria	*Myocaster coypus*
Muskrat	*Ondatra zibethicus*

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1989

13.4.13. Management and Control of Cattails

Richard S. Sojda
U.S. Fish and Wildlife Service
Office of Information Transfer
1201 Oak Ridge Drive, Suite 200
Fort Collins, Colorado 80525–5589

and

Kent L. Solberg
Minnesota Department of Natural Resources
306 Power Avenue North
Hinckley, Minnesota 55037

The response of wetland vegetation to management can only be interpreted by considering an intricate mix of physiological, ecological, and temporal factors. Because cattail management is important for many freshwater marshes, the purpose of this leaflet is to present autecological principles for such management.

A 50:50 ratio of open water and vegetation is a frequent objective when managing cattail marshes in North America. When a particular marsh has been extensively flooded for some time and few cattails remain, managers may wish to foster more cattails to develop such hemi-marsh conditions. The reverse is followed when a marsh is dominated by cattails. Hemi-marsh conditions are optimal for breeding migratory birds, including most waterfowl, black and Forster's terns, American coots, and yellow-headed blackbirds. During the nonbreeding season, the life history requirements of migratory birds are not as closely tied to the hemi-marsh conditions. However, such wetlands still provide excellent habitat.

Cattails are prolific and can quickly dominate a wetland plant community. Monotypic stands of cattails have reduced overall habitat value but do benefit some species of wildlife. They provide excellent habitat for wintering white-tailed deer and ring-necked pheasants and habitat for breeding marsh wrens, least bitterns, and various species of blackbirds. However, hemi-marshes also are habitat for these species, too.

Cattails also provide excellent roosting habitat for blackbirds that can severely damage adjacent crops, especially sunflowers in the prairie states. Elimination of the cattail stand removes roosting habitat and can reduce local damage, but the damage is often simply shifted to other areas where the displaced birds create new roosts.

Although the vegetation cycle in prairie marshes is based on the cycle of wet and dry years on the prairies, its basic principles apply to cattail management elsewhere. The cycle of a semipermanent marsh has four stages: dry, regenerating, degenerating, or lake marsh. Identifying the existing stage of a wetland is the first step toward determining the appropriate direction of subsequent management. Generally, all wetlands with cattails in their flora mimic aspects of this prairie marsh cycle. However, certain hydrologic conditions can lengthen the duration of any stage to such an extreme that no cycle is apparent.

There are four species of cattails in North America: the broad-leaved cattail (*Typha latifolia*), common cattail (*T. glauca*), narrow-leaved cattail (*T. angustifolia*), and southern or Dominican cattail (*T. domingensis).* The common cattail is widespread and is thought to be a hybrid between the broad-leaved and the narrow-leaved species. Whether the narrow-leaved cattail is a native, an exotic from Europe, or a hybrid is unclear. The autecological principles for the management of cattails are identical for all species, and minor differences among species are not addressed here. However, in deeper water and in periods of longer inundation, the common cattail has slightly greater vigor than the other species. The acreage of cattail-dominated wetlands in the north-central United States has increased drastically since the early twentieth century. Among the reasons are the increased prevalence of common cattail, sedimentation of wetland basins, and changes in hydrology and land use.

Cattail Autecology and Management Principles

Plant Structures

The cattail rhizome (Fig. 1) supports the plant, stores carbohydrates, and allows the plant to reproduce asexually. The rhizomes begin to elongate in early summer, and annual growth can be 2 feet (0.6 m) or longer under ideal conditions. The next year's stems begin as shoots (Fig. 1) that form on the rhizomes during midsummer. Subsequent shoot growth begins in late winter or early spring and can start even while ice cover remains on the marsh.

The aerenchyma (Fig. 2) provides air passage from the leaves to the rhizomes in cattails and other emergent plants. The structure is functional not only in living leaves but also in standing dead leaves as long as the leaves penetrate the water column and reach air. It is thought that a single leaf can provide oxygen to underground rhizomes for a radius of a few feet from that leaf. Interrupting the function of the aerenchyma is the key to the most effective nonchemical means of controlling cattails.

Germination

Cattails can produce seeds and contribute to the seed bank at all marsh stages, but recruitment occurs only during the dry stage. A single cattail head can contain as many as 250,000 seeds, and almost 1,000 seeds / m^2 may exist in the upper few inches of soil. Viability can approach 100% in the year after production, and seeds in the seed bank can remain viable for as long as 100 years. Cattail seeds, like those of almost all other emergent plants, do not germinate under more than 0.5 inch (1.3 cm) deep water. Light in combination with other environmental factors is critical to germination, and deeper water or shading in dense stands filters out enough light to prevent germination. One of the primary reasons cattails

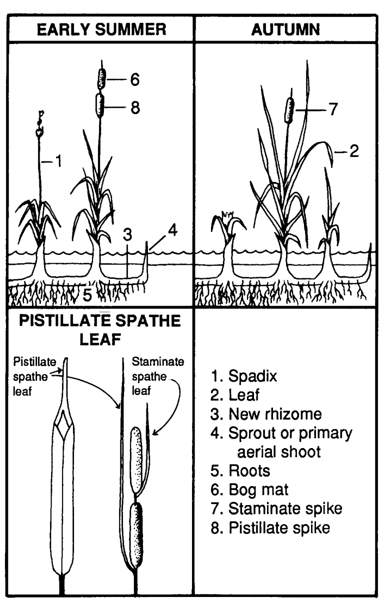


Fig. 1. The structure of a cattail plant: 1. spadix; 2. leaf; 3. new rhizome; 4. shoot or sprout; 5. roots; 6. staminate spike; 7. pistillate spike.

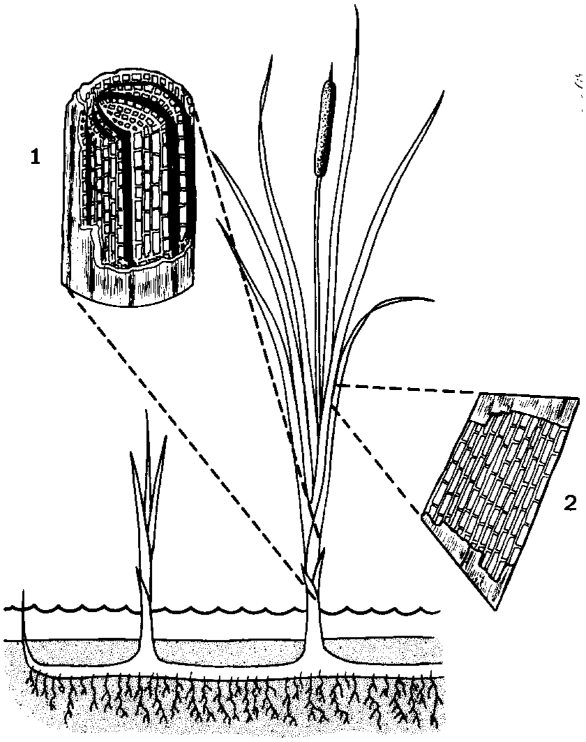


Fig. 2. Aerenchyma provides air passage from leaves to rhizomes. 1. Cross-section of a stem; 2. Longitudinal section of a leaf.

are so prolific is that seeds germinate under a wide range of temperatures if the soil is nearly saturated. The optimum soil–surface temperatures are 77–86^{o} F (25–30^{o} C) and usually occur in the northern United States from early summer to midsummer.

Depending on the successional stage of the marsh, a manager may either foster or obstruct germination of seeds from the seed bank. Because keeping areas flooded with 1 inch (2.5 cm) of water essentially prevents germination, a greater depth is not necessary. Shallow flooding is quick and usually inexpensive. However, shallow flooding of a portion of a wetland can leave a significant expanse of unflooded, saturated soils nearby where cattail germination may flourish. Shallowly flooded areas can become mud flats quickly when rates of evapotranspiration are high. This transition can easily happen in just a few days during warm weather. Knowledge of the bottom contours of a wetland basin allows the judicious use of water to prevent germination.

Carbohydrate Conversion

The control of cattails has to be timed to the annual cycle of carbohydrate storage (Fig. 3). During early spring, the shoots receive their energy for growth primarily from starches stored in the rhizomes. When the conversion of the starches is aerobic, the energy for initiating shoot growth is greatest. Aerobic conditions exist either when the marsh is dry or when standing dead leaves can supply rhizomes with oxygen via the aerenchyma. The depth of water that the shoot can penetrate is not limited in typical semipermanent wetlands when starch conversion is aerobic. If energy reserves are insufficient for the shoot to penetrate the water column, however, the plant dies.

When the conversion of starches is anaerobic, available energy may be limited and the shoot is not able to penetrate the water column. Conditions become anaerobic for the cattail when soils are flooded and the aerenchyma link between leaves and rhizomes is broken. This happens, for example, when a marsh is burned during winter and the remaining stalks are then flooded. The depth of water through which the shoot must grow in spring before it reaches air determines whether the plant has sufficient starch reserves in the rhizomes to survive.

Carbohydrate Storage

In summer when the pistillate spike is lime green and the staminate spike is dark green,

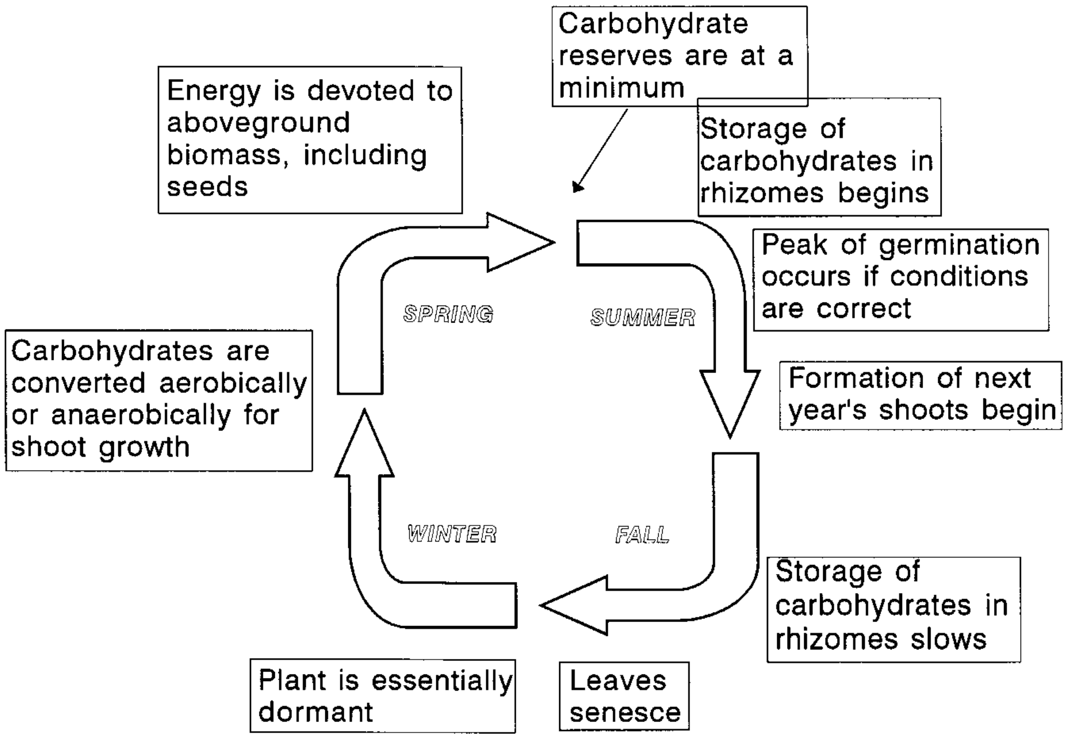


Fig. 3. The annual cycle of growth and carbohydrate storage in cattails.

starch reserves in the rhizomes are at their minimum (Fig. 2). Until this time, the plant has been committing its energy to leaf growth and flower development. Starting in midsummer, the energy is redirected toward building carbohydrate reserves for shoot growth in the following spring. Carbohydrate storage continues until the leaves are senescent. (Linde et al. [1976] provide the most comprehensive documentation of the annual cycle of growth and carbohydrate storage in cattails.)

Control techniques such as grazing and mowing are most effective when the starch reserves of the plant are lowest. Shortening the time during which carbohydrates are stored in the rhizomes does not immediately kill the plant but increases its vulnerability to stress during the subsequent spring.

The vigor of the plant depends principally on its efficient storage of carbohydrates in the rhizomes. Because cattails are adapted to semipermanent water regimes, either deep water or drying of the marsh stresses starch storage. However, cattails are also adapted to a wide range of environmental conditions, and the effects of the stress are subtle.

Effect of Herbivores

Direct mortality of mature cattail plants from muskrats, cattle, and other herbivores is rare. The season of grazing and the water levels in subsequent seasons determine to what degree the removal of the growing plant parts affects plant vigor. Grazing on the mature plant parts impedes carbohydrate storage or conversion. In contrast, grazing can kill seedlings, particularly grazing by Canada geese and greater snow geese that eat nearly the entire seedling. The removal of only aboveground parts can stunt the plant so much it does not survive to reproduce and contribute to the seed bank. When germination of seedlings has created a dense stand, geese may not remove all plants and the combined effects on stand development can be variable.

Hydrologic Changes

Long-term changes in water regimes in a marsh can have either subtle or drastic effects on plant species composition. Because they are best adapted to semipermanent water regimes, cattails can be eliminated by deeper and more permanent water levels. Likewise, a conversion to a drier water regime (e.g., a seasonal marsh) can shift the competitive ecological edge to other species. If drier conditions coincide with soil disturbance, wetlands in many areas of North America can change to being temporarily dominated by annual plants such as smartweeds and wild millets. Concurrent germination of more cattails should be prevented. Long-term plant communities of a drier regime may include *Carex* spp., *Scirpus* spp., perennial smartweeds, and some of the aquatic grasses.

Control Techniques: Why and When They Work

Water Level Control

Water levels should mimic long-term (10- to 20-year) drought cycles of the local area, particularly if the objective is the hemi-marsh stage. The resultant cycle of the marsh will follow the previously mentioned four-stage model.

Drawdowns in summer enhance cattail stem densities by stimulating germination. When cattails are absent, drawdowns in early spring stimulate germination of aquatic annuals such as smartweeds and millet. Then, shallow flooding during summer stimulates the growth of annuals while eliminating germination of cattails.

If indeed the aerenchyma link between rhizome and leaf is broken, high water levels that are above the tops of cattail shoots in spring extend the period during which the plant must anaerobically convert the stored starches to sugars for shoot growth. The depth of water necessary to kill the plant depends on temperatures, the quantity of starch the plant stored the previous year, and the general vigor of the plant. Therefore, no minimum water depth can be prescribed, but a rule of thumb would be to maintain 3–4 feet (0.9–1.2 m) of water over the tops of existing shoots in spring. It is critical to remember that, even if standing dead leaves from last year were completely removed, aerobic conditions are restored to the rhizome as soon as the new growing shoot penetrates the water surface. Cattails are well adapted to growing in anaerobic soil conditions.

If the leaves from the previous years were removed (e.g., by cutting or burning) and water control is effective, cattails can be controlled even if the actual quantity of available water is limited. If water remains only a few inches above the top of the growing shoots and standing dead leaves, oxygen is prevented from reaching the rhizomes. The use of water is efficient if the water level is raised progressively, so that all plant parts remain submerged by no more than a few inches.

Extremely high water levels—in excess of 4 feet (1.2 m)—in late spring and summer, even after the cattails reach their full height, sufficiently stress the plants by reducing the quantities of the stored carbohydrates for subsequent spring growth. However, the physiological mechanism that causes this reduction is poorly understood.

High water levels favor the survival of muskrats in winter. The ideal water depths are probably 4–5 feet (1.2–1.5 m) in most areas. The current marsh stage relative to the desired stage determines the manager’s decision to foster or retard muskrat survival with water levels in winter. Population levels of 10 muskrats / acre (10/0.4 ha) can nearly eliminate cattails in 2 years if combined with high water levels in spring to stress starch conversion in the rhizome. The effect of muskrats on cattail-dominated wetlands can be explained with the described autecological principles. In isolated marshes of the arid West, muskrats can be eliminated by drought, and recolonization can take many years irrespective of subsequent water conditions.

Salinity Alteration

Seawater is used locally to kill cattails in coastal areas in the southeastern United States where historic salt marshes have been impounded and managed as freshwater wetlands. Flooding a marsh during most of the growing season with water of 10 ppt salinity kills cattails. Flooding with sea-strength water for 2 months also kills plants. Water depth is not critical because the salinity directly affects plant physiology. In North America drought or purposeful drawdown can sufficiently increase water or soil salinities, mature plants can be killed, plant growth can be retarded, and germination can be prevented.

Cutting, Crushing, Shearing, and Disking

Cattails can be controlled by cutting, crushing, shearing, or disking. Details about effective water levels relative to shoot height, timing of shoot growth, and timing of control in relation to starch reserves are rarely provided in the literature. Almost no experimental work has been reported.

Cutting, crushing, shearing, and disking during the growing season can be used to impede starch storage. These treatments are effective if done during a 3-week window from 1 week before to 1 week after the pistillate spike is lime green and the staminate spike is dark green. However, the treatments are most effective during the 3–4 days when the spikes are so colored.

Deep disking can retard shoot formation and can damage the rhizomes, but the effect on plant survival is variable. The overall effect on the entire stand is minimal if water conditions are favorable for cattail survival. Control of water levels and of recruitment from the seed bank are necessary to prevent reestablishment of the cattails. Deep disking combined with continued drying and freezing in fall decreases plant survival. If the wetland can be kept sufficiently dry to repetitively disk in any two to three successive seasons, cattails can be eliminated or their stem densities severely reduced. For example, plant survival is significantly reduced if the marsh is disked in fall and again in the following spring and summer. In contrast, little effect is realized from disking alone in three successive falls. The cost of the equipment and personnel for these operations can be extreme. Airborne seeds released during these operations clog the equipment and irritate the operator.

When the plants are dormant, cutting, crushing, shearing, or disking is extremely effective for severing the aerenchyma link between the rhizomes and the leaves. To reduce plant survival, however, these techniques must be combined with high water levels in spring to induce stress from anaerobic starch conversion. Cattails can be cut with a rotary mower or sheared with a front-end loader on a tractor when equipment can be driven on ice, but airborne seeds are a nuisance. Subsequent water levels in spring must still inundate the cut stalks.

Bulldozer and Cookie Cutter

Bulldozers and cookie cutters remove plants from the local area of the marsh and can—sometimes inadvertently—alter wetland basin morphology. The desirability of the potential effect depends on the management objectives, permits, and other legal requirements. The control of cattails with a bulldozer or cookie cutter is the most expensive option. However, floating cattail mats cannot be removed with any other equipment.

The seed bank and the conditions for germination determine the floristic composition of the marsh after the next drawdown, whether dewatering is natural or controlled. If the seed bank is dominated by cattails, the effect of a bulldozer or cookie cutter may be short-lived. Alternatively, a depauperate seed bank may also result in an undesirable plant community. The domino effect of this may be a reduction of the diversity and abundance of invertebrates and a consequent lack of food for shorebirds, ducks, and other species. Creating deeper and possibly permanent water areas also creates better habitat for muskrats and minks.

Grazing

Grazing by cows, geese, muskrats, and other animals on seedling and young cattails without extensive rhizomes can remove entire plants, reducing stem densities or eliminating stands. Grazing on mature plants in association with proper water-level management reduces the survival of cattails through the combined effects of severing the aerenchyma link between the rhizomes and leaves and stressing the storage and conversion of starches. To minimize starch storage, cattails should be heavily grazed by cattle during the 3-week period centered on the time when the pistillate spike is lime green and the staminate spike is dark green.

Prescribed Burning

Burning cattails is difficult during the growing season, except during extreme low-water conditions. Dry residual cattail litter provides enough fuel to carry a fire through growing plants. The fire usually does not kill the plants but can stress starch storage. Fires in cattail marshes rarely are hot enough at ground level for heat penetration to impede rhizome function or shoot viability.

Most cattail marshes must be burned in winter or before significant growth has occurred in spring when fuels are dry enough to carry a fire. However, frozen or saturated soils can hamper the progress of the fire through cattail duff. When combined with high water levels in spring to smother the residual stalks, fire can be used to control cattails.

Prescribed burning can be used for cattail control even in wetlands where control of water levels is not always possible and the manager must rely on precipitation in spring for flooding. Cattails can be burned when water levels are naturally low in fall and winter. If water levels are high during the next spring, they force anaerobic conversion of starches in the rhizomes. Spring weather obviously is not known during the preceding fall, but dry falls followed by ample rain and high water levels in spring are not unusual in many parts of North America.

In wetlands with well developed peat soils, fires during drought conditions can destroy the entire cattail plant including the rhizomes. Such fires actually burn the peat, and the ability to smother the fire by reflooding the marsh must exist before prescribing such fires. Peat fires can also eliminate the existing seed bank and, if sufficiently severe, lower the relative bottom of a marsh. Local concern with the effects of peat fires on air quality can be substantial. In some locations (e.g., Minnesota), regulations prohibit the purposeful ignition of peat.

Fire prescriptions for cattail marshes should not solely address fire control but the ecological effects of fires at different intensities, at different seasons, and under different environmental conditions. Moreover, planned fires must be combined with water management that ultimately controls the cattails.

Herbicides

Herbicides, especially glyphosate, interrupt metabolic pathways and have been used successfully to kill cattails. Herbicides that are translocated to the rhizomes are most effective for cattail control. Application in mid- to late summer when carbohydrates are stored enhances the effectiveness of translocated herbicides. Therefore, herbicides have little effect on seed production during the year of application. If not all cattails are killed, a hemi-marsh is created, but surviving cattails can spread quickly and eliminate this effect if water levels cannot be manipulated. As with other techniques, the duration of the effect of herbicides depends on subsequent water-level control and recruitment from the seed bank.

The public and natural resource agencies are concerned about the use of herbicides in aquatic systems. Herbicides for the control of cattails should readily degrade in water, soil, or substrate. Glyphosate applied at label rates seems relatively safe for waterfowl and aquatic invertebrates. Habitat alteration from herbicide application, as from other cattail removal techniques, may reduce the distribution and abundance of invertebrates.

Herbicides can be expensive, although the cost of the application is a minor portion of the total cost. Aerial application can be the most efficient technique for managing cattails over a large area or over several smaller, inaccessible locations. Boom or wick applications are useful for small areas accessible by ground or airboat and when pesticide drift is a concern.

Permits

Many of the described control techniques require permits from local, state, or federal authorities.

Suggested Reading

Ball, J. P. 1990. Influence of subsequent flooding depth on cattail control by burning and mowing. Journal of Aquatic Plant Management 28:32–36.

Kadlec, J. A. 1992. Habitat management for breeding areas. Pages 590–610 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankeny, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, editors. Ecology and management of breeding waterfowl. University of Minnesota Press, Minneapolis.

Kantrud, H. A., J. B. Millar, and A. G. van der Valk. 1989. Vegetation of wetlands of the prairie pothole region. Pages 132–187 *in* A. G. van der Valk. Northern prairie wetlands. Iowa State University Press, Ames.

Linde, A. F., T. Janisch, and D. Smith. 1976. Cattail—the significance of its growth, phenology and carbohydrate storage to its control and management. Wisconsin Department of Natural Resources Technical Bulletin 94. 27 pp.

van der Valk, A. G. 1981. Succession in wetlands: a Gleasonian approach. Ecology 62:688–696.

Weller, M. W., and L. H. Fredrickson. 1974. Avian ecology of a managed glacial marsh. Living Bird 12:269–291.

Appendix. Common and Scientific Names of the Plants and Animals Named in the Text.

Plants

Sedges	*Carex* spp.
Wild millets	*Echinochloa* spp.
Smartweeds	*Polygonum* spp.
Bulrushes	*Scirpus* spp.
Cattails	*Typha* spp.

Animals

Canada goose	*Branta canadensis*
Greater snow goose	*Chen caerulescens atlantica*
Black tern	*Chlidonias niger*
Marsh wren	*Cistothorus palustris*
American coot	*Fulica americana*
Least bittern	*Ixobrychus exilis*
Mink	*Mustela vison*
White-tailed deer	*Odocoileus virginianus*
Muskrat	*Ondatra zibethicus*
Ring-necked pheasant	*Phasianus colchicus*
Forster's tern	*Sterna forsteri*
Yellow-headed blackbird	*Xanthocephalus xanthocephalus*

Note: Use of trade names does not imply U.S. Government endorsement of commercial products.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1993

13.4.18. Chufa Biology and Management

James R. Kelley, Jr., and Leigh H. Fredrickson
Gaylord Memorial Laboratory
The School of Natural Resources
University of Missouri–Columbia
Puxico, MO 63960

Introduction

Chufa (*Cyperus esculentus*) is an emergent perennial sedge that is common in seasonally flooded wetlands. Although chufa is common in many States, it is most abundant in the Southeast, including the Mississippi alluvial valley (Fig. 1). Belowground biomass of chufa, especially the tubers, serves as a valuable food source for waterfowl and cranes. Chufa tubers rank tenth among the most important waterfowl foods in the United States.

Identification

Other common names for chufa are yellow nutsedge, nutgrass, and ground almond. Plants are 8 inches to 3 feet tall and have 3-sided stems (Fig. 2). Leaves are bright green on emergence but become pale green as plants mature. Leaves are 0.2–0.4 inches wide and ribbonlike. The main stem terminates in an inflorescence that has 3–9 leaflike bracts, 2–10 inches long, at its base. The inflorescence comprises 5–10 stalks with strongly flattened spikes that are up to 1.25 inches long and yellow or golden-brown. The seeds are 3-sided, elliptical, rounded at the end, and 0.04–0.06 inches (1.2–1.5 mm) in length. Mature tubers are tan or black, sphere-shaped, and 0.2–0.4 inches long. Newly formed tubers are white.

Nutritional Value

Chufa tubers are an important, high-energy food for birds. The caloric density of tubers averages 4.26 kcal/g. Approximately 45% of the fresh weight of tubers is water. The major components of the dry weight of tubers are carbohydrate (58%), lipid (10%), protein (7%), and ash (3%). The major fatty acid in tubers is oleic (61% of total fatty acids), while other fatty acids include linoleic (24%), palmitic (12%), and stearic (2%).

Life History

Reproduction and Growth

Reproduction from seed is relatively unimportant. Seed production is variable and on some sites only a few or no seeds are produced, whereas heavy seed production occurs on other sites. Seeds often are inviable and seedlings produced from seed are usually weak. Sprouting from tubers is the primary mode of reproduction by chufa, and potential production from tubers is high. For example, in 1 year a single tuber in Minnesota produced 1,900 plants and 6,900 tubers.

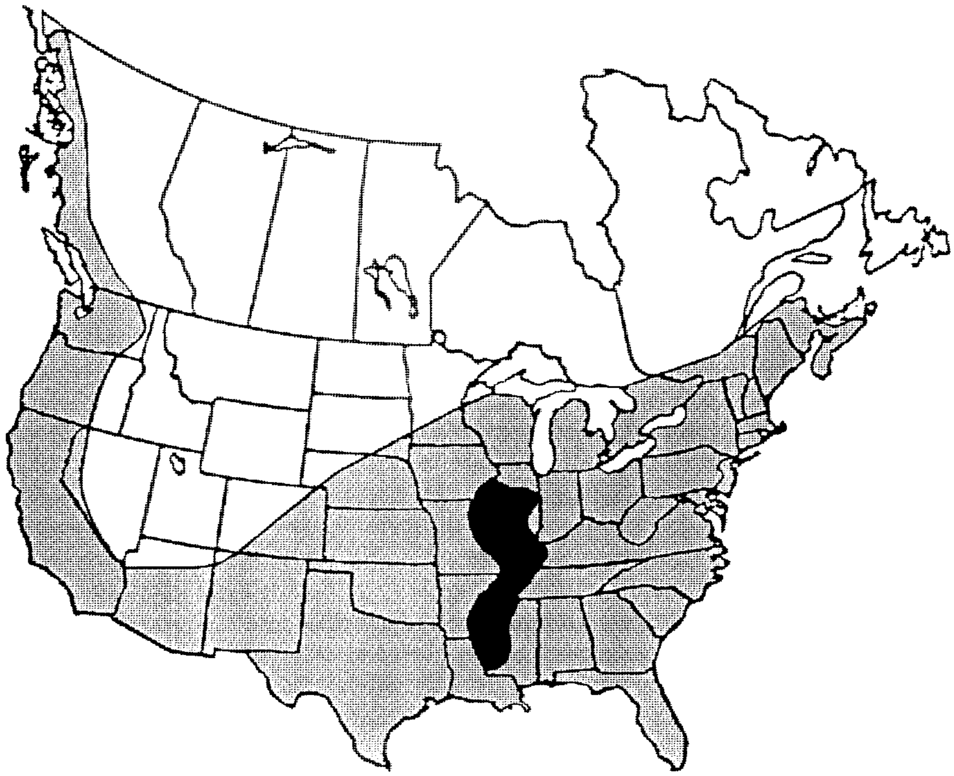


Fig. 1. Distribution of chufa in North America, showing principal range (*light shaded areas*) and areas of greatest abundance (*dark shading*).

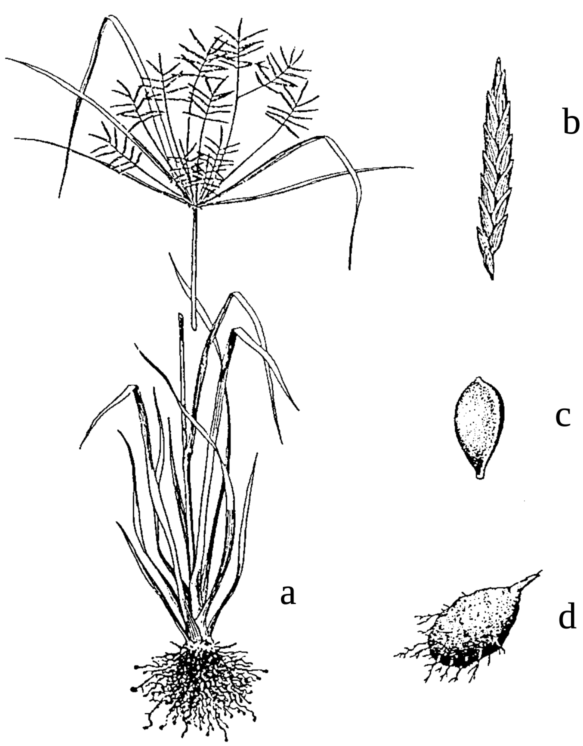


Fig. 2. Identifying characteristics of chufa: **a**) entire plant, **b**) spikelet, **c**) seed, and **d**) tuber.

Mature tubers have 5–7 buds, located in the axils of scale leaves. In spring, two buds usually sprout and form rhizomes. Removal of sprouts from tubers induces additional buds to sprout. Elongating rhizomes are indeterminate, underground stems that terminate in a bud that either forms a new tuber or a basal bulb. Basal bulbs produce leaves that elongate to form aerial shoots.

In wetland areas, the timing of shoot emergence is dependent on drawdown date. Removal of surface water stimulates sprouting of tubers, and shoots begin to emerge within a few days after surface water removal. Stem densities increase rapidly following drawdown, and peaks in aboveground biomass occur as soon as 40 days after drawdown (Fig. 3).

Production of new tubers occurs as soon as 18 days after drawdown. Tubers are formed throughout the growing season; however, most tuber development occurs within the first month after shoot emergence. Belowground biomass production peaks approximately 1 month after aboveground biomass has reached its peak (Fig. 3). At the end of the growing season, 85% of belowground biomass is composed of tubers. Tubers regularly survive winter conditions whereas aerial shoots, basal bulbs, and rhizomes rarely survive from one growing season to the next. Tubers can remain dormant for up to 3.5 years. Dormancy is broken by leaching of a growth inhibitor (abscisic acid) from tubers or by physical damage to tubers.

Soil Requirements

Chufa grows well in a variety of soil conditions: clay, clay loam, silty clay, loam, sandy gravel, and sand. Production is often greatest on silty clay soils and lowest in sand. Soils with pH values between 5.0 and 7.5 give the best production.

Temperature

The minimum temperature required for sprouting of tubers in the laboratory is 12° C

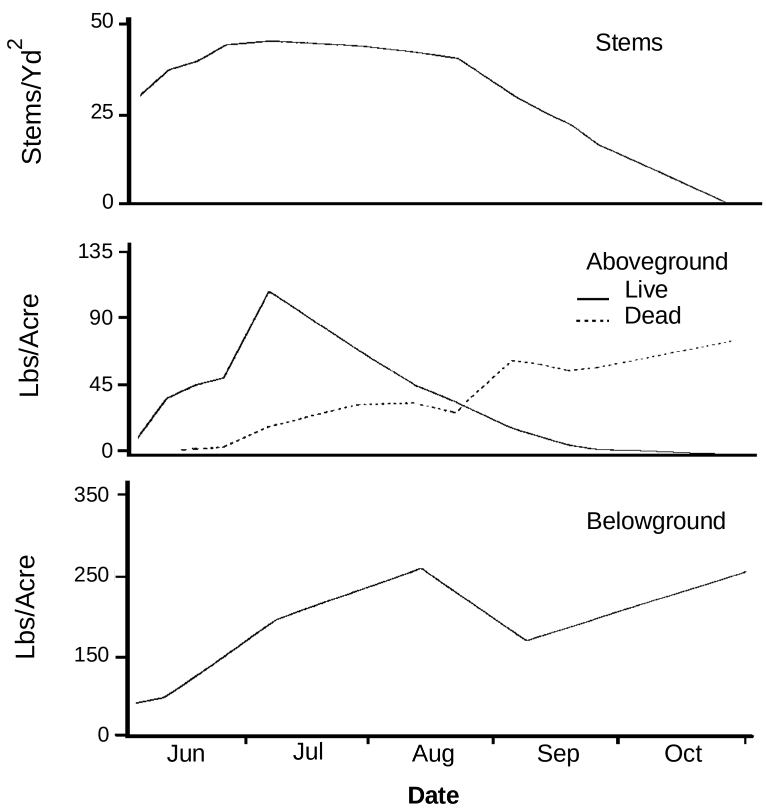


Fig. 3. Stem density (stems per square yard), live and dead aboveground biomass (pounds per acre), and total belowground biomass (pounds per acre) of chufa following a 27 May drawdown in southeast Missouri.

(54° F). Little is known about optimum temperature for sprouting in the field. Tubers can withstand winter soil temperatures of –7 to –10° C (14 to 19° F), but survival is greatest at temperatures above –4° C (25° F).

Moisture

Chufa is adapted to seasonally flooded environments. Emergence begins as soil temperatures increase following exposure of soil surfaces during drawdown. Maximum tuber production occurs in soils that remain moist or when stands are irrigated. Chufa can withstand temporary flooding if the plants are not completely covered with water. Prolonged flooding during the growing season is not recommended. Drought conditions severely reduce tuber production and cause mortality.

Light

Chufa competes poorly with other plants because of its light requirements. As little as 30% shade can reduce dry-matter production by 32%. The quick emergence and rapid growth of chufa allows plants to mature and produce tubers before being subjected to shading by other plant species. The early senescence of chufa often makes it difficult to detect at the time of fall flooding because most of the aboveground parts have decomposed.

Management Techniques

Soil Manipulations

Because most wetland management schemes are directed toward seed production, little information is published concerning manipulations that enhance tuber production. If chufa is present in the seed or bud bank of a seasonally flooded site, some tuber production likely will occur in the absence of active manipulations, depending on the growing conditions and other factors, such as soil disturbance by feeding waterfowl. However, chufa production may be enhanced by proper soil disturbance (e.g., disking or plowing), which is often used to eliminate woody growth and undesirable perennials in managed wetlands. Shallow (2–4 inches) disking detaches many chufa tubers from parent plants, which causes tubers to sprout and develop as additional plants (Fig. 4). Following disking, many parent plants remain on the surface, reestablish themselves, and continue tuber production. Disking scarifies some of the dormant tubers and induces sprouting. Sites should be irrigated after disking to prevent desiccation of tubers and parent plants. If irrigation is not possible after disking and dry conditions prevail, tuber production will be low because of poor growing conditions. However, the soil disturbance for chufa production is not wasted because the effects of disking carry over to the

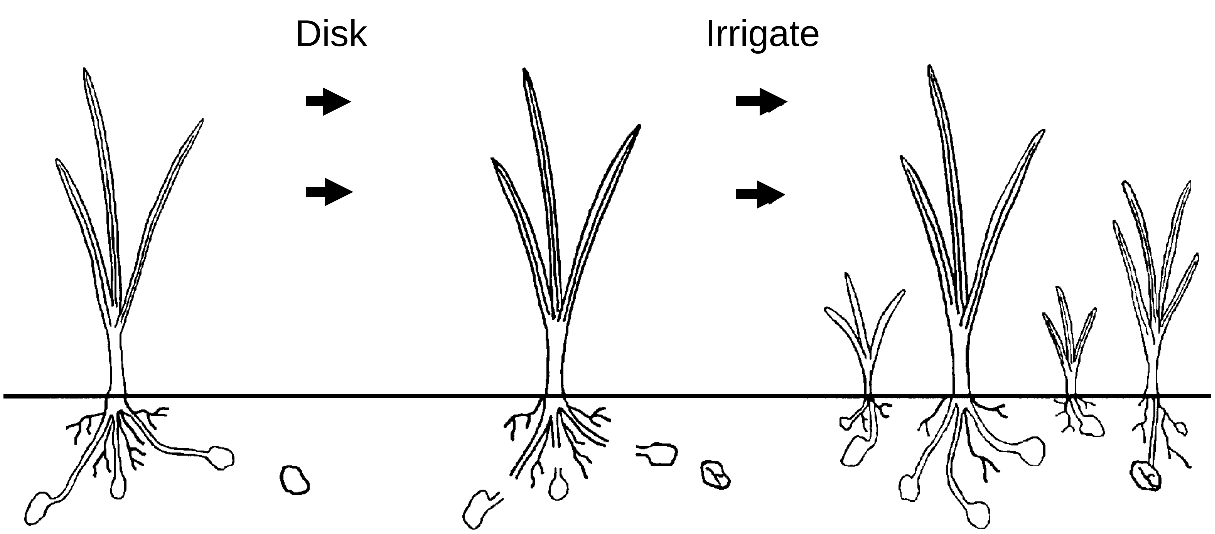


Fig. 4. Use of shallow disking and irrigation to stimulate additional sprouting of active and dormant chufa tubers to increase waterfowl food production.

following year. Thus, chufa production may be enhanced in the next growing season. Shallow disking may not be feasible over entire management units if eradication of severe vegetation problems requires deep disking. In situations where there is a history of good chufa production, deep disking might be restricted to patches of undesirable vegetation. Sites lacking vegetation problems, or where undesirable vegetation is less dense, might be shallowly disked. Because deep disking buries many parent chufa plants and results in low tuber production, whereas shallow disking stimulates tuber production, each management scenario can be expected to result in major differences in chufa production (Fig. 5.; Table 1).

Plantings

Most planting of chufa occurs on upland areas in the Southeast for wild turkey (*Meleagris gallopavo*) food production. If chufa is desired on wetland sites that contain no natural growth, propagation can be initiated by broadcasting tubers. Chufa tubers are available from wholesale seed companies, which generally sell them in 100-pound bags. A slow, early- to midseason (1 March–15 June) drawdown should be part of site preparation for planting. While sheet water is still present, tubers should be broadcast at the rate of 50 pounds per acre over sites lacking standing vegetation. Tubers will sprout when surface water recedes. Once established, additional plantings generally are not necessary. Grazing should be restricted when tubers are planted because cattle and hogs consume chufa tubers.

Availability to Birds

Waterfowl have unusual abilities to locate belowground tubers. By the time management units are flooded in fall, there is little evidence of aboveground parts. Nevertheless, waterfowl and cranes consistently locate and consume tubers. The availability of tubers for waterbirds is influenced by water depth. The majority of tubers are near the soil surface at a depth of 0–4 inches (Table 2). Thus, optimal water depth for dabbler utilization of tubers is 2–8 inches. Disking tends to loosen soil sediments and makes foraging for tubers easier for birds. When birds forage intensively on sites with good tuber production, they cause soil disturbance that is as effective as shallow disking. During the subsequent growing season such sites have the potential for good tuber production.

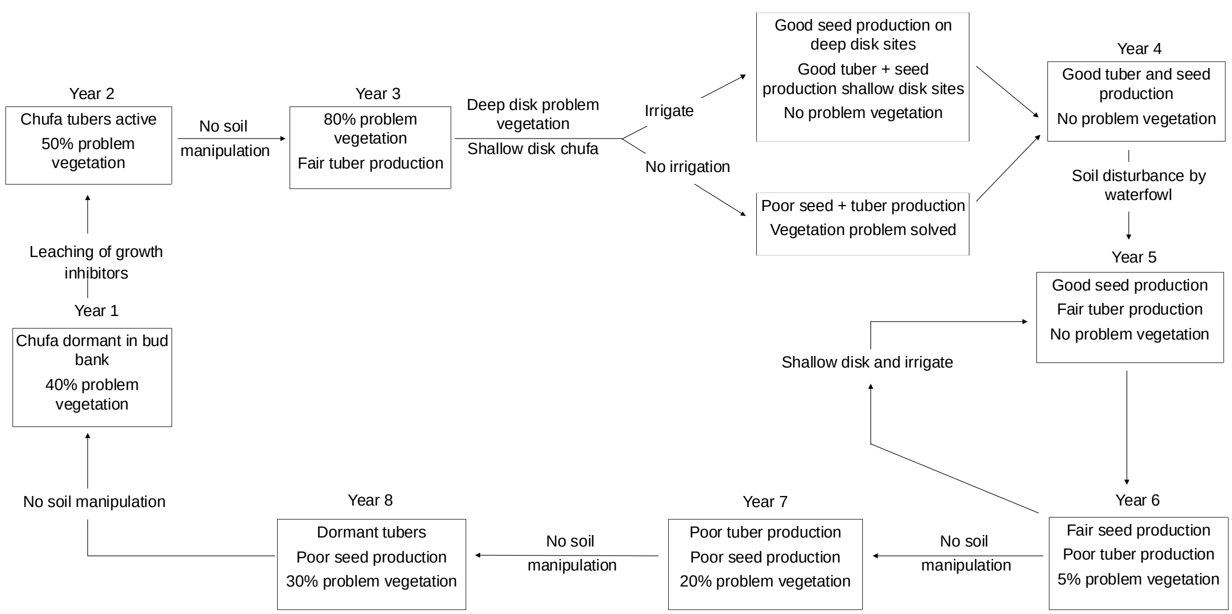


Fig. 5. Long-term conditions and manipulations to enhance chufa tuber production in a seasonally flooded impoundment. The flow chart illustrates the effects of no soil disturbance and how disking influences chufa tuber production and the control of undesirable vegetation. Problem vegetation refers to undesirable woody species and robust non-seed-producing perennials.

Table 1. *Chufa (*Cyperus esculentus*) belowground production (pounds per acre) following implementation of six different management scenarios involving combinations of disking depth and irrigation.*

	Disking treatment		
	No disk	Shallow (2 inches)	Deep (6 inches)
Irrigation after disking	159	327	13
No irrigation	144	62	26

Table 2. *Depth distribution of chufa (*Cyperus esculentus*) tubers in the soil profile.*

	Depth (inches)		
	0–2	2–4	4+
Percent of tubers	48	43	9
Percent of dry weight	25	62	13

Suggested Reading

Fredrickson, L. H., and T. S. Taylor. 1982. Management of seasonally flooded impoundments for wildlife. U.S. Fish Wildl. Serv., Resour. Publ. 148. 29 pp.

Kelley, J. R., Jr. 1990. Biomass production of chufa (*Cyperus esculentus*) in a seasonally flooded wetland. Wetlands 10:61–67.

Mitchell, W. A., and C. O. Martin. 1986. Chufa (*Cyperus esculentus*): Section 7.4.1, U. S. Army Corps of Engineers Wildlife Resources Management Manual, Technical Report EL-86-22. U.S. Army Corps Eng. Waterways Exp. Stn., Vicksburg, Miss.

Mulligan, G. A., and B. E. Junkins. 1976. The biology of Canadian weeds. 17. *Cyperus esculentus* L. Can. J. Plant Sci. 56:339–350.

Stoller, E. W., D. P. Nema, and V. M. Bhan. 1972. Yellow nutsedge tuber germination and seedling development. Weed Sci. 20:93–97.

Wills, D. 1971. Chufa tuber production and its relationship to waterfowl management on Catahoula Lake, Louisiana. Proc. Annu. Conf. Southeast. Assoc. Game Fish Comm. 24:146–153.

UNITED STATES DEPARTMENT OF THE INTERIOR
FISH AND WILDLIFE SERVICE
***Fish and Wildlife Leaflet* 13**
Washington, D.C. • 1991

Great Trinity Forest Management Plan

Wetlands

Focus on Fusconaia

	The Dragonflyer
	Volume 13 March—April 2007

The Dragonflyer

Inside this issue:

Focus on Fusconaia

by Jim Flood

That's "foos-cuh-nay'-uh" or in common vernacular Pig-Toe! I'm talking about a Freshwater Mussel.

Photo 1

Kingdom: Animalia
Class: Bivalvia
Order: Unionoida
Family: Unionidae
Genus: Fusconaia

The distribution and occurrence of this freshwater mussel has now been expanded to include the upper Trinity River in Dallas County thanks to a Master Naturalist project of freshwater mussel monitoring.

This genus Fusconaia has never been observed or collected in Dallas County until our October 2005 North Texas Chapter Master Naturalist's Freshwater Mussel field trip along the Trinity River made that discovery. Our report that was submitted to TPWD for this Mussel Watch canoe trip along the Trinity between Sylvan Ave and Loop 12 listed about 10 native species of Freshwater Mussel. One of these that was observed was ID'd as a Wabash Pig-Toe or Fusconaia flava. We found one intact clamped-shut shell that was in the gravel submerged in flowing water along a mid-stream gravel bar (photo 3) and collected several whole "recently dead" shells one measuring about 95 mm in length (photo 2). We photographed the live one (photo 1) and quickly returned it to the water. (In 2006 Tim Dalbey picked up a specimen of Fusconaia from the Trinity River near the Sylvan Ave boat ramp and that one opened and shut it's valves and squirted out water in a tell-tale fashion of bivalve "behavior")

I'm not sure how long a mussel can survive out of water but they siphon water from the ponds, lakes and rivers in which they reside and pass that water over its gills to breathe and then filter-feed algae for sustenance and pass that through a digestive system that includes a stomach and intestine. Mussels also have a kidney and a 3-chambered heart! The visceral anatomy of a mussel also includes a tough but delectable, at least to the early native Americans, muscular foot.

Photo 2

(Continued on page 3)

Trout Lily
Erythronium albidum

Beautiful Heralds of Spring

Photos taken by Rose Banzhaf at Spring Creek Forest

Amazingly this Oct 2005 Trinity field trip was our first organized Mussel Watch Field Trip. We've had two more since then, one on the West Fork Trinity (Nov 2005) and another at Lavon Lake in July 2006.

The Lavon Lake trip resulted in an observation of about 6 different native species totaling a count along 190 meters of shoreline of about 114 whole shells and 85 half shells or valves. Most of these were dead or near-dead (finding some clamped shut but out of water, we returned these to the receding lake) due to a major drop in the water level which exposed vast areas of normally submerged shoreline. The raccoons and herons would feed on these die-offs leaving behind opened pristine shells scattered by the thousands.


Photo 3

The Oct 2005 ID and report of Fusconaia in the Trinity attracted the attention of TPWD's Marsha May (formerly Reimer) with Texas Nature Trackers and Robert G. Howells who co-authored the book Texas Freshwater Mussels[1]. They initially had doubts about the ID and in January 2007 asked for a specimen. I sent them a specimen (photo 2) from our Oct 2005 collection and here is what Robert Howells said: "My best guess is about 70% for F. askewi and 30% for F. flava . . . For a long time, it appeared that both Fusconaia and Pleurobema had been lost in the Trinity. Then , in the late 90's, Mather and Bergmann found living Fusconaia at a site just upstream of Lake Livingston (north of Houston and east of Huntsville). These too were atypical, but I lean to suspecting they were an odd ecophenotype of Fusconaia askewi. So far, even DNA work has been unproductive with Fusconaia and Pleurobema on the southwestern edge of their ranges (TX, AR, etc)."

So I'm satisfied with a 70% determination for Fusconaia askewi or the Texas Pigtoe!

How do native freshwater mussels travel long distances or expand their range. The key are fish. Fish hosts! The reproduction of Freshwater Mussels involves a larval stage glochidium. These glochidium begin as fertilized eggs retained in the female's brood pouch. They then develop and when released they hitch a parasitic ride (just for a few weeks) on host fish gills or fins. What species fish and whether the ride is gill or fin depends upon the species of mussel. These glochidia can be very small from 0.005mm to 0.3mm. Despite their miniscule size structurally the glochidia are hinged bivalves with an adductor muscle.

I am amazed at what already is known by science but there is still much mystery, still much to be discovered. We Master Naturalists can play a role in that discovery.

While Freshwater Mussels have inhabited the earth for 400 million years the nearly 300 North American species are our most endangered fauna.

In this era of extinction of indigenous species and the expansion of invasive species the find of Fusconaia in the upper Trinity River is certainly good news.

The year 2007 will be another one for continuing field trips in north Texas in search of freshwater mussels and now with a special focus on Fusconaia.

[1] Freshwater Mussels of Texas, R.G. Howells, R.W. Neck, H.D. Murray, Texas Parks and Wildlife Department, Inland Fisheries Division, 1996.

Great Trinity Forest Management Plan

Wetlands

Mussels Make Good Habitat!

What's in a name?

A paper published in 2006 proposed giving several of our common Texas species a new genus name. Although these changes are not yet in widespread use, you might run into the following changes:

- Gulf Coast Toad (formerly *Bufo valliceps*; now *Cranopsis nebulifer*)
- Marine Toad (formerly *Bufo*; now *Chaunus*)
- All other toads (formerly *Bufo*; now *Anaxyrus*)
- Chirping frogs (formerly *Eleutherodactylus*; now returned to *Syrrhophus*)
- Barking frog (formerly *Eleutherodactylus*; now *Craugaster*)
- All Ranids (formerly *Rana*; now *Lithobates*)

When in doubt, just give us your best description of the species and its name, and we'll make sure it goes into the correct category!!

Mussels Make Good Habitat!

Marsha E. May, Texas Nature Tracker Biologist

At the 2007 Freshwater Mollusk Conservation Society Workshop and Symposium in Little Rock, Arkansas, a paper was presented on the importance of mussels in the aquatic ecosystem. Dr. Caryn C. Vaughn spoke about the research that she and Daniel E. Spooner published in 2006. They found that where there are beds of native freshwater mussels, there also are many benthic macroinvertebrates! Benthic macroinvertebrates are very small animals without backbones (invertebrates) that live in the river bottom on rocks, logs, sediment, debris and aquatic plants during some time in their lives. These animals include crayfish, snails, worms, aquatic insects and the larvae of mayflies, damselflies and dragonflies. They play a very important role in the aquatic food chain.

Caryn C. Vaughn and Daniel E. Spooner of the Oklahoma Biological Survey and Department of Zoology, University of Oklahoma, published their work "Unionid mussels influence macroinvertebrate assemblage structure in streams" in the 2006 *Journal of the North American Benthological Society*. They compared benthic macroinvertebrate densities in mussel beds in 30 study sites and 10 patches or quadrats per study site in eight streams in Arkansas and Oklahoma. They found that macroinvertebrate densities were significantly higher in patches containing mussels than in patches without mussels. Therefore, mussel density was positively correlated with macroinvertebrate density across the 300 quadrats. Vaughn and Spooner (2006) stated that mussels probably assist macroinvertebrate production by creating biogenic structure, stabilizing stream sediments, and providing food resources.

In another study, "Context-dependent effects of freshwater mussels on stream benthic communities," which Daniel E. Spooner and Caryn C. Vaughn published in the 2006 *Freshwater Biology Journal*, they looked at the influence of unionid mussels on the distribution and abundance of benthic algae and invertebrates. In this study they conducted an experiment in the Kiamichi River in Oklahoma, where they compared the benthic community in live mussel beds versus just the presence of mussel shells and also a mussel-free control. Spooner and Vaughn (2006) found that the algae and invertebrate abundance was higher in the live mussel beds than in either the mussel shells or mussel-free control areas. They suggest that the invertebrates were responding to higher levels of organic matter and nutrients deposited by the live mussels. Also they concluded that the invertebrates were responding to the increased amount of algae on live mussels as food and/or shelter.

Therefore, not only are freshwater mussels good habitat for benthic macroinvertebrates, but their filter feeding cleans the water of detritus and bacteria, and they are an important food source for many aquatic and terrestrial animals. There are about 53 species of freshwater mussels in Texas, and six species can only be found in Texas. About 38 percent of those 53 species are thought to be in danger of becoming extinct. These amazing creatures are very sensitive to changes in their environment such as siltation from construction sites, pollutants, river flow alterations, and salinity.

Texas Mussel Watch volunteers help by monitoring populations of these incredibly beautiful and increasingly rare species and helping biologists map out their distributions. To learn more about these amazing creatures and a program called Texas Mussel Watch, please check out this Web site: www.tpwd.state.tx.us/mussels.

Great Trinity Forest Management Plan

Wetlands

2006 Texas Mussel Watch

2006 Texas Mussel Watch

Marsha E. May, Texas Nature Tracker Biologist

What a great year for Texas Mussel Watch! More volunteers monitored mussels then ever before (see Figure 1). Since Texas Mussel Watch (TMN) began in 1999, 75 volunteers have participated in monitoring mussels in Texas. A special **thank you** goes out to **Ronald Rushing,** who has monitored the Navasota River with his science camp students for five years running; and to **Mike McKay** and **Allen Bartell**, who have involved Texas students in monitoring mussels in Hubbard Creek Lake and Lake Livingston, respectively, for four years.

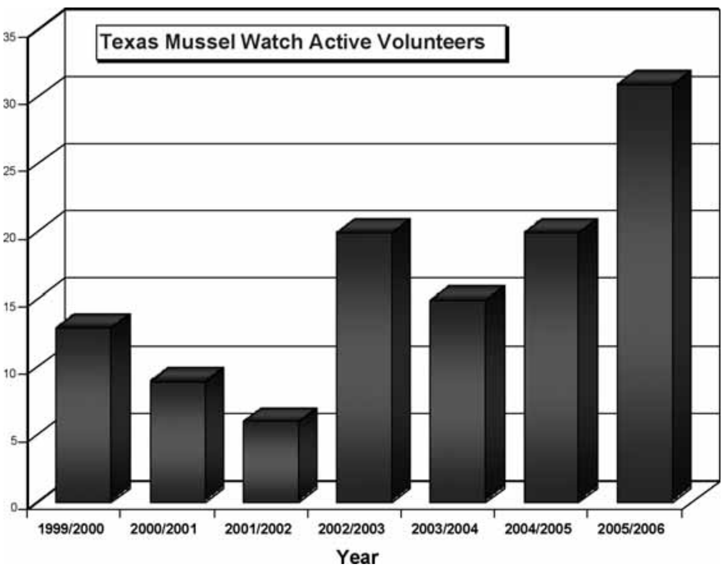


Figure 1. Number of Texas Mussel Watch volunteers who contributed data throughout the years.

Locations within nine Texas drainage basins in 21 counties (see Figure 2) were examined for freshwater mussel species by 33 TMW volunteers, students from Ronald Rushing's Summer Science Camp, Houston ISD's Outdoor Education Center students taught by Allen Bartell, students from Mike McKay's Texas State Technical College Environmental Biology Class, and three TMW workshops. A total of 26 out of 53 Texas native freshwater mussels were observed. The Trinity River drainage basin had the greatest number of species, with a total of 19. Asian clams (*Corbicula fluminea*) were recorded in 17 out of 21 counties and no zebra mussels (*Dreissena polymorpha*) observed.

Eight species on the Special Animal List by the Texas Biological and Conservation Data System were recorded by TMW monitors:

- **rock pocketbook** (*Arcidens confragosus*) – Trinity River
- **pigtoe species** (either *Fusconaia flava* or *F. askewi*) – Trinity River
- **smooth pimpleback** (*Quadrula houstonensis*) – Colorado, Brazos and Navasota River
- **pistolgrip** (*Tritogonia [Quadrula] verrucosa*) – Trinity and Brazos River
- **Texas fawnsfoot** (*Truncilla macrodon*) – Brazos River
- **little spectaclecase** (*Villosa lienosa*) – San Jacinto River

We would like to thank every one of our Texas Mussel Watch volunteers for bestowing their precious time and energy by mucking around in the lakes, rivers, and creeks collecting data on these wonderful creatures.

PHOTO: ©MARSHA MAY

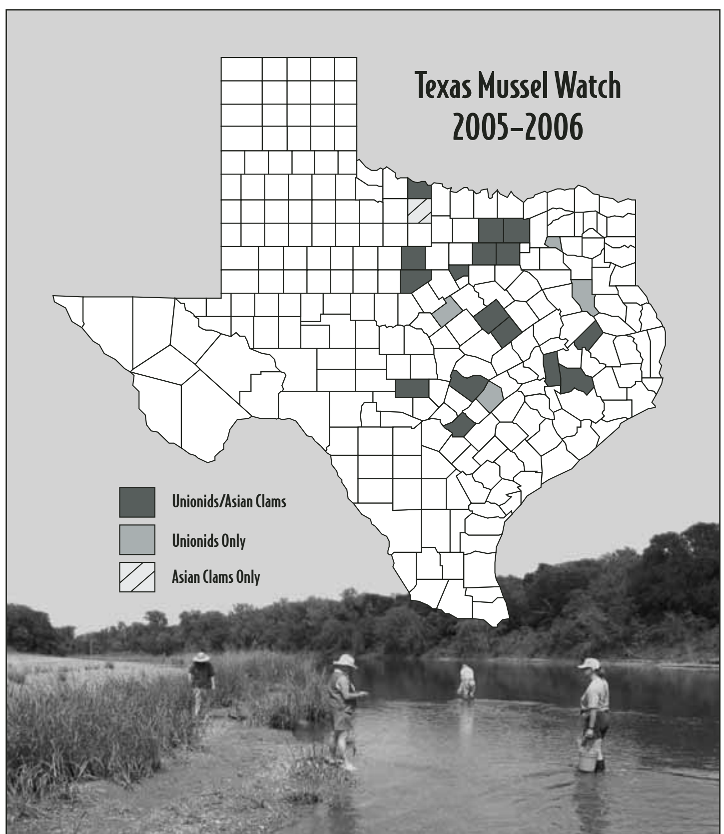


Figure 2. Counties where Texas Mussel Watch volunteers recorded unionid mussels and Asian clams (*Corbicula fluminea*). Photo is of the Rio Brazos Master Naturalists.

2006 Texas Mussel Watch Volunteers

Michael Adams
Allen Bartell
John Caldeira
Diane Cutler
Tim Dalbey
Denise Evans
Jim Flood
Neil Ford
Laura Gillis
David Jayroe
Annette Jones
Judy Lewis
Melissa Macdougall
Kathleen McCormack

Jane McGough
Mike McKay
Penny Miller
Ben Morris
James Mueck
Timothy Mueck
Melissa Mullins
Roger Myers
Mary Phelan
April Proudfit
Ronald Rushing
Nora Schell
Tamara Sevier
Victoria Sevier

Linda Sharp
Bill Stout
Betty Watkins
Elisabeth Welsh
Terry Young

Heart of Texas
Master Naturalists Chapter

The Preserve at
Forest Glen Springs

Rio Brazos
Master Naturalists Chapter

For more information on Texas Mussel Watch, please go to our Web site at: www.tpwd.state.tx.us/mussels

2006 Texas Mussel Watch in Breckenridge

Denise Evans, Student at TSTC

Students of the Texas State Technical College Environmental Science Department, Breckenridge Campus, have been participants in Texas Mussel Watch since 2001. Two students attended the Texas Mussel Watch Workshop in Waco in the spring of 2006 so that they could bring rest of the students in the class up to date on the program. The class was very informative and aided the students in their research, projects, and student driven lab. They were curious to see how years of drought had affected the local area.

The students had expected to see a sharp decline in the mussel population of Hubbard Creek Lake due to the drop in water level and the increase in salinity that generally goes along with that, so they were pleased to find an area of with a fairly large population of mussels. The specimens found varied from live specimens to very-recently dead, and included southern mapleleaf (*Quadrula apiculata*), bleufer (*Potamilus purpuratus*), and pink papershell (*Potamilus ohiensis*). Unfortunately, the ongoing lack of rainfall in the area could take its toll if we do not see a change soon.

This year's project was headed by Michael Adams and Denise Evans. Along with the students of TSTC, they were also joined by some of the local children of Breckenridge. They hope to pass on a degree of knowledge and awareness to younger generations, while increasing interest in the field. Texas State Technical College is proud to continue to support the conservation and awareness efforts of the Texas Parks and Wildlife Department's Texas Nature Tracker programs.

Great Trinity Forest Management Plan

Wetlands

Fishes, mussels, crayfishes and aquatic habitats of the Hoosier-Shawnee Ecological Assessment Area

Fishes, Mussels, Crayfishes, and Aquatic Habitats of the Hoosier-Shawnee Ecological Assessment Area

Brooks M. Burr, Justin T. Sipiorski, Matthew R. Thomas, Kevin S. Cummings, and Christopher A. Taylor

ABSTRACT

The Hoosier-Shawnee Ecological Assessment Area, part of the Coastal Plain and Interior Low Plateau physiographic provinces, includes 194 native fish species, 76 native mussel species, and 34 native crayfish species. Five of the subregions (e.g., Mississippi Embayment) that make up the assessment area were recently ranked as either globally or bioregionally outstanding aquatic resource areas. Fish, mussel, and crayfish diversity was analyzed for richness and density within and between the 39 hydrologic units that make up the assessment area. Species richness averaged 76 fish and 26 mussel species per hydrologic unit, and ecological units positioned as ecotones tended to be associated with primary levels of richness. At least 12 fish species are of conservation concern within the Hoosier and Shawnee National Forest boundaries; another 10 species are poorly known and need status surveys or other forms of conservation evaluation. Nearly 30 mussel species and 10 crayfish species are of conservation concern in the area, but fewer than 10 of these actually occur within national forest boundaries or would be directly affected by national forest activities. Commercial and recreational fisheries are popular in the region, and commercial exploitation of both mussels and crayfishes occurs in the assessment area. The most valuable and unique aquatic habitats in the area include springs, spring runs, karst aquifers, wetlands, swamps, mainstem large rivers, and upland, gravel-bottomed streams in both the Hoosier and Shawnee National Forests. The responsibility and challenges the USDA Forest Service shoulders in manageing and protecting the unique aquatic resources on its properties are staggering, especially in regard to the recently acknowledged global need for usable fresh water.

About the Author:

Brooks M. Burr
Professor, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501. Phone: 618-453-4112; e-mail: burr@zoology.siu.edu

Justin T. Sipiorski
Doctoral Graduate Assistant, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501

Matthew R. Thomas
Doctoral Graduate Assistant, Department of Zoology and Center for Systematic Biology, Southern Illinois University, Carbondale, Illinois 62901-6501

Kevin S. Cummings
Malacologist, Center for Biodiversity, Illinois Natural History Survey, Champaign, Illinois 61820

Christopher A. Taylor
Carcinologist, Center for Biodiversity, Illinois Natural History Survey, Champaign, Illinois 61820

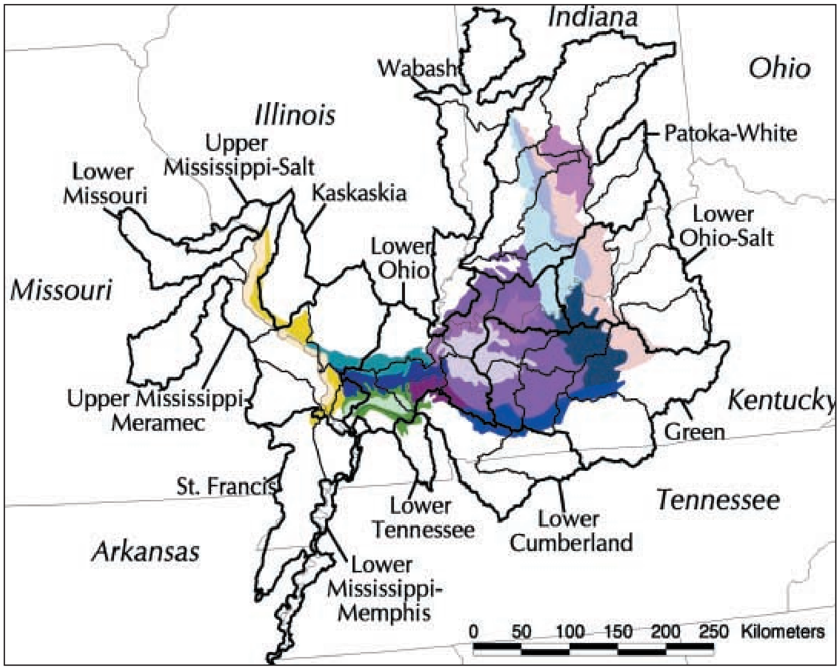


Figure 1. The 12 major river basins (divided into hydrologic units–watersheds) in the Hoosier-Shawnee Ecological Assessment Area.

We review the diversity, conservation status, and commercial significance of aquatic species and their habitats within the Hoosier-Shawnee Ecological Assessment Area. For analysis and discussion, aquatic species were restricted to three major taxonomic groups: fishes, unionid mussels, and crayfishes. Rather than use physiographic provinces as a way of analyzing patterns of distribution and diversity, we chose to use hydrological units to provide a more ecologically refined way to examine patterns across the watersheds of the assessment area (as explained in the "Data Sources and Methods of Analysis" subsections).

DIVERSITY OF FISHES, MUSSELS, AND CRAYFISHES

The fish, mussel, and crayfish fauna of the lower Ohio and middle Mississippi basins, including here portions of the Coastal Plain and Interior Low Plateau Provinces, is part of a region—the Southern and lower Midwestern United States—that harbors a significant portion of the richest temperate aquatic fauna on the North American continent (Warren et al. 2000). The combination of both upland and lowland streams and subterranean waters, along with a large river component, accounts for at least 193 native fish species, 76 native mussels, and 34 native crayfishes. These three aquatic groups represent over 24, 26, and 9 percent, respectively, of all native freshwater fishes, mussels, and crayfishes in the continental United States. The fishes alone represent over 50 percent of the native fauna of the entire Mississippi River basin and about 18 percent of all native freshwater fishes on the North American continent (Burr and Mayden 1992, Warren and Burr 1994, Warren et al. 2000). Illinois, Indiana, and Kentucky each have high to moderately high fish and mussel diversity, falling within the top eight States east of the Mississippi River and surpassing or equaling all States west of the Mississippi River except Missouri and Arkansas (Warren and Burr 1994). A major portion of that diversity is concentrated in the assessment area (Burr and Mayden 1992, Burr and Page 1986, Cummings and Mayer 1992).

The fishes, mussels, and crayfishes documented from the assessment area reside within a much larger natural region that encompasses the lower reaches of large tributaries of the Mississippi alluvial basin (e.g., Kaskaskia and Big Muddy Rivers), and all or significant portions of major drainages of the lower Ohio River basin (e.g., Green, Wabash, and Cache Rivers). It borders or encompasses parts of four ecological sections (see "Data Sources and Methods of Analysis"). Complex drainage histories beginning before the Pleistocene age set the stage for fragmentation, isolation, and mixing of faunas that in large part account for the richness and distinctiveness of the region's fishes, mussels, and crayfishes (Burr and Page 1986; Mayden 1987, 1988; Strange and Burr 1997). The region brings together two major dispersal corridors for fishes and mussels with approximately 330 river miles of the mainstem Ohio River and 165 river miles of the mainstem Mississippi River included in the assessment area.

The Forest Service's national hierarchical framework for classifying and mapping aquatic ecological units (Maxwell et al. 1995) places the Hoosier-Shawnee Ecological Assessment Area in the Arctic-Atlantic Bioregion, Mississippi Region, and Teays-Old Ohio Subregion. Small pieces of the Mississippi, Mississippi Embayment, Central Prairie, and Tennessee-Cumberland Subregions are part of the assessment area. As major rivers flow into the assessment area, most breach or border one or more major ecotones (transitional zones between ecological communities) that influence diversity and composition of fishes (Jenkins and Burkhead 1994). To the north and west, the region is bounded by the Interior Low Plateaus and Ozark Highlands, respectively, and to the south and east, by the Gulf Coastal Plain and the Appalachian Plateaus, respectively. These factors—major river systems with varied histories and ecological settings—provide the backdrop for the uniqueness and high diversity of aquatic species in the assessment area. In fact, the World Wildlife Fund's recent (Abell et al. 2000) conservation assessment of freshwater ecoregions of North America ranks three of the assessment area's subregions as globally outstanding and the remaining two as bioregionally outstanding. These two categories, globally outstanding and bioregionally outstanding, are the highest conservation rankings possible and clearly indicate the uniqueness and natural resource value of the assessment area.

DATA SOURCES AND METHODS OF ANALYSIS

Within constraints of time and the patterns of diversity in the assessment area, we modeled our summary of aquatic diversity after the excellent chapters on *Diversity of Fishes* (Warren and Hlass 1999), *Diversity of Mussels* (Harris 1999), and *Diversity of Crayfishes* (Warren et al. 1999) as published in Ozark-Ouachita Highlands Assessments Aquatic Condition (General Technical Report SRS-33 (1999) regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). To examine the distribution of fish, mussel, and crayfish species, each of the 12 (lower Missouri, upper Mississippi-Salt, Kaskaskia, upper Mississippi-Meramec, St. Francis, lower Tennessee, lower Cumberland, Green, Wabash, Patoka-White, lower Ohio (to Mississippi River confluence), and lower Ohio (to mile 703)) major basins within the assessment area was subdivided into hydrologic units (watersheds) according to standard eight-digit hydrologic unit codes (HUCs) (fig. 1). Only 5 (Rough, Lower Green, Pond, and Tradewater) of 39 hydrologic units fell entirely within the assessment area and represented the entire area (mi^2) of their respective HUC (table 1), 16 overlapped between 13 and 99 percent of their total area, and 18 units overlapped the assessment area by 12 percent or less of their total area (fig. 1). Several of the hydrologic units also contain portions of more than one ecological subsection (figs. 1, 2) (e.g., Cache and lower Ohio units share Shawnee Hills and Gulf Coastal Plain Subsections). Only that portion of a HUC that lies within the assessment area was used for tabulation of aquatic diversity.

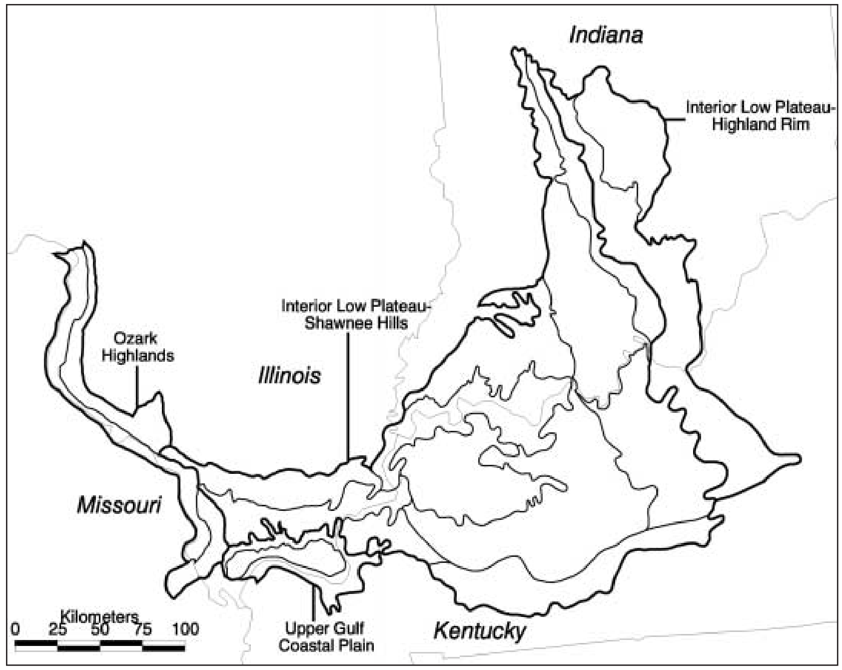


Figure 2. The four Ecological Sections of the Hoosier-Shawnee Ecological Assessment Area.

Table 1. Native fish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi^2	mi^2	no.	no. per mi^2		
Lower Missouri River Basin							
Lower Missouri	10300200	1,590	20.67	56 (19)	2.71 (3)	22	4
Upper Mississippi-Salt River Basins							
Peruque-Piasa	07110009	633	14.559	61 (17)	4.19 (1)	18	2
Kaskaskia River Basin							
Lower Kaskaskia	07140204	1,600	88	60 (18)	0.68 (4)	22	4
Upper Mississippi-Meramec River Basins							
Cohokia-Joachim	07140101	1,650	618.75	101 (5)	0.16 (15)	20	3(3)
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	129 (1)	0.32 (7)	8	1(1)
Big Muddy	07140106	2,350	289.05	85 (9)	0.29 (9)	18	2(2)
Whitewater	07140107	1,210	33.88	23 (27)	0.68 (4)	31	12
Cache	07140108	352	302.72	72 (13)	0.24 (12)	25	7(6)
St. Francis River Basin							
New Madrid-St. Johns	08020201	703	7.03	2 (33)	0.28 (10)	43	18
Little River Ditches	08020204	2,620	36.68	25 (25)	0.68 (4)	29	10
Lower Tennessee River Basin							
Lower Tennessee	06040006	689	79.235	47 (22)	0.59 (5)	27	8
Lower Cumberland River Basin							
Lower Cumberland	05130205	2,300	317.4	65 (16)	0.20 (13)	29	10
Red	05130206	1,450	55.1	5 (32)	0.09	32	13
Green River Basin							
Upper Green	05110001	3,130	1,311.47	87 (8)	0.07 (20)	28	9(8)
Barren	05110002	2,230	138.26	37 (24)	0.27 (11)	35	16
Middle Green	05110003	1,010	968.59	101 (5)	0.10 (18)	23	5(4)
Rough	05110004	1,070	1,070	51 (21)	0.05 (22)	43	18(15)
Lower Green	05110005	911	911	83 (11)	0.09 (19)	30	11(10)
Pond	05110006	784	784	72 (13)	0.09 (19)	32	13(11)
Wabash River Basin							
Middle Wabash-Little Vermillion	05120108	2,230	6.69	22 (28)	3.29 (2)	30	11
Lower Wabash	05120113	1,300	202.8	76 (12)	0.37 (6)	18	14
Patoka-White River Basins							
Upper White	05120201	2,700	278.1	24 (26)	0.09 (19)	45	19(16)
Lower White	05120202	1,650	664.95	67 (15)	0.10 (18)	33	14(12)
Eel	05120203	1,200	231.6	38 (23)	0.16 (15)	38	17(14)
Driftwood	05120204	1,150	40.25	12 (30)	0.30 (8)	38	17
Upper East Fork White	05120206	806	29.016	2 (33)	0.07 (20)	53	21
Muskatatuck	05120207	1,130	14.69	0 (34)	0.00 (23)	57	22
Lower East Fork White	05120208	2,030	1,822.94	104 (3)	0.06 (21)	24	6(5)
Patoka	05120209	854	620.004	67 (15)	0.11 (17)	32	13(11)

(table continued on next page)

(table 1 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi^2	mi^2	no.	no. per mi^2		
Lower Ohio River Basin (to Miss. R. confl.)							
Lower Ohio-Little Pigeon	05140201	1,370	1370	90 (7)	0.07 (20)	27	8(7)
Highland-Pigeon	05140202	1,000	957	84 (10)	0.09 (19)	29	10(9)
Lower Ohio-Bay	05140203	1,090	1,079.10	107 (2)	0.10 (18)	20	3(3)
Saline	05140204	1,160	300.44	54 (20)	0.18 (14)	34	15(13)
Tradewater	05140205	936	936	68 (14)	0.07 (20)	34	15(13)
Lower Ohio	05140206	928	668.16	103 (4)	0.15 (16)	20	3(3)
Lower Ohio Rver Basin (to mile 703)							
Silver-Little Kentucky	05140101	1,240	12.4	0 (34)	0.00 (23)	57	22
Salt	05140102	1,450	30.45	18 (29)	0.59 (5)	34	15
Rolling Fork	05140103	1,430	105.82	11 (31)	0.10 (18)	49	20
Blue Sinking	05140104	1,880	1,757.80	94 (6)	0.05 (22)	28	9(8)

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relative importance. See text for further discussion.

Determination of Fish, Mussel, and Crayfish Distributions

Fishes

The distribution of fishes within a particular hydrologic unit was determined primarily from spot-distribution maps in Burr and Warren (1986), Gerking (1945), Pflieger (1997), and Smith (1979). The determination of a species occurrence within a unit depended on the temporal (time) coverage, quality, and scale of source distribution maps. Distributions from cited sources (above) were presented as drainage maps for each species with dots indicating the occurrence of a fish species at that point within the drainage. The drainage maps allowed us to make relatively unambiguous interpretations of fish distributions. An unpublished report (i.e., gray literature) on fishes of the Hoosier National Forest (McComish and Brown 1980) is the most recent comprehensive source of written information for fishes in southern Indiana, but questions of quality and sources of distributional data, and accuracy of identifications make it clear that our knowledge of Indiana fishes is inferior to both the Illinois and Kentucky databases. Nevertheless, the scale of these maps, along with textual descriptions of distributions, permitted reasonably accurate delineation of a species' occurrence in a hydrological unit. Pflieger (1997) reported known collections of fishes in Missouri from about 1905 to 1995. Smith (1979) documented fish collections in Illinois from 1876 to 1978. The fish collection database for Kentucky covered records from about 1819 to 1985, with most samples dating from post-1950 (Burr and Warren 1986). Gerking (1945) made collections of fishes in Indiana from 1940 through 1943 and used many literature records from the era of David Starr Jordan and his students (1875-1894).

Information from these primary sources was augmented with fish distributional data presented in Burr and Page (1986), Lee et al. (1980), and Page and Burr (1991). Scientific and common names of fishes generally follow Mayden et al. (1992). Distributions of species described or their distributions clarified subsequent to the previously cited works were obtained from Burr and Page (1993, frecklebelly darter), Ceas and Page (1997, Shawnee darter), Dimmick et al. (1996, rosefin shiner), Eisenhour (1997, channel shiner), Page et al. (1992, guardian darter), and Poly and Wilson (1998, fringed darter). Known but as yet undescribed species of darters that occur only in the Kentucky portion of the assessment area have been included either under orangethroat darter or speckled darter.

Fish faunal composition among drainages of the region was taken from existing works for Kentucky (Burr and Warren 1986), Kentucky and Tennessee (Warren et al. 1991), Illinois and surrounding areas (Burr and Page 1986), and Missouri (Pflieger 1971). Although methods of analysis varied among these authors, each relied on comparing distributions of native fish species and classifying the resulting similarity patterns into fish faunal regions. In a novel approach, Mayden (1988) used major river drainages as analogous to "taxonomic" units and native fish species as analogous to "characters" to produce a "phylogeny" (or evolutionary tree) of drainage units in the Central United States. The fish faunal regions or drainage units recognized by these authors are compatible and generally congruent, and we assumed that sections of drainages not included in these previous works (e.g., some parts of Indiana) are classified in the same fish faunal regions as adjacent drainages in Illinois or Kentucky.

Mussels

Specific information on mussel distributions within much of the assessment area has not been published. Approximate range maps in Cummings and Mayer (1992) for mussels in Indiana, Illinois, and Missouri do not provide the resolution needed to determine specific distributions within the assessment area. Comprehensive surveys by Baker (1906) and Parmalee (1967), along with unpublished observations of Max Matteson (former zoologist with the University of Illinois, Urbana), have provided the early foundations for mussel distributions in Illinois. A recent summary of mussel distributions in Illinois was provided by Cummings and Mayer (1997). Comprehensive distributional information for mussels in Indiana was provided by Call (1900), Daniels (1903), and Goodrich and van der Schalie (1944). Several more recent studies of mussel distributions in southern Indiana were conducted on the Wabash, White, and East Fork White Rivers (Meyer 1974) and primary tributaries of the East Fork White River (Clarke et al. 1999, Cummings et al. 1992, Harmon 1998, Taylor 1982, Weilbaker et al. 1985). Updated spot-distribution maps compiled by Cummings for mussels of Illinois and Indiana (Cummings 2001, unpublished maps) were used primarily to determine current and historical mussel distributions within the assessment area in those States. Although a considerable body of literature exists on mussels in Kentucky, Cicerello et al. (1991) provided the most recent comprehensive summary of current and historical mussel distributions statewide. Updated spot-distribution maps provided by Cicerello (Cicerello 2001, unpublished maps) for the State of Kentucky served as the primary source of information on specific distributions of mussels within the assessment area in Kentucky. For the small portion of the assessment area that penetrates Missouri, spot-distribution maps in Oesch (1984) served as the primary data source. Scientific and common names of mussels generally follow Williams et al. (1993) except that subspecies are not recognized (Cummings and Mayer 1992).

Crayfishes

Data sources used to plot historic and recent distribution data of crayfishes onto the 39 watersheds of the assessment area included the following: Page (1985), Page and Mottesi (1995), and Taylor and Anton (1999) for Illinois; Pflieger (1996) for Missouri; the Illinois Natural History Survey (INHS) database (as of August 2001) and Taylor and Schuster (2001, unpublished spot-distribution maps) for

Kentucky; and the INHS database (as of August 2001) for Indiana. The INHS data on crayfish distribution in Kentucky included historic records as well as a relatively larger body of more recent collection records to be used in a future publication. However, aside from older publications—Hay (1896) and Eberly (1955), both with inexact locality information—very little publicly available data exist on the historic or current distribution of Indiana crayfishes. There were relatively few INHS crayfish records for Indiana counties in the assessment area, and those few records were generally concentrated in the Patoka River watershed as well as direct tributaries of the lower Ohio River.

Twenty-one of the thirty-four species in the assessment area have common names that derive from a variety of sources but that have not been uniformly sanctioned by a professional society. For the sake of consistency, we coined common names for the 13 species that lack them. Most of the scientific names of crayfishes in this report agree with those presented in Taylor et al. (1996). The following are exceptions. All *Cambarus bartonii* are of the subspecies *C. b. cavatus,* not *C. b. carinirostris* or *C. b. bartonii.* The subspecies *Orconectes inermis inermis* and *O. i. testii* are both included under the name *O. inermis*. *Orconectes ronaldi* and *O. margorectus* are newly described species in Taylor (2000) and Taylor (2002), respectively. *Orconectes palmeri palmeri* is the only subspecies recorded in the assessment area (Pflieger 1996) and is referred to here as *O. palmeri.* According to Taylor et al. (1996), both *Cambarus diogenes* and *Procambarus acutus* are comprised of species complexes and warrant further study.

Analysis of Aquatic Diversity

Fish, mussel, and crayfish species were noted as present or absent within each hydrologic unit and classified as native or endemic. Aquatic species occurring in peripheral (outside the assessment area) hydrologic units were not included. The status of a fish, mussel (i.e., live individual or dead shells), or crayfish species reflects its known historical presence within a unit but does not necessarily indicate its continued present-day occurrence in a unit. Information to account for changes to the fauna is inadequately synthesized for area-wide analysis. Fishes, mussels, and crayfishes were considered native if the assessment area was within their known historical range and no evidence of their having been artificially introduced was available. Depending on scale, biologists define endemic species as those that have a restricted range within one locale (or drainage). Introduced species are defined as those that have been intentionally or accidentally released in a locale. Some species can be described as native and introduced. For example, largemouth bass initially were found in the assessment area and they also have been stocked from hatchery-produced progeny into many farm ponds, impoundments, and artificial lakes in the area. Therefore, largemouth bass occur in two categories at once. Introduced bivalves (i.e., Asian clam and zebra mussel) and sphaeriid clams were not included in our analyses.

Diversity was analyzed using native species richness and native species density. Native species richness is the number of native species (i.e., fish, mussel, or crayfish) within each hydrologic unit. Hydrological units vary in areal extent, and species richness often increases with increases in stream size or area drained. To examine the effect of areal additivity (increases in area may be accompanied by an increase in species), native species richness was divided by the number of square miles in a given hydrologic unit (or partial unit) to produce native species density values for each HUC. In addition, the log of native species richness was regressed on the log area of hydrologic units to examine the relationship between species richness and unit size. Native species richness and a ranked sum of richness and density were plotted on separate hydrologic unit

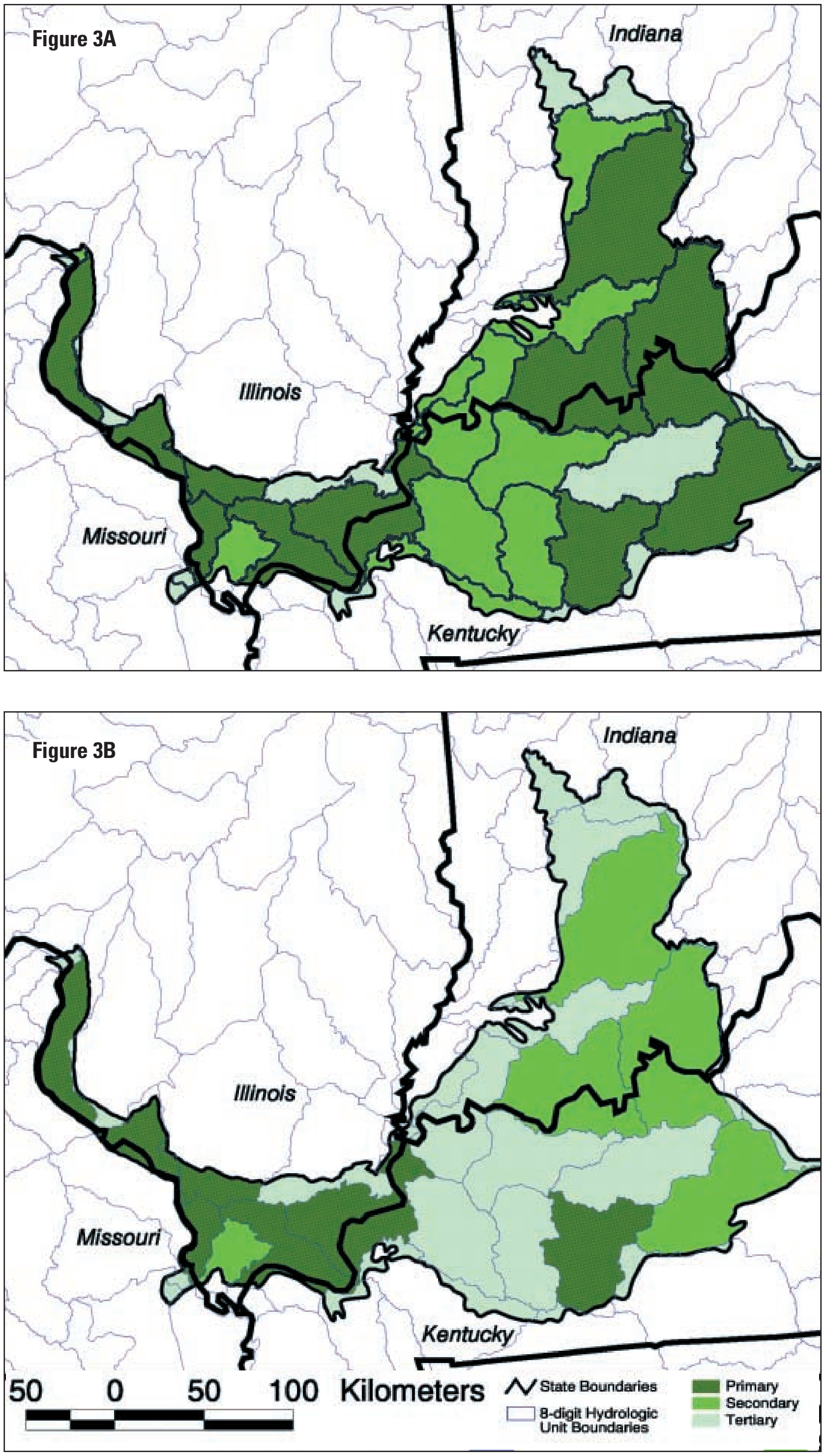


Figure 3. Levels of fish species richness (A) and fish species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

maps. Rank values of species richness in all hydrologic units and ranks of overall importance in hydrologic units with 12 percent or more of their area in the assessment area were divided into quartiles. Three levels of relative richness were recognized among hydrologic units: primary, secondary, and tertiary. Primary levels were assigned to the 9-10 units (depending on tied scores) with the highest values, secondary levels were assigned to the next highest 8-10 units, and tertiary levels were assigned to the remaining units. Hence, primary levels approximate values in the fourth quartile or top 25 percent, secondary levels approximate values in the third quartile or second 25 percent, and tertiary levels approximate values in the first and second quartiles or bottom 50 percent.

Watersheds with less than 12 percent of their total area in the assessment area had artificially high species density values. Therefore, species richness was considered a "real" descriptor of non-random distribution that was not as heavily burdened by watershed size as was species density. For this reason, no figure of species density was included, even though species density values were used in calculating the index of overall importance (but only for watersheds with 12 percent or more of their area in the assessment area).

Individual rank orders of the hydrologic units for native species richness and native species density were summed to create an index of overall relative importance of hydrologic units as freshwater habitats in the assessment area. Species richness and ranked sum of richness and density were plotted on separate hydrologic unit maps to show patterns of richness and relative overall importance (figs. 3-5). All ranking procedures used integer values. The hydrologic units or partial units with lowest ranks were considered the most important with regard to either richness, density, or overall rank. All tied calculated values received the same rank value.

PATTERNS AND TRENDS

Composition of Native Freshwater Fishes

Native fish diversity is divided unevenly among families in the assessment area. In the region, 194 native fish species placed in 24 families are represented (table 2). The five richest families—minnows (58 native species), perches (42), suckers (18), sunfishes and basses (16), and bullhead catfishes (14),—account for about 76 percent of the fish fauna. Just over 50 percent of the native fish fauna is made up of minnows (Cyprinidae) and darters (Percidae, perch family). Ten families have only one species represented in the assessment area, and other families support a significant number of North American species. For example, 50 percent of all cavefishes (Amblyopsidae) and about 25 percent of lampreys (Petromyzontidae) are recorded from the assessment area (Mayden et al. 1992).

Fish faunal composition has been independently analyzed for Missouri (Pflieger 1971), Kentucky (Burr and Warren 1986), Kentucky and Tennessee (Warren et al. 1991), and Illinois and surrounding areas (Burr and Page 1986). All of these analyses used different units of scale, generally larger drainage units than the eight-digit hydrologic units used here. Three of these studies also were limited to the political boundaries of their respective states and varied in the level of classification achieved. The primary findings relevant to the assessment area are summarized here; for details, the reader is referred to the original studies.

Pflieger (1971) recognized four primary faunal regions in Missouri: Ozark, lowland, prairie, and big river. The Ozark fish faunal region was restricted primarily to the Ozark Highlands or about the southern half of the State. Fish communities here are distinctively fluvial and unique, especially considering the high degree of endemism in the region. Noteworthy are the numbers of geminate pairs of fishes that occur in the Ozark Highlands and that have their next closest relatives occurring in the Appalachian Highlands (Burr and Page 1986). The lowland fish faunal region is a community of fishes restricted primarily to the southeastern corner of Missouri in the “bootheel” of the State. The species and habitats identified for this community in Missouri are similar to what is found in the assessment area in southern Illinois south of the Shawnee Hills continuing through the lower Cumberland-Tennessee region and including the lower Green River drainage. The prairie fish faunal region dominates the northern half of Missouri and is similar to the fish communities recognized in the assessment area in those hydrological units bordering the Mississippi and lower Missouri Rivers. The fourth and final fish faunal region recognized, the big river, includes primarily the mainstem channels of the Mississippi and Missouri Rivers. The assessment area includes about 165 miles of the mainstem Mississippi River and only a few miles of the extreme lower reaches of the Missouri River. The lower Ohio River is different in character (i.e., lower turbidity, narrower unbraided channel, less fluctuation in flow) from the Mississippi and lower Missouri Rivers but is more similar faunistically to the big river faunal region than any of the others recognized.

Burr and Warren (1986) analyzed fish diversity in Kentucky in two ways: 1) on the basis of 28 faunal or watershed units and 2) on the basis of 25 previously recognized physiographic units. Faunal similarity among watershed units was influenced by size, geographic proximity, geological history, and physical and biological characteristics of the units themselves. Three basic faunal groupings were formed: 1) a big river/lowland fauna, 2) an upland fauna, and 3) Terrapin Creek. The first two groupings are relevant to the assessment area and overlap in fish composition with the similar groupings in Missouri. Characteristic of the big river group are the shovelnose sturgeon, paddlefish, skipjack herring, goldeye, river shiner, silverband shiner, flathead chub, and blue sucker. At least four species, pallid sturgeon, sturgeon chub, sicklefin chub, and plains minnow, occur only in the mainstem Mississippi River in the assessment area.

The group most closely associated with the big river assemblage was the lowlands, including the Coastal Plain proper and environmentally similar areas of the lower Green and Tradewater

Table 2. Conservation ranks of native fishes of the Hoosier-Shawnee Ecological Assessment Area.

			Occurrence		Conservation ranks										
Family	**Species**	**Common name**	**SNF**	**HNF**	**Global**	**Federal**	**AFS**	**HNF**	**SNF**	**MIS HNF**	**MIS SNF**	**IL**	**IN**	**KY**	**MO**
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon	X	X	G3		T	R				E	E	E	S1
Acipenseridae	*Scaphirhynchus albus*	Pallid sturgeon	X		G1G2	E	E					E		E	S1
Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	X	X	G4										
Amblyopsidae	*Amblyopsis spelaea*	Northern cavefish		X	G3	T	T	R					E	S	
Amblyopsidae	*Forbesichthys agassizi*	Spring cavefish	X		G4G5										S1
Amblyopsidae	*Typhlichthys subterraneus*	Southern cavefish		X	G4		V						E	S	S2,S3
Amiidae	*Amia calva*	Bowfin	X	X	G5										
Anguillidae	*Anguilla rostrata*	American eel	X	X	G5										
Aphredoderidae	*Aphredoderus sayanus*	Pirate perch	X	X	G5										
Atherinopsidae	*Labidesthes sicculus*	Brook silverside	X	X	G5										
Atherinopsidae	*Menidia beryllina*	Inland silverside	X		G5									T	
Catostomidae	*Carpiodes carpio*	River carpsucker	X	X	G5										
Catostomidae	*Carpiodes cyprinus*	Quillback	X		G5										
Catostomidae	*Carpiodes velifer*	Highfin carpsucker	X	X	G4G5										S2
Catostomidae	*Catostomus commersoni*	White sucker	X	X	G5										
Catostomidae	*Cycleptus elongatus*	Blue sucker	X	X	G3G4		V						S		S3
Catostomidae	*Erimyzon oblongus*	Creek chubsucker	X	X	G5										
Catostomidae	*Erimyzon sucetta*	Lake chubsucker	X	X	G5									T	
Catostomidae	*Hypentelium nigricans*	Northern hog sucker	X	X	G5										
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo	X	X	G5										
Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	X	X	G5										
Catostomidae	*Ictiobus niger*	Black buffalo	X		G5									S	
Catostomidae	*Minytrema melanops*	Spotted sucker	X	X	G5										
Catostomidae	*Moxostoma anisurum*	Silver redhorse		X	G5										
Catostomidae	*Moxostoma carinatum*	River redhorse		X	G4							T	S		
Catostomidae	*Moxostoma duquesnei*	Black redhorse	X	X	G5										
Catostomidae	*Moxostoma erythrurum*	Golden redhorse	X	X	G5T4										
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse	X	X	G5T?										
Centrarchidae	*Ambloplites rupestris*	Rock bass	X	X	G5					M					
Centrarchidae	*Centrarchus macropterus*	Flier	X	X	G5										S3
Centrarchidae	*Lepomis auritus*	Redbreast sunfish			G5										
Centrarchidae	*Lepomis cyanellus*	Green sunfish	X	X	G5										
Centrarchidae	*Lepomis gulosus*	Warmouth	X	X	G5										
Centrarchidae	*Lepomis humilis*	Orangespotted sunfish	X	X	G5										
Centrarchidae	*Lepomis macrochirus*	Bluegill	X	X	G5					M					
Centrarchidae	*Lepomis megalotis*	Longear sunfish	X	X	G5										
Centrarchidae	*Lepomis microlophus*	Redear sunfish	X	X	G5										
Centrarchidae	*Lepomis miniatus*	Redspotted sunfish	X		G5							T		T	
Centrarchidae	*Lepomis symmetricus*	Bantam sunfish	X		G5				R			T	S		S2
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	X	X	G5					M					
Centrarchidae	*Micropterus punctulatus*	Spotted bass	X	X	G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks										
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Centrarchidae	*Micropterus salmoides*	Largemouth bass	X	X	G5					M					
Centrarchidae	*Pomoxis annularis*	White crappie	X	X	G5										
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	X	X	G5										
Clupeidae	*Alosa alabamae*	Alabama shad			G3	C	V						Ex	E	S2
Clupeidae	*Alosa chrysochloris*	Skipjack herring	X	X	G5										
Clupeidae	*Dorosoma cepedianum*	Gizzard shad	X	X	G5										
Clupeidae	*Dorosoma petenense*	Threadfin shad	X	X	G5										
Cottidae	*Cottus bairdi*	Mottled sculpin		X	G5T?										
Cottidae	*Cottus carolinae*	Banded sculpin	X	X	G5										
Cyprinidae	*Campostoma anomalum*	Central stoneroller	X	X	G5										
Cyprinidae	*Campostoma pullum*	Mississippi stoneroller		X	G5										
Cyprinidae	*Campostoma oligolepis*	Largescale stoneroller			G5										
Cyprinidae	*Cyprinella lutrensis*	Red shiner	X		G5										
Cyprinidae	*Cyprinella spiloptera*	Spotfin shiner	X	X	G5										
Cyprinidae	*Cyprinella venusta*	Blacktail shiner	X		G5									S	
Cyprinidae	*Cyprinella whipplei*	Steelcolor shiner	X	X	G5										
Cyprinidae	*Ericymba buccata*	Silverjaw minnow	X	X	G5										
Cyprinidae	*Erimystax dissimilis*	Streamline chub			G4										
Cyprinidae	*Erimystax x-punctatus*	Gravel chub		X	G4									Ex	
Cyprinidae	*Hybognathus argyritis*	Western silvery minnow	X		G4										S2
Cyprinidae	*Hybognathus hayi*	Cypress minnow	X	X	G5							E		E	S1
Cyprinidae	*Hybognathus nuchalis*	Mississippi silvery minnow	X	X	G5										S3,S4
Cyprinidae	*Hybognathus placitus*	Plains minnow	X		G4									S	S2
Cyprinidae	*Hybopsis amblops*	Bigeye chub	X	X	G5							E			
Cyprinidae	*Hybopsis amnis*	Pallid shiner	X	X	G4		V					E		H	SX
Cyprinidae	*Luxilus chrysocephalus*	Striped shiner	X	X	G5										
Cyprinidae	*Luxilus cornutus*	Common shiner		X	G5										
Cyprinidae	*Luxilus zonatus*	Bleeding shiner			G5										
Cyprinidae	*Lythrurus fasciolaris*	Scarletfin shiner	X	X	G5										
Cyprinidae	*Lythrurus fumeus*	Ribbon shiner	X	X	G5										
Cyprinidae	*Lythrurus umbratilis*	Redfin shiner	X	X	G5					M					
Cyprinidae	*Macrhybopsis gelida*	Sturgeon chub	X		G2	C	V					E		H	S3
Cyprinidae	*Macrhybopsis hyostoma*	Speckled chub	X	X	G5										
Cyprinidae	*Macrhybopsis meeki*	Sicklefin chub	X		G3	C	V							H	S3
Cyprinidae	*Macrhybopsis storeriana*	Silver chub	X	X	G5										S3
Cyprinidae	*Nocomis biguttatus*	Hornyhead chub	X	X	G5									S	
Cyprinidae	*Nocomis effusus*	Redtail chub			G4										
Cyprinidae	*Notemigonus crysoleucas*	Golden shiner	X	X	G5										
Cyprinidae	*Notropis ariommus*	Popeye shiner		X	G3		V						Ex		
Cyprinidae	*Notropis atherinoides*	Emerald shiner	X	X	G5										
Cyprinidae	*Notropis blennius*	River shiner	X	X	G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks										
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Cyprinidae	*Notropis boops*	Bigeye shiner	X	X	G5							E			
Cyprinidae	*Notropis buchanani*	Ghost shiner	X	X	G5										S2
Cyprinidae	*Notropis chalybaeus*	Ironcolor shiner		X	G5		V					T			S1
Cyprinidae	*Notropis dorsalis*	Bigmouth shiner	X		G5										
Cyprinidae	*Notropis hudsonius*	Spottail shiner	X		G5									S	
Cyprinidae	*Notropis ludibundus*	Sand shiner	X	X	G5										
Cyprinidae	*Notropis maculatus*	Taillight shiner	X	X	G5							E		T	S1
Cyprinidae	*Notropis nubilus*	Ozark minnow	X		G5										
Cyprinidae	*Notropis photogenis*	Silver shiner		X	G5										
Cyprinidae	*Notropis rubellus*	Rosyface shiner		X	G5										
Cyprinidae	*Notropis shumardi*	Silverband shiner	X	X	G5										
Cyprinidae	*Notropis texanus*	Weed shiner			G5							E			
Cyprinidae	*Notropis volucellus*	Mimic shiner	X	X	G5										
Cyprinidae	*Notropis wickliffi*	Channel shiner	X	X	G5										
Cyprinidae	*Opsopoeodus emiliae*	Pugnose minnow	X	X	G5					M					S4
Cyprinidae	*Phenacobius mirabilis*	Suckermouth minnow	X	X	G5										
Cyprinidae	*Phenacobius uranops*	Stargazing minnow			G4									S	
Cyprinidae	*Phoxinus erythrogaster*	Southern redbelly dace	X	X	G5					M					
Cyprinidae	*Pimephales notatus*	Bluntnose minnow	X	X	G5										
Cyprinidae	*Pimephales promelas*	Fathead minnow	X	X	G5										
Cyprinidae	*Pimephales vigilax*	Bullhead minnow	X	X	G5										
Cyprinidae	*Platygobio gracilis*	Flathead chub	X		G5		V					E		S	S1
Cyprinidae	*Pteronotropis hubbsi*	Bluehead shiner	X		G3		V		R			E			
Cyprinidae	*Rhinichthys atratulus*	Blacknose dace	X	X	G5										
Cyprinidae	*Rhinichthys cataractae*	Longnose dace	X		G5										
Cyprinidae	*Semotilus atromaculatus*	Creek chub	X	X	G5										
Elassomatidae	*Elassoma zonatum*	Banded pygmy sunfish	X		G5										
Esocidae	*Esox americanus*	Grass pickerel	X	X	G5					M					
Esocidae	*Esox lucius*	Northern pike	X	X	G5										
Esocidae	*Esox masquinongy*	Muskellunge		X	G5								S		
Esocidae	*Esox niger*	Chain pickerel			G5									S	
Fundulidae	*Fundulus catenatus*	Northern studfish	X		G5								S		
Fundulidae	*Fundulus dispar*	Starhead topminnow	X		G4									E	S2
Fundulidae	*Fundulus notatus*	Blackstripe topminnow	X	X	G5										
Fundulidae	*Fundulus olivaceus*	Blackspotted topminnow	X		G5										
Gadidae	*Lota lota*	Burbot			G5									S	
Hiodontidae	*Hiodon alosoides*	Goldeye	X		G5										
Hiodontidae	*Hiodon tergisus*	Mooneye	X	X	G5										S3
Ictaluridae	*Ameiurus melas*	Black bullhead	X	X	G5										
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	X	X	G5										
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	X	X	G5										S3?

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks											
Family	Species	Common name	SNF	HNF	Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Ictaluridae	*Ictalurus furcatus*	Blue catfish	X		G5										
Ictaluridae	*Ictalurus punctatus*	Channel catfish	X	X	G5										
Ictaluridae	*Noturus elegans*	Elegant madtom			G4										
Ictaluridae	*Noturus eleutherus*	Mountain madtom		X	G4										S1,S2
Ictaluridae	*Noturus exilis*	Slender madtom	X		G5									E	
Ictaluridae	*Noturus flavus*	Stonecat	X	X	G5										
Ictaluridae	*Noturus gyrinus*	Tadpole madtom	X	X	G5										
Ictaluridae	*Noturus miurus*	Brindled madtom	X	X	G5										
Ictaluridae	*Noturus nocturnus*	Freckled madtom	X	X	G5										
Ictaluridae	*Noturus stigmosus*	Northern madtom		X	G3		V					E		S	
Ictaluridae	*Pylodictis olivaris*	Flathead catfish	X	X	G5										
Lepisosteidae	*Atractosteus spatula*	Alligator gar	X		G5		V					Ex		E	SX
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	X		G5										
Lepisosteidae	*Lepisosteus osseus*	Longnose gar	X	X	G5										
Lepisosteidae	*Lepisosteus platostomus*	Shortnose gar	X	X	G5										
Moronidae	*Morone chrysops*	White bass	X		G5										
Moronidae	*Morone mississippiensis*	Yellow bass	X	X	G5										
Percidae	*Ammocrypta clara*	Western sand darter	X		G3		V					E			S2,S3
Percidae	*Ammocrypta pellucida*	Eastern sand darter		X	G3		V	R				T			
Percidae	*Crystallaria asprella*	Crystal darter			G3		V					Ex			S1
Percidae	*Etheostoma asprigene*	Mud darter	X		G4 G5										
Percidae	*Etheostoma barbouri*	Teardrop darter			G4 G5										
Percidae	*Etheostoma bellum*	Orangefin darter			G4 G5										
Percidae	*Etheostoma blennioides*	Greenside darter		X	G5										
Percidae	*Etheostoma caeruleum*	Rainbow darter	X	X	G5						M				
Percidae	*Etheostoma camurum*	Bluebreast darter		X	G4					FSOC		E			
Percidae	*Etheostoma chlorosoma*	Bluntnose darter	X	X	G5										
Percidae	*Etheostoma crossopterum*	Fringed darter			G4										
Percidae	*Etheostoma flabellare*	Fantail darter	X	X	G5										
Percidae	*Etheostoma flavum*	Saffron darter			G4										
Percidae	*Etheostoma gracile*	Slough darter	X	X	G5										
Percidae	*Etheostoma histrio*	Harlequin darter			G4							E			S2
Percidae	*Etheostoma kennicotti*	Stripetail darter	X		G4 G5										
Percidae	*Etheostoma maculatum*	Spotted darter			G2		V								
Percidae	*Etheostoma nigrum*	Johnny darter	X	X	G5										
Percidae	*Etheostoma oophylax*	Guardian darter			G4 G5										
Percidae	*Etheostoma proeliare*	Cypress darter	X		G5										
Percidae	*Etheostoma rafinesquei*	Kentucky darter													
Percidae	*Etheostoma smithi*	Slabrock darter			G4										
Percidae	*Etheostoma spectabile*	Orangethroat darter	X	X	G5										
Percidae	*Etheostoma squamiceps*	Spottail darter	X		G4 G5										

(table continued on next page)

(table 2 continued)

			Occurrence		Conservation ranks										
Family	**Species**	**Common name**	**SNF**	**HNF**	**Global**	**Federal**	**AFS**	**HNF**	**SNF**	**MIS HNF**	**MIS SNF**	**IL**	**IN**	**KY**	**MO**
Percidae	*Etheostoma stigmaeum*	Speckled darter			G5										
Percidae	*Etheostoma tecumsehi*	Shawnee darter			G1		T								
Percidae	*Etheostoma tippecanoe*	Tippecanoe darter		X	G3		V	Ex							
Percidae	*Etheostoma variatum*	Variegate darter		X	G5										
Percidae	*Etheostoma virgatum*	Striped darter			G4										
Percidae	*Etheostoma zonale*	Banded darter		X	G5										
Percidae	*Perca flavescens*	Yellow perch		X	G5										
Percidae	*Percina caprodes*	Logperch	X	X	G5										
Percidae	*Percina copelandi*	Channel darter		X	G4										S3
Percidae	*Percina evides*	Gilt darter			G4										
Percidae	*Percina maculata*	Blackside darter	X	X	G5										
Percidae	*Percina phoxocephala*	Slenderhead darter	X	X	G5										
Percidae	*Percina sciera*	Dusky darter	X	X	G5										
Percidae	*Percina shumardi*	River darter	X	X	G5										S3
Percidae	*Percina stictogaster*	Frecklebelly darter			G4 G5										
Percidae	*Percina vigil*	Saddleback darter			G5										
Percidae	*Stizostedion canadense*	Sauger	X	X	G5										
Percidae	*Stizostedion vitreum*	Walleye	X		G5										
Percopsidae	*Percopsis omiscomaycus*	Trout-perch	X	X	G5		V								S1?
Petromyzontidae	*Ichthyomyzon bdellium*	Ohio lamprey		X	G5										
Petromyzontidae	*Ichthyomyzon castaneus*	Chestnut lamprey	X	X	G3 G4										
Petromyzontidae	*Ichthyomyzon fossor*	Northern brook lamprey		X	G4							E			
Petromyzontidae	*Ichthyomyzon unicuspis*	Silver lamprey	X	X	G5										
Petromyzontidae	*Lampetra aepyptera*	Least brook lamprey	X	X	G5							T			
Petromyzontidae	*Lampetra appendix*	American brook lamprey			G4										S2
Poeciliidae	*Gambusia affinis*	Western mosquitofish	X		G5										
Polyodontidae	*Polyodon spathula*	Paddlefish	X		G4		V								S3
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	X	X	G5										
Umbridae	*Umbra limi*	Central mudminnow	X	X	G5										S1

E = Endangered
T = Threatened
S = Special concern
V = Vulnerable (American Fisheries Society)
Ex = Extirpated from the area/state in question
C = Candidate for listing federally
G1 = Critically imperiled globally (typically occurs in 5 or fewer counties)
G2 = Imperiled globally (typically occurs in 6 to 20 counties)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T4 = Taxonomic subdivision: widespread, abundant, and apparently secure globally
S1 = Missouri-Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Missouri-Imperiled in the State (typically 6 to 20 occurrences)
S3 = Missouri-Rare and uncommon in the State (21 to 100 occurrences)
S4 = Missouri-Widespread and abundant but of long-term concern

SX = Missouri-Extirpated
H = Historic (Extirpated-Kentucky)
? = Inexact or uncertain
R= Rare within a national forest
FSOC = Forest Species of Concern
M = Management Indicator Species in the national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species

Rivers. Indicative of the lowlands are the spotted gar, cypress minnow, pugnose minnow, ribbon shiner, lake chubsucker, pirate perch, flier, redspotted sunfish, banded pygmy sunfish, mud darter, bluntnose darter, and slough darter. Species more characteristic of the Coastal Plain include the chain pickerel, central mudminnow, blacktail shiner, taillight shiner, bantam sunfish, and cypress darter. The distribution of lowland fishes is strongly associated with a lack of topographic relief and low stream gradients. As a group they inhabit standing waters or sluggish streams and ditches with sand or mud bottoms. Many are also found among or near debris or dense growths of submerged aquatic vegetation. Because parts of the Interior Low Plateaus have aquatic habitats similar to those on the Coastal Plain, especially the floodplains of large streams and rivers, many species primarily distributed on the Gulf Coastal Plain have dispersed to areas far beyond the Mississippi Embayment.

A number of streams in the Ohio basin are representative of fish communities inhabiting upland habitats. Burr and Page (1986) referred to this upland cluster as the "Ohio River Uplands group." Among the most characteristic fishes of this group are the streamline chub, popeye shiner, silver shiner, rosyface shiner, stonecat, Tippecanoe darter, spotted darter, variegate darter, and gilt darter. As a group the upland fauna seems to be intolerant of continuous turbidity and siltation and requires streams with permanent flow, high gradients, and coarse gravel or rock bottoms. The distinctiveness of the upland fauna is probably related to topographic and habitat diversity, a relatively long history of drainage stability, constant base flows, and the isolation associated with inhabiting small streams and rivers. The upland faunal group emphasizes that faunal similarity among the drainages is influenced by geographic propinquity and major drainage basin. These findings are similar to those using physiographic units and others that relied almost exclusively on drainage units (e.g., Burr and Page [1986] for Illinois and surrounding areas, Warren et al. [1991] for Kentucky and Tennessee).

In Mayden's (1988) unique approach to fish faunal assemblages in the assessment area, he used 34 major drainages (e.g., Wabash, Green, Big Muddy Rivers) as analogous to "taxonomic units" and used fish species as the "characters" supporting the branching patterns of the "phylogeny" (estimate of evolutionary history) of the drainage units. His study derived a phylogeny consistent with the known pre-Pleistocene geological history of eastern North American rivers and supported the hypothesis of an ancient ichthyofauna in the Central Highlands region (including the Ouachita, Ozark, and Appalachian Highlands). Among the more intriguing findings of this study and others is that some endemic fish species in the Ozark Highlands have their closest relatives in the Ouachita Highlands, and these two regions together have their next closest relatives in the Appalachian Highlands of eastern Kentucky. For further details on geological and drainage history of the assessment area, see Burr and Page (1986), Burr and Warren 1986), Mayden (1988), Strange and Burr (1997), and Wiley and Mayden (1985).

Native fish species richness and density

The number of native fish species is not evenly distributed among the hydrologic units (fig. 3A), nor is it oriented to a simple geographic axis or compass point. Species richness averaged 76 fish species per hydrologic unit (after removal of HUCs that have only a small proportion of their area in the assessment area) and ranged from 37 to 129 species. Most units, however, displayed diverse fish faunas; 21 of the 27 units in the assessment area had more than 60 species.

Two separate geographical centers with primary levels of fish species richness (85 to 129 species) are apparent (fig. 3A). One occurs along the southwestern and southern edge of Illinois and the other occurs primarily along the eastern border of the assessment area. The southwestern-southern center is comprised of units within the Mississippi-lower Ohio drainage (Cahokia-Joachim, upper Mississippi-Cape Girardeau, Big Muddy, lower Ohio, and lower Ohio-Bay). The eastern center is comprised of units within the Green, Ohio and Wabash River drainages (lower East Fork White, Blue-Sinking, lower Ohio-Little Pigeon, upper Green, and Pond).

Units with secondary levels of fish species richness (61 to 84 species) are located in the extreme southwest (Cache unit), and the central units (Tradewater, middle Green, lower Green, Highland Pigeon, lower Wabash, Patoka, and lower White) of the assessment area (fig. 3A). Minor secondary units with little space in the assessment area include the lower Cumberland and Piasa (fig. 3A). Those units with tertiary levels (60 or fewer species) were primarily narrow strips of area or incomplete border units. The one exception to this pattern is the Rough unit in the Green River drainage with only 51 recorded species.

Ecological units positioned as ecotones tended to be associated with primary levels of richness. The cluster of hydrological units in the west and south reflects their ecotonal position between the uplands of the Shawnee Hills (in Illinois not Kentucky) and the lowlands of both the Gulf Coastal Plain and the Mississippi Alluvial Plain. These units are enriched by having representatives of both upland and lowland fish communities and the uniqueness of the mainstem Mississippi River's "big river" fauna (Burr and Page 1986, Burr and Warren 1986, Pflieger 1971). The primary richness levels along the eastern edge of the assessment area reflect a dominance of upland habitat, close proximity to the high number of endemic fishes in the Ohio basin, and perhaps an artifact of more thorough sampling efforts in these units. The aggregate of units in the central portion of the assessment area with secondary levels of fish species richness are situated primarily in the lowlands of the lower Green and Tradewater Rivers. Much of this region has been subjected to extensive strip mining, stream channelization, and outdated land-use practices. These kinds of habitat changes and degradation have resulted in a more depauperate fish fauna when compared to surrounding units. The fish fauna in these units is not enriched to the extent of other units that are positioned as ecotones, although as noted this may be an artifact of more extensive historical changes in that region.

The density of native fish species (number of fishes per unit area) was highly variable throughout the assessment area, and small HUCs had inflated species densities that do not accurately reflect density patterns recorded for larger HUCs. We therefore summed the rank order for both richness and density per hydrologic unit and arrived at an overall rank order of importance (table 1, fig. 3B). The overall rank order of importance was identical to native fish species richness in the southwestern and southern units of Illinois. The eastern units that ranked high in richness mostly dropped to secondary levels of overall rank order of importance, except that the middle Green unit maintained its status of primary importance. The number of tertiary units increased in the eastern half of the assessment area.

Small hydrologic units in the assessment area may show high native fish species densities because these units are influenced by the fish fauna of surrounding units. If these units were isolated from their respective surrounding units, we predict that species density would decline. The log of native fish species density in a unit was correlated negatively with the log of unit area ($P < 0.0005$). Regression of the log of native fish species richness with the log of square miles in units was positive and statistically significant ($P < 0.005$). Thus, areal additivity is a factor in consideration of species richness and area, but richness approaches some asymptotic value as area increases. Nevertheless, units with primary and secondary levels of richness and overall rank importance should be considered exceptional areas of fish diversity in the assessment area.

Endemic fishes

In the strictest sense, only one fish species, the Shawnee darter, is endemic to the assessment area. Its entire range is found in the upper Pond River (Ceas and Page 1997) and the hydrologic unit of the same name. Some 11 additional species are narrow range endemics that in six cases have significant portions of their ranges in the assessment area. Additionally, ongoing studies indicate that several currently recognized species are, in fact, two or more distinct species. For example, Layman (1994) demonstrated that at least two distinct species now masquerading under the name speckled darter have narrow ranges that include the assessment area. Likewise, the orangethroat darter consists of additional distinct, but not yet formally described, species (Ceas 1997) whose ranges fall partially within the assessment area. Several other subspecies of fishes in the area likely will be recognized as distinct endemic species after further study (Mayden et al. 1992, Warren et al. 2000).

Endemic fishes within the assessment area represent four families: the perches, minnows, catfishes, and cavefishes. The perches (darters) have the highest number of endemic species with 9, or 23 percent of all darters recorded in the area. In addition, the assessment area harbors one endemic minnow (Ozark minnow), one endemic madtom catfish (elegant madtom), and one endemic cavefish (northern cavefish).

The primary region of endemicity in the assessment area is the upper Green River and its major tributaries (i.e., Rough, Barren, and Pond Rivers). Four endemics (Kentucky darter, teardrop darter, orangefin darter, and elegant madtom) occur in this region including some combination of the upper Green, Rough, and middle Green hydrologic units. One species (striped darter) is restricted to the Cumberland River including the Red hydrologic unit. Two species (saffron darter, slabrock darter) are restricted range endemics in the Cumberland and Tennessee drainages and found only in the lower Cumberland hydrologic unit in the assessment area. The frecklebelly darter, the only fish species exclusively shared by the Green and Kentucky River drainages in Kentucky and Tennessee, occupies the upper Green and Rough hydrologic units. The guardian darter occurs in tributaries of the lower Tennessee River, including only the lower Tennessee hydrologic unit in the assessment area. The Ozark minnow, an Ozark Highlands-Driftless Area endemic, barely ranges into the assessment area and is found only in the narrow eastern border referred to here as the Cahokia-Joachim and upper Mississippi-Cape Girardeau hydrologic units. Additionally, the cavefish family has three representatives in the assessment area that occupy subterranean waters or surface springs closely connected to karst environments. One of these, the northern cavefish, has nearly its entire hypogean range within the assessment area where it has been recorded in the lower East Fork White, Blue-Sinking, Rough, and upper Green hydrologic units.

On a larger scale the assessment area captures portions of the ranges of big river endemics including the pallid sturgeon, sturgeon chub, and sicklefin chub. All three of these species are found only in the mainstem of the Missouri River and the Mississippi River below the mouth of the Missouri River. None of these species occupy the main channel of the Ohio

River. About 165 river miles of the ranges of these three species are included in the assessment area. No endemic fishes are known in either the Shawnee or Hoosier National Forests, but stable populations of the spring cavefish and northern cavefish occur on Forest Service properties and present unique opportunities for study and protection.

Composition of Native Mussel Species

Freshwater mussels of the families Unionidae and Margaritiferidae (commonly called naiads, unionids, bivalves, or clams) are found worldwide but achieve their greatest diversity in eastern North America with approximately 297 taxa (281 species and 16 subspecies) currently recognized (Williams et al. 1993). Seventy-six species have been recorded within the boundaries of the assessment area, representing 26 percent of the North American fauna. This includes 92 percent of the species reported to occur or to have occurred in Illinois (Cummings 2001, unpublished data); 97 percent of the species reported in Indiana (Cummings 2001, unpublished data); 71 percent of the species reported in Kentucky (Cicerello 2001, unpublished data); and 39 percent of the species and subspecies reported in Missouri (Oesch 1984).

Many of the mussel species occurring in the assessment area are widely dispersed throughout the Mississippi and Ohio River drainages, whereas others are restricted to a specific stream type (e.g., headwaters and small creeks). Large river drainages traverse different physiographic provinces (ecological subregions) within the assessment area, providing conditions suitable for different aquatic faunal groups, including mussels and fishes. Most mussel species rely on fishes as hosts during the parasitic larval (glochidial) stage of their life cycle. This temporary attachment of the glochidia onto passing fish serves as the means for their dispersal. Pliocene and Pleistocene events affecting zoogeography of fishes in the lower Ohio-upper Mississippi basin have similarly played an important role in the distribution and diversification of freshwater mussels. Mussel species richness (table 3) within the assessment area has resulted from complex drainage histories and varied aquatic habitats, and complex co-evolutionary histories with fish hosts.

The 76 native freshwater mussel species in the assessment area are placed in 36 genera (table 4). The most species-rich genera include *Epioblasma* (8 native species), *Quadrula* (6 species) and *Lampsilis* (6 species). Nineteen genera (25 percent) are represented by a single species. Of the three subfamilies in the Unionidae, 39 lampsilines, 26 amblemines, and 11 anodontines occur within the assessment area. The second family, Margaritiferidae, is represented by a single species *Cumberlandia monodonta* (table 4).

Species richness for hydrologic units within 12 major river basins ranged from a high of 48 in the lower Tennessee to being entirely absent from units in the St. Francis and lower Missouri River basins (table 3). In descending order, average species richness for the remaining nine major river basins was as follows: lower Ohio River (to Mississippi River confluence) (34), Green River (31), lower Cumberland River (19), lower Ohio (to mile 703) (14), Kaskaskia River (13), Patoka-White River (13), upper Mississippi-Meramec River (9), upper Mississippi-Salt River (6), and Wabash River (1).

Roughly half of the native mussel species occurring within the assessment area are representative of a ubiquitous fauna widely dispersed in both the Mississippi and Ohio Rivers (Cummings and Mayer 1992, Johnson 1980). Twenty species are widespread and common within the assessment area—threeridge, Wabash pigtoe, pimpleback, mapleleaf, cylindrical papershell, white heelsplitter, giant floater, creeper, pond papershell, mucket, pocketbook,

Table 3. Native fish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi^2	mi^2	*no.*	*no. per mi^2*		
Lower Missouri River Basin							
Lower Missouri	10300200	1,590	20.67	0 (24)	0.000 (28)	52	21
Upper Mississippi-Salt River Basins							
Peruque-Piasa	07110009	633	14.559	6 (19)	0.412 (2)	21	8
Kaskaskia River Basin							
Lower Kaskaskia	07140204	1,600	88	13 (17)	0.148 (5)	22	9
Upper Mississippi-Meramec River Basins							
Cohokia-Joachim	07140101	1,650	618.75	12 (18)	0.019 (23)	41	17(13)
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	18 (14)	0.045 (11)	25	11(7)
Big Muddy	07140106	2,350	289.05	2 (22)	0.007 (25)	47	20(16)
Whitewater	07140107	1,210	33.88	0 (24)	0.000 (28)	52	21
Cache	07140108	352	302.72	13 (17)	0.043 (13)	30	15(11)
St. Francis River Basin							
New Madrid-St. Johns	08020201	703	7.03	0 (24)	0.000 (28)	52	21
Little River Ditches	08020204	2,620	36.68	0 (24)	0.000 (28)	52	21
Lower Tennessee River Basin							
Lower Tennessee	06040006	689	79.235	48 (2)	0.606 (1)	3	1(1)
Lower Cumberland River Basin							
Lower Cumberland	05130205	2,300	317.4	37 (5)	0.117 (7)	12	3(3)
Red	05130206	1,450	55.1	0 (24)	0.000 (28)	52	21
Green River Basin							
Upper Green	05110001	3,130	1,311.47	58 (1)	0.044 (12)	13	4(4)
Barren	05110002	2,230	138.26	20 (13)	0.145 (6)	19	6
Middle Green	05110003	1,010	968.59	37 (5)	0.038 (14)	19	6(5)
Rough	05110004	1,070	1,070	30 (7)	0.028 (19)	26	12(8)
Lower Green	05110005	911	911	25 (10)	0.027 (20)	30	15(11)
Pond	05110006	784	784	16 (15)	0.020 (22)	37	16(12)
Wabash River Basin							
Middle Wabash-Little Vermillion	05120108	2,230	6.69	0 (24)	0.000 (28)	52	21
Lower Wabash	05120113	1,300	202.8	1 (23)	0.005	23	10
Patoka-White River Basins							
Upper White	05120201	2,700	278.1	3 (21)	0.011 (24)	45	18(14)
Lower White	05120202	1,650	664.95	21 (12)	0.032 (17)	29	14(10)
Eel	05120203	1,200	231.6	14 (16)	0.060 (9)	25	11(6)
Driftwood	05120204	1,150	40.25	13 (17)	0.323 (3)	20	7
Upper East Fork White	05120206	806	29.016	0 (24)	0.000 (28)	52	21
Muskatatuck	05120207	1,130	14.69	0 (24)	0.000 (28)	52	21
Lower East Fork White	05120208	2,030	1,822.94	48 (2)	0.026 (21)	23	10(6)
Patoka	05120209	854	620.004	4 (20)	0.006 (26)	46	19(14)

(table continued on next page)

(table 3 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *
		mi^2	mi^2	no.	no. per mi^2		
Lower Ohio River Basin (to Miss. R. confl.)							
Lower Ohio-Little Pigeon	05140201	1,370	1370	46 (3)	0.034 (16)	19	6(5)
Highland-Pigeon	05140202	1,000	957	29 (8)	0.030 (18)	26	12(8)
Lower Ohio-Bay	05140203	1,090	1,079.10	40 (4)	0.037 (15)	19	6(5)
Saline	05140204	1,160	300.44	14 (16)	0.047 (10)	26	12(8)
Tradewater	05140205	936	936	26 (9)	0.028 (19)	28	13(9)
Lower Ohio	05140206	928	668.16	48 (2)	0.072 (8)	10	2(2)
Lower Ohio Rver Basin (to mile 703)							
Silver-Little Kentucky	05140101	1,240	12.4	0 (24)	0.00 (28)	52	21
Salt	05140102	1,450	30.45	0 (24)	0.00 (28)	52	21
Rolling Fork	05140103	1,430	105.82	24 (11)	0.23 (4)	15	5
Blue Sinking	05140104	1,880	1,757.80	31 (6)	0.02 (22)	28	13(9)

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relativeimportance. See text for further discussion.

fatmucket, fragile papershell, threehorn wartyback, hickorynut, pink heelsplitter, pink papershell, lilliput, fawnsfoot, and deertoe. Although many species have broad distributions, several of these are uncommon or sporadically distributed throughout their range, due to either human-related impacts or specific habitat restrictions (Cummings and Mayer 1992). Eighteen species are broadly distributed but are uncommon or sporadic within the assessment area—purple wartyback, elephant ear, spike, round pigtoe, Ohio pigtoe, pyramid pigtoe, pistolgrip, pondhorn, elktoe, fluted shell, butterfly, wavy-rayed lampmussel, yellow sandshell, black sandshell, round hickorynut, kidneyshell, rainbow, and little spectaclecase. Another 16 species are rare within the assessment area or have been recorded in less than 10 percent of the hydrologic units—crackling pearlymussel, orangefoot pimpleback, clubshell, rough pigtoe, sugarspoon, leafshell, catspaw, Tennessee riffleshell, northern riffleshell, Wabash riffleshell, tubercled blossom, snuffbox, bleufer, purple lilliput, rayed bean, and Kentucky creekshell.

The majority of the native freshwater mussel species within the assessment area are representatives of the rich Interior Basin fauna, which encompasses the entire Mississippi River basin, excluding the Ozarkian and Cumberlandian faunal areas (Parmalee and Bogan 1998, van der Schalie and van der Schalie 1950). One Cumberlandian species (sugarspoon) has been reported to have occurred in the lower Tennessee River (lower Tennessee hydrologic unit), based on an archaeological record (Cicerello et al. 1991). Johnson (1980) subdivided the Interior Basin into Ohioan, Mississippian, and Gulf Coastal regions, based on several species unique to each area. Thus defined, 7 species within the assessment area are characteristic of the Mississippian region and 20 are characteristic of the Ohioan region. Two Gulf coastal species (bleufer and Texas lilliput) reaching the northern limits of their range are represented in only 10 percent of the hydrologic units along the Mississippi and lower Ohio Rivers. The remaining 47 species are uniformly distributed in both the Mississippian and Ohioan regions.

Table 4. Conservation ranks of native freshwater mussels of the Hoosier-Shawnee Ecological Assessment Area.

Family Subfamily	Species	Common name	Occurrence SNF	Occurrence HNF	Conservation ranks Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Margaretiferidae	*Cumberlandia monodonta*	Spectaclecase	X		G2G3		T					E	EX	E	S3
Unionidae															
Ambleminae	*Amblema plicata*	Threeridge	X	X	G5			R							
Ambleminae	*Cyclonaias tuberculata*	Purple wartyback	X	X	G5		SC					T			
Ambleminae	*Elliptio crassidens*	Elephant ear	X	X	G5							T			
Ambleminae	*Elliptio dilatata*	Spike	X	X	G5			R				T			
Ambleminae	*Fusconaia ebena*	Ebonyshell	X	X	G4G5							T			E
Ambleminae	*Fusconaia flava*	Wabash pigtoe	X	X	G5										
Ambleminae	*Fusconaia subrotunda*	Long-solid		X	G3		SC						E	SC	
Ambleminae	*Hemistena lata*	Cracking pearlymussel			G1		E						EX		
Ambleminae	*Megalonaias nervosa*	Washboard	X	X	G5										
Ambleminae	*Plethobasus cicatricosus*	White wartyback			G1		E						E		
Ambleminae	*Plethobasus cooperianus*	Orange-foot pimpleback	X	X	G1	E	E					E	E	E	
Ambleminae	*Plethobasus cyphyus*	Sheepnose	X	X	G3		T					E	E	SC	E
Ambleminae	*Pleurobema clava*	Clubshell		X	G2	E	E						E	E	
Ambleminae	*Pleurobema sintoxia*	Round pigtoe		X	G3										
Ambleminae	*Pleurobema cordatum*	Ohio pigtoe	X	X	G3		SC					E	T		
Ambleminae	*Pleurobema plenum*	Rough pigtoe		X	G1	E	E						E	E	
Ambleminae	*Pleurobema rubrum*	Pyramid pigtoe		X	G2		T					E	E	E	
Ambleminae	*Quadrula nobilis*	Southern mapleleaf			G5										
Ambleminae	*Quadrula cylindrica*	Rabbitsfoot	X	X	G3T3		T					E	E	T	S1
Ambleminae	*Qudrula metanevra*	Monkeyface	X	X	G4										
Ambleminae	*Quadrula nodulata*	Wartyback	X		G4										S3
Ambleminae	*Quadrula pustulosa*	Pimpleback	X	X	G5										
Ambleminae	*Quadrula quadrula*	Mapleleaf	X	X	G5										
Ambleminae	*Tritogonia verrucosa*	Pistolgrip	X	X	G4										
Ambleminae	*Uniomerus tetralasmus*	Pondhorn	X	X	G4										
Anodontinae	*Alasmidonta marginata*	Elktoe			G5		SC							T	S2?
Anodontinae	*Alasmidonta viridis*	Slippershell			G4G5		SC					T			
Anodontinae	*Anodonta suborbiculata*	Flat floater	X	X	G5										S2
Anodontinae	*Anodontoides ferussacianus*	Cylindrical papershell		X	G5					M					S1?
Anodontinae	*Arcidens confragosus*	Rock-pocketbook	X	X	G4										S3
Anodontinae	*Lasmigona complanata*	White heelsplitter	X	X	G5										
Anodontinae	*Lasmigona costata*	Fluted shell		X	G5										
Anodontinae	*Pyganodon grandis*	Giant floater	X	X	G5										
Anodontinae	*Simpsonaias ambigua*	Salamander mussel		X	G3		SC					E	T	T	S1
Anodontinae	*Strophitus undulatus*	Squawfoot		X	G5					M					
Anodontinae	*Utterbackia imbecillis*	Paper pondshell		X	G5										
Lampsilinae	*Actinonaias ligamentina*	Mucket	X	X	G5										
Lampsilinae	*Cyprogenia stegaria*	Fanshell		X	G1	E	E		R			E	E	E	
Lampsilinae	*Ellipsaria lineolata*	Butterfly	X	X	G4					M		T			
Lampsilinae	*Epioblasma archaeformis*	Sugarspoon			GX		E*								
Lampsilinae	*Epioblasma flexuosa*	Leafshell			GX		E*			M			EX		
Lampsilinae	*Epioblasma obliquata*	Catspaw			G1	E	E						E	E	
Lampsilinae	*Epioblasma propinqua*	Tennessee riffleshell		X	GX		E*						EX		
Lampsilinae	*Epioblasma rangiana*	Northern riffleshell		X	G2T2		E						E	E	

(table continued on next page)

(table 4 continued)

Family Subfamily	Species	Common name	Occurrence SNF	Occurrence HNF	Conservation ranks Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Lampsilinae	*Epioblasma sampsonii*	Wabash riffleshell			GX		E*						EX		
Lampsilinae	*Epioblasma torulosa*	Tubercled blossom		X	G2T2	E	E						E		
Lampsilinae	*Epioblasma triquetra*	Snuffbox		X	G3		T					E	E	SC	S1
Unionidae															
Lampsilinae	*Lampsilis abrupta*	Pink mucket	X		G2	E	E					E	E	E	E
Lampsilinae	*Lampsilis cardium*	Pocketbook	X	X	G5		SC								
Lampsilinae	*Lampsilis fasciola*	Wavy-rayed lampmussel		X	G4							E	T		
Lampsilinae	*Lampsilis ovata*	Pocketbook	X		G1		SC							E	
Lampsilinae	*Lampsilis siliquoidea*	Fatmucket	X	X	G5										
Lampsilinae	*Lampsilis teres*	Yellow sandshell	X	X	G5										
Lampsilinae	Leptodea fragilis	Fragile papershell	X	X	G5										
Lampsilinae	*Ligumia recta*	Black sandshell	X	X	G5		SC					T			S1S2
Lampsilinae	*Ligumia subrostrata*	Pondmussel	X		G4G5										
Lampsilinae	*Obliquaria reflexa*	Threehorn wartyback	X	X	G5										
Lampsilinae	*Obovaria olivaria*	Hickorynut	X	X	G4										S2S3
Lampsilinae	*Obovaria retusa*	Ring pink	X		G1	E	E						EX	E	
Lampsilinae	*Obovaria subrotunda*	Round hickorynut	X	X	G4		SC					E	T		
Lampsilinae	*Potamilus alatus*	Pink heelsplitter	X	X	G5										
Lampsilinae	*Potamilus capax*	Fat pocketbook	X	X	G1	E	E					E	E	E	E
Lampsilinae	*Potamilus ohiensis*	Pink papershell	X	X	G5										
Lampsilinae	*Potamilus purpuratus*	Bleufer	X		G5									E	
Lampsilinae	*Ptychobranchus fasciolaris*	Kidneyshell	X	X	G4G5							E	T		
Lampsilinae	*Toxolasma lividus*	Purple lilliput			G2		SC					E	T	E	S2
Lampsilinae	*Toxolasma parvus*	Lilliput			G5										
Lampsilinae	*Toxolasma texasensis*	Texas lilliput	X		G4					M				E	S3
Lampsilinae	*Truncilla donaciformis*	Fawnsfoot	X	X	G5										
Lampsilinae	*Truncilla truncata*	Deertoe	X	X	G5										
Lampsilinae	*Villosa fabalis*	Rayed bean			G1G2		SC					E	T	E	
Lampsilinae	*Villosa iris*	Rainbow			G5							E			
Lampsilinae	*Villosa lienosa*	Little spectaclecase		X	G5							E	T	SC	
Lampsilinae	*Villosa ortmanni*	Kentucky creekshell			G2		SC							T	
Unioninae	*Plectomerus dombeyanus*	Bankclimber			G4G5										S3

E* = possibly extinct
EX = extirpated from the study area
G1 = Critically imperiled globally (typically 5 or fewer occurrences)
G2 = Imperiled globally (typically 6 to 20 occurrences)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T2 = Taxonomic subdivision; imperiled globally (typically 6 to 20 occurrences)
T3 = Taxonomic subdivision; very rare and local throughout range or found locally in a restricted range
S1 = Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Imperiled in the State (typically 6 to 20 occurrences)
S3 = Rare and uncommon in the State (21 to 100 occurrences)
? = Inexact or uncertain
SC = Species of special concern
E = Endangered
T = Threatened

R= Rare within a national forest
M = Management Indicator Species in the national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species
IL (Herckert 1992)
KY (KSNPC 1996)
IN (www.in.gov/dnr/fishwild 2001)
MO (www.conservation.state.mo.us 2001)

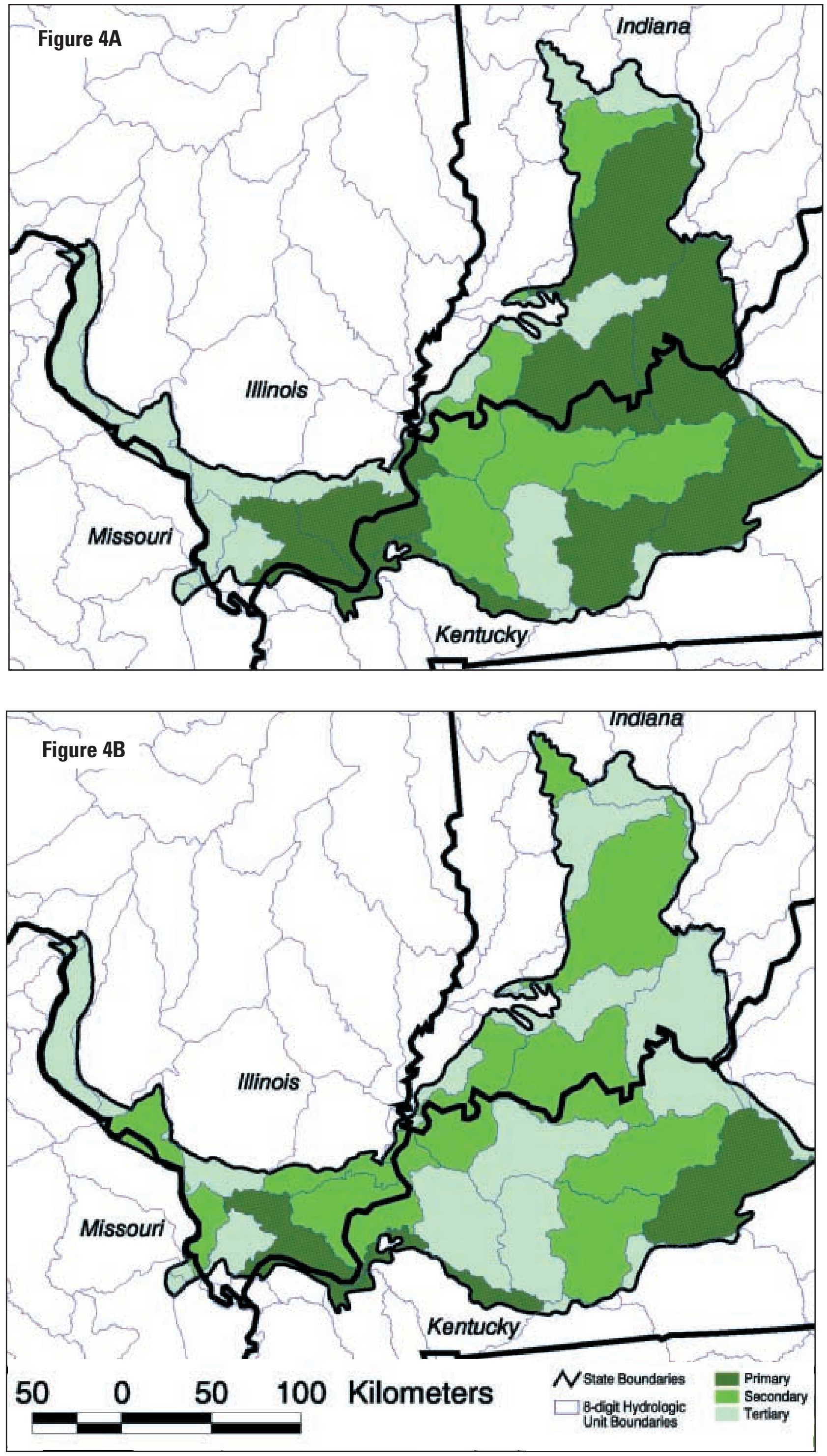


Figure 4. Levels of mussel species richness (A) and mussel species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

Native mussel species richness and density

Several of the hydrologic units within the assessment area occupied less than 3 percent of the area of their respective HUCs native freshwater mussels are absent from these units either because it was impossible to determine whether species records fell within the unit boundaries or because the units contained no streams or bodies of water large enough to support freshwater mussels. Species richness averaged 26 species per hydrologic unit (following removal of hydrologic units having only a small proportion of their area in the HUC), but varied considerably between and within major river basins (table 3). For example, within the Patoka-White River basin, only 4 species are known from the Patoka hydrologic unit, whereas 48 are known from the lower East Fork White unit. Primary levels of species richness (31 to 58 species) are concentrated in the southwestern-central (lower Ohio and lower Ohio Bay) units and in the eastern (lower Ohio-Little Pigeon, Blue-Sinking, lower East Fork White, middle Green, and upper Green) units (fig. 4A). Minor primary units having little space within the assessment area include the lower Cumberland and lower Tennessee. Units with secondary levels of mussel species richness (21 to 30 species) are located in the central (Tradewater, Highland-Pigeon, and lower Green) units and in the eastern (Rough, lower White, and Rolling Fork) units. Units with tertiary levels of species richness (20 or fewer species) were primarily those distributed along the borders of the assessment area occupying a small portion of their respective HUCs (fig. 4A).

Hydrologic units in areas that permit a mixture of faunal elements tended to be associated with primary levels of species richness. For example, the southwestern-central units (including the lower Tennessee and lower Cumberland) are enriched by Interior Basin and Cumberlandian species (or Interior Basin species having a Cumberlandian origin) (van der Schalie and van der Schalie 1950). Species-rich units in the Green River basin (middle Green and upper Green) are part of what is recognized to be an important refugium for Ohioan species that repopulated other Ohio River basin tributaries subsequent to Pleistocene glacial events (Johnson 1980). Other hydrologic units (Ohio-Little Pigeon, Blue-Sinking, and lower East Fork

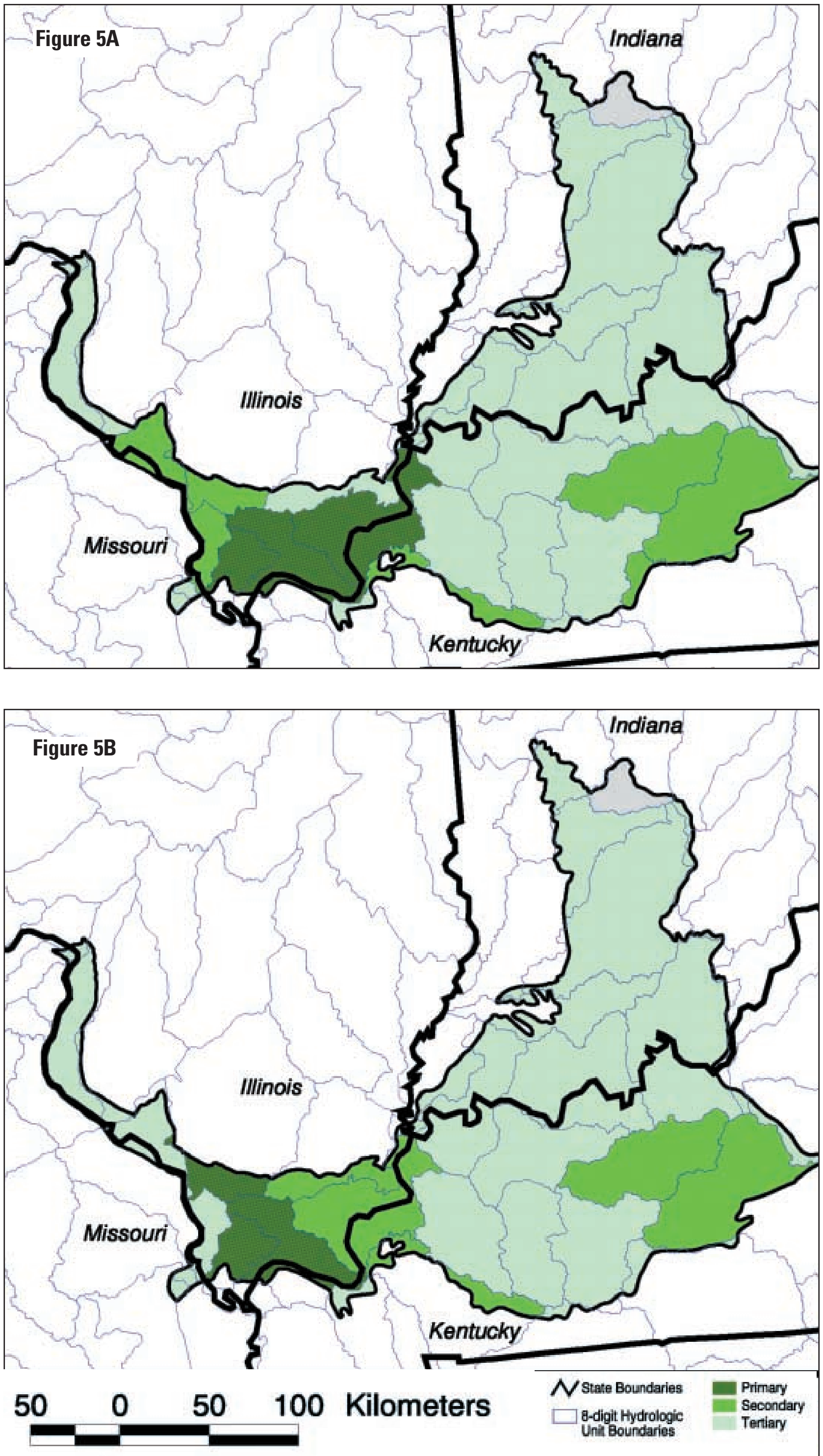


Figure 5. Levels of crayfish species richness (A) and crayfish species rank of overall importance (B) by watershed in the Hoosier-Shawnee Ecological Assessment Area.

White) are positioned on ecotones between uplands of the Interior Low Plateau and lowlands of the lower Ohio-Cache-Wabash Alluvial Plains. These units contained species characteristic of both tributaries and larger rivers and thus exhibited higher species richness.

Native mussel species density (number of species per square mile) was highly variable among hydrologic units, ranging from 0.007 to 0.6; average mussel species density was 0.07 species per mi^2. Regression of species richness with unit area was significant ($P < 0.05$), but the relationship between species density and unit area was not significant ($P \sim 0.2$). In mussels, therefore, richness increases at a constant rate as area increases at a constant rate (i.e., a linear relationship). Those hydrologic units representing a small portion of the HUCs (peripheral units) had inflated species densities that do not accurately reflect density patterns recorded for larger units. We therefore summed rank order values for species richness and density for each hydrologic unit to give an "index of relative importance" (table 3, fig. 4B). Hydrologic units having primary levels of species richness that also maintained primary rank orders of overall importance were the upper Green and lower Ohio. Eastern units (lower East Fork White, lower Ohio-Little Pigeon, Blue-Sinking, and Pond) ranking high in species richness mostly dropped to secondary levels of overall rank of importance, except that the Blue-Sinking unit dropped to a tertiary level of importance. All peripheral hydrologic units, or those with very small proportions in a particular HUC, were relegated to tertiary importance. The lower Tennessee and lower Cumberland units maintained ranks of primary importance because of their exceptional species richness. Although these units represent small portions of their respective HUCs, species density problems did not inflate their overall ranks. Four hydrologic units were assigned primary levels of relative importance—lower Tennessee, lower Ohio, lower Cumberland, and upper Green. Of these units, the lower Tennessee ranked first in species density (0.6 species per mi^2) and the Green ranked first in species richness (58 species). All 10 species federally listed as endangered have been reported from at least one of the units assigned primary levels of relative importance. The upper Green hydrologic unit contains the largest number of species federally listed as endangered—clubshell, rough pigtoe, fanshell, catspaw, northern riffleshell, pink mucket, and ring pink.

Composition of Native Crayfish Species

Approximately 390 species and subspecies of crayfish are endemic to North America (Lodge et al. 2000a, Taylor et al. 1996). The diversity of crayfish species in the assessment area represents only a small portion of North American diversity, although crayfishes nevertheless are a conspicuous and moderately diverse component of the local aquatic fauna. There are 34 species of crayfish in the assessment area (table 5) and all are members of the family Cambaridae. There are two dwarf species in the genus *Cambarellus*, subfamily Cambarellinae. Otherwise, the assessment area is host to five genera of crayfish all in the subfamily Cambarinae: *Barbicambarus, Cambarus, Fallicambarus, Orconectes,* and *Procambarus*. The largest genus, *Orconectes*, with 19 species, makes up almost 56 percent of the crayfish fauna in the assessment area. The genus *Cambarus* is represented by six species, *Procambarus* by four species, and *Barbicambarus* and *Fallicambarus* each by a single species.

Even though the relative diversity of crayfish species in the assessment area is low compared to other Forest Service assessment areas (e.g., Warren et al. 1999), crayfishes in the region play a significant ecological role and serve as an integral food source for recreationally and commercially important fishes (Lodge et al. 2000a, Taylor et al. 1996). Crayfishes can make up a large portion of the biomass in freshwater ecosystems and may be the largest individual invertebrates present there (Lodge et al. 2000a). Lodge et al. (2000a) also noted that, "Crayfishes are often a central part of freshwater foodwebs and ecosystems. They are dominant consumers of benthic invertebrates, detritus, macrophytes, and algae in streams and lakes, and are themselves important forage for fishes . . . Thus, additions or removals of crayfish species often lead to large ecosystem effects, in addition to changes in fish populations, and losses of biodiversity."

The high numbers of crayfish species supported by the Tennessee-Cumberland and Mississippi Embayment ecoregions are considered globally outstanding by Abell et al. (2000), and the Teays-Ohio and Central Prairie ecoregions also support fairly high numbers of crayfish species. The Tennessee-Cumberland and Mississippi Embayment ecoregions also support the highest number of endemic crayfishes of all North American ecoregions. These major ecoregions and their varied habitats and complexity are primary factors responsible for the crayfish diversity recorded from the assessment area.

Native crayfish species richness and density

Crayfish species richness, species density, index of relative importance, and rank of overall importance are reported for each hydrologic unit in the assessment area (table 6). Watersheds in the assessment area exhibiting primary, secondary, and tertiary levels of crayfish species richness are shown in figure 5A. The center of primary crayfish species richness occurs in the lower Ohio drainage, from roughly its confluence with the Wabash River to approximately its confluence with the Mississippi River. Nearly the entire Cache River drainage is included in the center of primary richness. There are two centers of secondary crayfish species richness: 1) the entire catchment of the Rough River, the approximately lower half of the upper Green River watershed, and the lower 6 percent of the Barren River watershed; and 2) the lower Mississippi River and its direct Illinois tributaries, from its confluence with the Kaskaskia River to roughly its confluence with the Cache River, and including the lower 12 percent of the Big Muddy River watershed. Secondary richness status also was achieved in two small portions of the lower Cumberland River drainage and its direct tributaries below Lake Barkley, as well as some of its headwater tributaries bordering the Pond and Tradewater River watersheds. No crayfish distribution data were available for the portions of the upper White River and middle White-Little Vermillion watersheds in Indiana. This pattern of species richness has implications for the Shawnee National Forest because all the watersheds making up the assessment area's center of primary species richness either underlie or border the Shawnee.

Watersheds in the assessment area exhibiting primary, secondary, and tertiary ranks of overall importance are shown in figure 5B. The area of primary rank of overall importance includes portions of three watersheds: the lower 12 percent of the Big Muddy River watershed, most of the Cache River watershed, and the lower Ohio River drainage from downstream of Ledbetter, Kentucky, to its approximate confluence with the Mississippi River. There are two centers of secondary overall importance: 1) the lower half of the upper Green and the entire Rough River watershed; and 2) portions of three watersheds including the lower Cumberland River and its direct tributaries below Lake Barkley, as well as some headwater tributaries bordering the Pond and Tradewater River watersheds; the lower Ohio River drainage from its confluence with the Wabash River to Ledbetter, Kentucky; and the southern 26 percent of the Saline River watershed. No distribution data were available for the portions of the upper White River and middle White-Little Vermillion watersheds in Indiana.

Endemic crayfishes

Six crayfish species are endemic to the assessment area: the Illinois crayfish (*Orconectes illinoisensis*) (Page 1985), the Indiana crayfish (*O. indianensis*) (Page 1985), the Kentucky crayfish (*O. kentuckiensis*) (Page 1985), the Crittenden crayfish (*O. bisectus*) (Taylor and Schuster 2001, unpublished spot-distribution maps), Rafinesque's crayfish (*O. rafinesquei*) (Taylor and Schuster 2001, unpublished spot-distribution maps), and Cobble crayfish (*O. margorectus*) (Taylor 2002).

The range of *O. illinoisensis* is completely contained within Illinois and for the most part coincides with the boundaries of the Shawnee National Forest, except that it also occurs in several rocky, Coastal Plain tributaries of the lower Ohio River. It is considered to be currently stable in the state, is common throughout its range, and can be locally abundant. Although *O. indianensis* is considered endemic to the assessment area, its historic range extends beyond the assessment boundaries, mainly via the North Branch of the Saline River in Illinois and via direct tributaries of the Wabash River north of Greathouse Island to almost its confluence with the White River. Although formerly more widespread in Illinois, the current distribution of *O. indianensis* falls within the assessment area. It is listed as endangered in Illinois (table 5). Except for one collection locality—14 specimens (INHS 112, 4568)—recent collections of *O. indianensis* in Indiana have been within the assessment area, and most of those collections have come from within the Hoosier National Forest. This crayfish species is presumed to be currently stable in Indiana (table 5). Nearly the entire range of *O. kentuckiensis* falls within the assessment area except for a small reach of the lower Cumberland River and its direct tributaries below Lake Barkley. It is listed as endangered in Illinois, occurring only in a few rocky, direct tributaries of the Ohio River in southeastern Illinois. In Kentucky, it occurs in several direct tributaries of the Ohio River in three counties—Crittenden, Livingston, and Union—and is considered to be currently stable.

Orconectes bisectus has the most limited range of the six crayfish species endemic to the assessment area. It is found only in Camp and Crooked Creeks, direct tributaries of the Ohio River, in Crittenden County, Kentucky. It is listed as threatened in Kentucky. *Orconectes margorectus*

Table 5. Conservation ranks of native freshwater crayfishes of the Hoosier-Shawnee Ecological Assessment Area.

Family Subfamily	Species	Common name	Occurrence SNF	Occurrence HNF	Conservation ranks Global	Federal	AFS	HNF	SNF	MIS HNF	MIS SNF	IL	IN	KY	MO
Cambaridae															
Cambarellinae	*Cambarellus puer*	Cajun dwarf crayfish	X		G4G5									E	S3?
Cambarellinae	*Cambarellus shufeldtii*	Shufeldt's dwarf crayfish	X		G5									S	S3?
Cambarinae	*Barbicambarus cornutus*	Bottlebrush crayfish			G3G4									S	
Cambarinae	*Cambarus bartonii*	Appalachian brook crayfish			G5										
Cambarinae	*Cambarus diogenes*	Devil crayfish	X	X	G5										
Cambarinae	*Cambarus graysoni*	Nashville crayfish			G5										
Cambarinae	*Cambarus ortmanni*	Lentic crayfish			G4G5										
Cambarinae	*Cambarus rusticiformis*	Riffle crayfish	X		G4G5										
Cambarinae	*Cambarus tenebrosus*	Spring grayfish	X	X	G5										
Cambarinae	*Fallicambarus fodiens*	Digger crayfish	X		G5										S2S3
Cambarinae	*Orconectes barrenensis*	Green River crayfish			G4		E								
Cambarinae	*Orconectes bisectus*	Crittenden crayfish			G2									T	
Cambarinae	*Orconectes illinoiensis*	Illinois crayfish	X		G3		SC								
Cambarinae	*Orconectes immunis*	Papershell crayfish	X	X	G5										
Cambarinae	*Orconectes indianensis*	Indiana crayfish	X	X	G2G3		SC		R			E			
Cambarinae	*Orconectes inermis*	Subterranean crayfish		X	G5T3T4			R							
Cambarinae	*Orconectes kentuckiensis*	Kentucky crayfish	X		G2		T		R			E			
Cambarinae	*Orconectes lancifer*	Shrimp crayfish			G5							E		E	S1S2
Cambarinae	*Orconectes luteus*	Golden crayfish			G5										
Cambarinae	*Orconectes margorectus*	Cobble crayfish			?	?	?								
Cambarinae	*Orconectes palmeri*	Gray-speckled crayfish			G5									E	
Cambarinae	*Orconectes pellucidus*	Eyelash crayfish			G3									S	
Cambarinae	*Orconectes placidus*	Placid crayfish	X		G5				R			E			
Cambarinae	*Orconectes putnami*	Disjunct crayfish			G5										
Cambarinae	*Orconectes rafinesquei*	Rafinesque's crayfish			G2		SC								
Cambarinae	*Orconectes ronaldi*	Mud River crayfish			G3										
Cambarinae	*Orconectes rusticus*	Rusty crayfish	X		G5										
Cambarinae	*Orconectes stannardi*	Little Wabash crayfish			G2		T								
Cambarinae	*Orconectes tricuspis*	Headwater crayfish			G4										
Cambarinae	*Orconectes virilis*	Virile crayfish	X		G5										
Cambarinae	*Procambarus acutus*	White River crayfish	X		G5										
Cambarinae	*Procambarus clarkii*	Red swamp crayfish	X	X	G5										
Cambarinae	*Procambarus gracilis*	Prairie crayfish	X		G5										
Cambarinae	*Procambarus viaeviridis*	Vernal crayfish	X		G5									T	S3

E = Endangered in the State
T = Threatened in the State
S = Special concern in the State
SC = Special concern federally
G1 = Critically imperiled globally (typically occurs in 5 or fewer counties)
G2 = Imperiled globally (typically occurs in 6 to 20 counties)
G3 = Very rare and local throughout range or found locally in a restricted range
G4 = Widespread, abundant, and apparently secure globally
G5 = Demonstrably widespread, abundant, and secure globally
T3 = Taxonomic subdivision: very rare and local throughout range or found locally in a restricted range
T4 = Taxonomic subdivision: widespread, abundant, and apparently secure globally
S1 = Missouri-Critically imperiled in the State (typically 5 or fewer occurrences)
S2 = Missouri-Imperiled in the State (typically 6 to 20 occurrences)
S3 = Missouri-Rare and uncommon in the state (21 to 100 occurrences)
R= rare within a national forest
SNF = Shawnee National Forest
HNF = Hoosier National Forest
AFS = American Fisheries Society
MIS = Management Indicator Species

Table 6. Native crayfish species richness, density, index of relative importance, and overall rank order for watersheds of the Hoosier-Shawnee Ecological Assessment Area.

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *	Endemic Species
		mi²	*mi²*	*no.*	*no. per mi²*			
Lower Missouri River Basin								
Lower Missouri	10300200	1,590	20.67	1 (12)	0.048 (7)	19	8	0
Upper Mississippi-Salt River Basins								
Peruque-Piasa	07110009	633	14.559	1 (12)	0.069 (3)	15	4	0
Kaskaskia River Basin								
Lower Kaskaskia	07140204	1,600	88	1 (12)	0.011 (15)	27	13	0
Upper Mississippi-Meramec River Basins								
Cohokia-Joachim	07140101	1,650	618.75	4 (9)	0.006 (19)	28	14(12)	0
Upper Mississippi-Cape Girardeau	07140105	1,690	397.15	8 (5)	0.020 (12)	17	6(7)	0
Big Muddy	07140106	2,350	289.05	8 (5)	0.028 (10)	15	4(5)	1
Whitewater	07140107	1,210	33.88	4 (9)	0.118 (2)	11	2	0
Cache	07140108	352	302.72	10 (3)	0.033 (9)	12	3(1)	1
St. Francis River Basin								
New Madrid-St. Johns	08020201	703	7.03	0 (13)	0.000 (24)	37	17	0
Little River Ditches	08020204	2,620	36.68	5 (8)	0.136 (1)	9	1	0
Lower Tennessee River Basin								
Lower Tennessee	06040006	689	79.235	4 (9)	0.050 (6)	15	4	1
Lower Cumberland River Basin								
Lower Cumberland	05130205	2,300	317.4	8 (5)	0.025 (11)	16	5	1
Red	05130206	1,450	55.1	2 (11)	0.036 (8)	19	8	0
Green River Basin								
Upper Green	05110001	3,130	1,311.47	8 (5)	0.006 (19)	24	10(8)	0
Barren	05110002	2,230	138.26	7 (6)	0.051 (5)	11	2	0
Middle Green	05110003	1,010	968.59	6 (7)	0.006 (19)	26	12(10)	0
Rough	05110004	1,070	1,070	9 (4)	0.008 (17)	21	9(7)	0
Lower Green	05110005	911	911	6 (7)	0.007 (18)	25	11(9)	0
Pond	05110006	784	784	5 (8)	0.006 (19)	27	13(11)	0
Wabash River Basin								
Middle Wabash-Little Vermillion	05120108	2,230	6.69	ND ND	ND ND	ND	ND	ND
Lower Wabash	05120113	1,300	202.8	0 (9)	0.000 (24)	33	16	0
Patoka-White River Basins								
Upper White	05120201	2,700	278.1	ND ND	ND ND	ND	ND	ND
Lower White	05120202	1,650	664.95	0 (13)	0.000 (24)	37	17	0
Eel	05120203	1,200	231.6	0 (13)	0.000 (24)	37	17(15)	0
Driftwood	05120204	1,150	40.25	0 (13)	0.000 (24)	37	17	0
Upper East Fork White	05120206	806	29.016	0 (13)	0.000 (24)	37	17	0
Muskatatuck	05120207	1,130	14.69	0 (13)	0.000 (24)	37	17	0
Lower East Fork White	05120208	2,030	1,822.94	3 (10)	0.002 (23)	33	16(14)	0
Patoka	05120209	854	620.004	4 (9)	0.006 (19)	28	14(12)	1

(table continued on next page)

(table 6 continued)

River Basin Hydrologic unit name	Watershed code (HUC)	Total area	Area of HUC in assessment	Species richness (rank order)	Species density (rank order)	Index of relative importance (sum rank orders)	Overall rank order *	Endemic Species
		mi^2	mi^2	no.	no. per mi^2			
Lower Ohio River Basin (to Miss. R. confl.)								
Lower Ohio-Little Pigeon	05140201	1,370	1,370	6 (7)	0.004 (21)	28	14(12)	1
Highland-Pigeon	05140202	1,000	957	5 (8)	0.005 (20)	28	14(12)	1
Lower Ohio-Bay	05140203	1,090	1,079.10	11 (2)	0.010 (16)	18	7(5)	2
Saline	05140204	1,160	300.44	6 (7)	0.020 (12)	19	8(6)	1
Tradewater	05140205	936	936	5 (8)	0.005 (20)	28	14(12)	1
Lower Ohio	05140206	928	668.16	12 (1)	0.018 (14)	15	4(2)	1
Lower Ohio River Basin (to mile 703)								
Silver-Little Kentucky	05140101	1,240	12.4	0 (13)	0.000 (24)	37	17	0
Salt	05140102	1,450	30.45	2 (11)	0.066 (4)	15	4	0
Rolling Fork	05140103	1,430	105.82	2 (11)	0.019 (13)	24	10	0
Blue Sinking	05140104	1,880	1,757.80	6 (7)	0.003 (22)	29	15(13)	0

* The overall ranks in parentheses have been determined with the small Hydrologic Units (less than 12% proportion of inclusion in the assessment area) removed from the ranking procedure. Small Hydrologic Units have inflated species densities and therefore convey artificailly high indicies of relative importance. See text for further discussion.

(Taylor 2002) occurs in Crittenden and Livingston Counties in Kentucky, and it is found in Deer Creek and its tributaries, Buck Creek, and the mainstem of the Cumberland River just upstream of Smithland, Kentucky. The description of this species (Taylor 2002) is so recent that no government agency has given *O. margorectus* official conservation status. *Orconectes rafinesquei,* found only in Kentucky, is endemic to the entire Rough River basin, Highland Creek in Henderson and Union Counties, the South Fork of Panther Creek in Ohio County, and two tributaries to the Green River, Pond Creek in Muhlenberg County and Deer Creek in Webster County. Kentucky lists this species as currently stable.

As an aside to crayfish endemicity in the assessment area, if the entire lower Cumberland and lower Tennessee watersheds were included in the assessment area, *O. tricuspis* would also be considered endemic. It occurs in upper Pond River tributaries, tributaries to Lake Barkley, the mainstem of the Cumberland River, and one tributary of Kentucky Lake. Although *O. tricuspis* is not a true endemic to the assessment area, aquatic management plans encompassing that portion of western Kentucky could certainly have an effect on individuals from throughout most of the species' range.

Implications and Opportunities

We synthesized information on diversity and the geographic patterns of fish, mussel, and crayfish distribution within the assessment area. The synthesis revealed that the assessment area and its surrounding hydrologic units support a large portion of continental, national, and regional fish, mussel, and crayfish species diversity, including a moderate number of endemic species. For example, the eastern half of North America represents the center of diversity for freshwater mussels worldwide. In fact, the World Wildlife Fund's recent (Abell et al. 2000) conservation assessment of freshwater ecoregions of North America ranks three of the assessment area's subregions as globally outstanding and the remaining two as bioregionally outstanding. These two categories, globally outstanding and bioregionally outstanding, are the highest conservation rankings possible on a worldwide scale. The implications of these rankings are almost mind boggling because temperate freshwater faunas in other parts of the world (e.g., Europe, China) have experienced severe degradation and loss of diversity. The Forest Service carries a staggering responsibility for management and protection of this unique resource within the hydrologic units included on its property.

We were able to examine these rich aquatic faunas only on a relatively large and coarse scale (i.e., presence or absence of fishes, mussels, and crayfishes in hydrologic units). The synthesis relied on available literature and did not account for declines in populations in recent times even though abundant evidence is available that several fish and mussel species have experienced a reduction in range or fragmentation of populations within the assessment area (Burr and Page 1986, Burr and Warren 1986, Cummings 1991, Cummings and Mayer 1997, Smith 1979, Warren et al. 2000). For example, of the 297 native freshwater mussels in North America, 213 species (nearly 72 percent) are considered endangered, threatened, or of special concern (Williams et al. 1993). More than 75 percent of these species are believed to be suffering from range reductions, leaving distantly isolated populations that may be functionally extinct—having numbers too low to support a viable population (Watters 2000).

Many aquatic species in the assessment area are found in waters under Federal management (i.e., in national forests), including several hydrologic units of either primary or secondary rank of overall importance. Given the trend toward continued human population growth, the concomitant increase in consumption, and the accompanying modification of aquatic habitats across the assessment area, waters on federally managed lands are becoming increasingly critical for the continued existence of viable populations and communities of native aquatic species. For example, studies are needed to determine how many of the original mussel communities in the assessment area are still viable, but maintenance of stable mussel communities requires an understanding of the factors involved in recruitment, especially the presence of suitable fish hosts.

The effect of forest management practices on fishes, mussels, and crayfishes is a significant, but little understood, component of land management within the assessment area. The response of Pacific salmon and trout to forest disturbance has been examined extensively in the Pacific Northwest. As yet, no comparable body of literature exists for fishes, mussels, or crayfishes of the assessment area, even though the fishes are the best known and most visible members of the aquatic community. Provisional assessments of forest cutting and removal of riparian zones indicate that stream fish and mussel communities generally suffer losses in both diversity and abundance of species (Cummings and Mayer 1997, Smith 1971, Page 1991), but carefully planned experimental studies of these sorts of practices have not yet been done in either the Shawnee or Hoosier National Forests.

The introduction and spread of exotic freshwater bivalve species such as the zebra mussel (*Dreissena polymorpha*) and Asian clam (*Corbicula fluminea*) have had significant impacts on native mussels. These exotic species have established high-density populations and have been implicated in the decline of native mussels (Williams et al. 1993). Efforts are needed to control the spread of these nuisance species and their subsequent impacts on additional native mussel communities.

We consider the synthesis of data about the distribution and diversity of fishes, mussels, and crayfishes to be a starting point for identifying and prioritizing information needs that can then be used to better conserve aquatic diversity.

ENDANGERED, THREATENED, AND OTHER AQUATIC SPECIES OF SPECIAL CONCERN

North America's freshwater habitats support some of the most extraordinary biotic assemblages in the world (Abell et al. 2000), and yet in a few short decades we have systematically recorded the loss of a significant number of native American fishes and mussels that took the concerted efforts of hundreds of individuals more than 200 years to discover, record, and describe (Warren and Burr 1994). The major proximate causes of declines in fishes, mussels, and crayfishes are (1) physical habitat loss, degradation, or alteration; (2) chemical pollution or alteration; (3) overexploitation; and (4) introduction of competitive nonindigenous organisms (Allan and Flecker 1993, Williams et al. 1993). The process of extinction in the Eastern United States can be related to landscape-scale phenomena that decrease habitat area or quality and ultimately fragment and isolate populations (Angermeier 1995). This process usually takes place gradually with total extinction or extirpation preceded by local losses or regional annihilations (Angermeier 1995). Understanding and eventually preventing local extirpations or total extinctions will surely require greater attention to landscape-level patterns and processes than has been done in the past.

Recent case histories have demonstrated that one of the most powerful defenses against aquatic biodiversity loss, at least in the United States, is the Endangered Species Act (ESA) of 1973, as amended. Additionally, the Clean Water Act (CWA) of 1972, as amended, is another powerful statutory tool for habitat and species conservation that can prevent human-caused endangerment of aquatic communities and environments (Angermeier and Karr 1994). Under the ESA, "species" are interpreted as including species, subspecies, and certain distinctive populations. Those species listed by Federal authority are provided legal protection under specific categories such as endangered, threatened, proposed endangered, and proposed threatened. Species determined as worthy of protection are maintained on official lists by the U.S. Fish and Wildlife Service (1997a, b).

Other private organizations and State agencies are playing increasingly significant roles in the early recognition, listing, and protection of those species potentially at risk of decline or extirpation. Using protocols developed by The Nature Conservancy and State Natural Heritage Programs, listed species have their distributions and conservation statuses monitored. Globally ranked (i.e., G1, G2, or G3) taxa and those considered imperiled at the state level (a variety of categories used here) are also tracked by natural heritage programs and other independent organizations.

More recently, the American Fisheries Society, using panels of professional biologists, has provided additional independent rankings of conservation status for fishes (Warren et al. 2000), mussels (Williams et al. 1993), and crayfishes (Taylor et al. 1996). In this report, we have included rankings from the four State Natural Heritage Programs and the reports by expert panels representing the American Fisheries Society, as well as the Federal listings. The information provided by these varied listings will be an aid to the Fish and Wildlife Service to draw from in considering possible future candidate species for listing and can help with prioritizing and planning of recovery efforts, status surveys, and research on aquatic species.

DATA SOURCES

Within constraints of time and the patterns and trends in the assessment area, we modeled the following section after the excellent chapter on *Endangered, Threatened, and Other Species of Special Concern* (Warren and Tinkle 1999), in *Ozark-Ouachita Highlands Assessment: Aquatic*

Conditions (General Technical Report SRS-33 (1999), regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). We synthesized information in tabular format on endangered, threatened, and special concern aquatic organisms including fishes, mussels, and crayfishes. We included species with Federal status (i.e., endangered or threatened under the ESA or candidate species); those ranked globally as G1, G2, or G3 by The Nature Conservancy (Natureserve Web site 2001); and those ranked by State Natural Heritage Programs (Illinois Endangered Species Protection Board 2000, Indiana Department of Fish and Wildlife Web site 2001, Kentucky State Nature Preserves Commission Web site 2001, Missouri Natural Heritage Program 2000). Separate columns were used for the conservation status rankings of the American Fisheries Society (Taylor et al. 1996, Warren et al. 2000, Williams et al. 1993) and the USDA Forest Service (Chad Stinson, Forest Service, personal communication).

We used the latest lists of endangered and threatened animals compiled by the Missouri, Illinois, Indiana, and Kentucky natural heritage or conservation programs and posted on their respective Web sites or their less frequently published lists (e.g., Illinois Endangered Species Protection Board 2000). Some species in the lists may no longer occur where they were once documented, and their listing does not indicate the continued existence of a species in a particular watershed or State. We corrected any inconsistencies between various lists by consulting the most recent species occurrence data available, including that accumulated by several of us actively researching the target aquatic groups. We also included global rankings for all species in the assessment area to provide the status of all taxa at a given point in time (i.e., September 2001).

PATTERNS AND TRENDS

Fishes

Only two federally listed fish species, pallid sturgeon and northern cavefish, occur within the assessment area (table 2). The endangered pallid sturgeon is narrowly restricted to the main channel of the Mississippi and Missouri Rivers in the region and has never been reported in the mainstem Ohio or Wabash Rivers. As a big river inhabitant, it is technically outside the boundaries of the Shawnee National Forest; its status and management are being actively studied by a team of aquatic biologists from several states bordering the Mississippi and Missouri Rivers. The range of the threatened northern cavefish falls within some of the property under jurisdiction of the Hoosier National Forest but presents an unusual case because it occurs only in karst habitat where subterranean streams may be difficult to access. A reasonably comprehensive status survey of this species was completed by Pearson and Boston (1995), whose distributional and population estimates indicated the species was stable but subject to decline through vandalism, overcollecting, groundwater pollution, and other factors.

Three candidate species within the assessment area are the Alabama shad, sturgeon chub, and sicklefin chub. All three of these species are denizens of the mainstem Mississippi River, with a few historical records of the Alabama shad available from the mainstem Ohio River (Burr and Warren 1986). The shad appears to have declined precipitously in the last century, at least in the upper Mississippi River basin. It is unique in our area for being the only species that migrates from the Gulf of Mexico up the Mississippi River into freshwater streams to spawn. In fact, the only known spawning reaches in the entire upper Mississippi basin are in the State of Missouri (Pflieger 1997); none are known in Illinois, Indiana, or Kentucky. The two chub species are being studied by both Illinois and Missouri personnel, and a new technique involving trawl nets in water about 12 feet deep or less has revealed more adults and young-of-the-year than expected. The new populational and distributional data indicate that neither species may meet requirements for listing as federally endangered or threatened. Once again, all three of these species are peripheral to either the Shawnee or Hoosier National Forests.

Other species listed by more than one State and known to presently occur within the assessment area include the lake sturgeon and southern cavefish. Lake sturgeon records from the Ohio and Mississippi Rivers were far more frequent in the past 10 years than the previous 20. Both Missouri and Wisconsin have released hatchery stock into public waters, which may account in part for the number of recent records, especially because this species is known to travel long distances in more northern waters (Becker 1983). A probable breeding population of the lake sturgeon is apparently present in the White River, Indiana, where the species is being intensively studied. This is the only known potential site of reproduction in the entire assessment area. The cavefish is an obligate cave dweller (troglobite) and is extremely rare in the southern Indiana karst region. A status survey of the southern cavefish is needed for Kentucky.

Rare fishes in the Shawnee and Hoosier Forests

Perhaps of greatest relevance to the assessment area is the status of fish species known to presently inhabit streams of the Shawnee and Hoosier National Forests. Of some 140 fish species documented from Shawnee National Forest waters, those with restricted or sporadic ranges or naturally low population numbers include the least brook lamprey, bluehead shiner, bigeye chub, rosefin shiner, slender madtom, starhead topminnow, bantam sunfish, and redspotted sunfish. The least brook lamprey has had one of only five spawning streams in southern Illinois decimated by recent reservoir construction (Burr and Stewart 1999, Weitzell et al. 1998). Other Shawnee populations appear currently stable. The bluehead shiner is probably extinct in Illinois although it once occurred in the LaRue-Pine Hills Research Natural Area (see Burr et al. 1996). The bigeye chub and rosefin shiner were both known historically from Big Creek, Hardin County, within traditional Shawnee National Forest boundaries. Neither species has been found in the southeastern Illinois forest region in decades. The slender madtom is known only from small streams in the upper Clear Creek system in the western region of the Shawnee (e.g., Green and Hutchins Creeks). It is currently stable but highly restricted in range in national forest waters. The starhead topminnow, bantam sunfish, and redspotted sunfish all occur in the LaRue-Pine Hills Research Natural Area where they are currently stable but have very narrow ranges within southern Illinois and the Shawnee boundaries. Additional species worthy of conservation attention in the Shawnee include the southern redbelly dace, lake chubsucker, and spring cavefish. All three occur in sensitive habitats, including springs, spring runs, karst areas, wetlands, and swamps that have been drastically altered in surrounding regions.

Of the 128 native fishes in the Hoosier National Forest, a few are of conservation concern including the muskellunge, northern cavefish, bluebreast darter, and Tippecanoe darter. These four species are all listed by the State of Indiana as either endangered or extirpated. Numerous additional species of conservation concern are known from streams in areas near the Hoosier National Forest boundaries and may occur within the national forest, but the lack of comprehensive sampling data in Indiana waters by competent and well-trained ichthyologists and aquatic biologists has hampered our assessment of aquatic animals at all scales. Nonetheless, status surveys in southern Indiana should target the following rare or restricted (and listed) species: lake sturgeon, popeye shiner, northern studfish, harlequin darter, spotted darter, variegate darter, gilt darter, and eastern sand darter.

According to McComish and Brown (1980), the muskellunge was caught by anglers in different watersheds in the southern portion of Hoosier National Forest up until the 1960s. Apparently no voucher specimens are known and accurate identification is equivocal. The species may be extirpated or at such low population levels that detection by conventional sampling methods has not been forthcoming. Known to anglers as an elusive and challenging sportfish, this species warrants a comprehensive plan for appropriate stocking and management. A thorough and recent field study of the northern cavefish documented reliable records for the species at 44 different sites in southern Indiana (Pearson and Boston 1995). These authors conservatively estimated that there were at least 5,602 individuals of northern cavefish in Indiana and Kentucky combined, the entire known range of this species. Further extrapolations, based on probable phreatic conduits among cave openings and the probable number of cave openings not explored, indicated the population may reach at least 56,000 individuals. For details, the reader is referred to the excellent report by Pearson and Boston (1995). The bluebreast and Tippecanoe darters are both known from the East Fork White River, but published information based on thorough sampling in the drainage is not available. Other fishes that historically occurred in the Hoosier but that are becoming uncommon in the Midwest and need status surveys are the following: all lamprey species, gravel chub, bigeye chub, pallid shiner, trout perch, and channel darter. Searches for the southern cavefish within karst areas of the Hoosier are also desired because Pearson and Boston (1995) found none in the Indiana locations they and others surveyed.

Extirpated and extinct fishes

Of the nearly 200 native fish species recorded in the assessment area, at least 125 are considered currently stable; with thorough field searches in appropriate habitat an additional 20 or so species could probably be removed from further conservation concern. These numbers are reassuring but could be misleading considering that a number of species have already disappeared from national forest watersheds in both Indiana and Illinois. Over the latter half of the 20th century, three species—alligator gar, pallid shiner, and harelip sucker (*Lagochila lacera* or *Moxostoma lacerum*)—have been documented as extinct or nearly extirpated from waters of the upper Mississippi River basin. The alligator gar has not been recorded in the assessment area since the 1960s (Burr et al. 1996, Poly 2001), and the pallid shiner has virtually disappeared from the region since the 1950s (Burr and Warren 1986, Pflieger 1997, Warren and Burr 1988). The harelip sucker, last observed in 1893, once occurred in Indiana waters (Jenkins in Jenkins and Burkhead 1994) but is considered extinct throughout its range. On a smaller scale, 19th century records (Forbes and Richardson 1909) of the blacknose and longnose daces are available for streams in the western Shawnee; no records since that time are known. The rosefin shiner and bigeye chub once occurred in Spring Branch or Big Creek, Hardin County, in the eastern Shawnee, but neither species has been documented in southern Illinois since 1900 (Smith 1979) and 1935 (B. M. Burr, personal observation), respectively. The popeye shiner once occurred in the East Fork White River, Indiana, in the late 19th century, but appears to be extirpated there (and elsewhere in Indiana) now (Gilbert 1969). This location was near the western edge of the Hoosier.

Mussels

Conservation ranks assigned to the 76 native mussel species occurring within the assessment area reveal that 42 are currently stable, 13 are of special concern, 5 are threatened, and 16 are either endangered or possibly extinct, according to the assignment of status categories by the American Fisheries Society Endangered Species Committee (Williams et al. 1993). Ten species are federally listed as endangered—orangefoot pimpleback, clubshell, rough pigtoe, fanshell, catspaw, northern riffleshell, tubercled blossom, pink mucket, ring pink, and fat pocketbook (http://ecos.fws.gov). Nearly 70 percent of the species within the assessment area are considered rare, threatened, or endangered in at least one of the States included in the assessment area. Global ranks (Association for Biodiversity www.natureserve.org) assigned to native freshwater mussels occurring within the assessment area show that 48 species are secure or apparently secure, 8 are vulnerable, 16 are either imperiled or critically imperiled, and 4 are presumed extinct (table 4).

Crayfishes

Four crayfish species (*Orconectes bisectus, O. kentuckiensis, O. rafinesquei*, and *O. stannardi*) in the assessment area are globally imperiled, three (*O. illinoisensis, O. pellucidus,* and *O. ronaldi*) are globally very rare (i.e., locally restricted ranges), and one species (*O. indianensis*) is designated as globally imperiled or at least very rare (table 5). Three of these species (*O. illinoisensis, O. indianensis,* and *O. kentuckiensis*) occur in at least one watershed that drains the Shawnee National Forest, and one species (*O. pellucidus*) occurs in several watersheds of the Hoosier National Forest. All other species are locally abundant throughout their ranges and are considered globally secure. The assessment area harbors no federally listed crayfish species. The American Fisheries Society lists one crayfish species as endangered (*O. barrenensis*), two as threatened (*O. kentuckiensis* and *O. stannardi*), and three species of special concern (*O. illinoisensis, O. indianensis, O. rafinesquei*). The Forest Service lists one species as threatened (*O. indianensis*) and two species (*O. kentuckiensis* and *O. placidus*) of special concern in the Shawnee National Forest, and one species (*O. inermis*) of special concern in the Hoosier National Forest.

Implications and Opportunities

Increased and coordinated efforts to conduct status surveys and inventories of aquatic species are highly desired for the assessment area. We cannot emphasize enough the lack of available data for the Hoosier National Forest or the State of Indiana, especially for aquatic organisms. For example, Indiana listed no crustaceans as endangered, threatened, or of special concern, even though two crayfishes are listed as globally rare. In comparison to Kentucky, Illinois, and Missouri, where biologists have accumulated nearly comprehensive data sets for fishes, mussels, and crayfishes, Indiana agencies and personnel need to strive for establishing baseline data on aquatic species except those identified as of sport or commercial value. For example, springs and spring runs are among the most valuable of groundwater resources. Both the Shawnee and Hoosier National Forests have numerous springs and spring runs and yet there has been no concerted effort to simply document and describe these unique habitats and examine in some detail their aquatic communities.

The current information available for judging the true status (population sizes, distribution, trends, and threats) of many species is so fragmentary that some species now considered imperiled may not deserve consideration whereas other species may be in jeopardy of extinction but go unrecognized (Williams and Neves 1992). It is apparent from recent work documenting the distribution and status of aquatic species (e.g., Pflieger 1996) that comprehensive inventory efforts in some states are given higher priority and greater support than in others. The ability of natural resource managers to recognize species threatened with extinction or experiencing population declines depends on the timeliness, quality, and comprehensiveness of inventory information available to them. The database assembled for this report provides a basis for increased interstate and Federal-State coordination of efforts to provide up-to-date status information on aquatic species in the assessment area.

COMMERCIALLY AND RECREATIONALLY IMPORTANT SPECIES

Angling or recreational fishing continues to be a favorite pastime in the United States; nationwide, 17 percent of the population 16 years of age and older have participated in sport fishing activities. Recent figures for Illinois and other states in the assessment area are similar. Angling is also a significant source of revenue; sport fishers spend nearly $40 billion annually pursuing their sport nationwide. In Illinois alone, angler expenditures totaled more than $1.6 billion in 1999. The assessment area is home to thriving musky guide services; popular fishing resorts; major fishing, boat, and tackle manufacturers, large and productive aquaculture facilities and fish farms; and major professional sport fishing tournaments and champions. These activities are highly visible and generate huge revenues for the economies of the assessment area.

The intense level of interest in angling would not have developed if a significant fishery resource had not existed naturally. Historical accounts of early inhabitants indicate that they found a plentiful supply of stream and river fisheries. In the assessment area, however, flowing waters have been altered by construction of dams, levees, channelization and dredging, gravel mining, locks, impoundments, and ponds and by ever increasing demands on the harvest of fishery resources.

Fishery managers respond to the challenge of altered aquatic environments by trying to manage for sustainable yield (through natural fish reproduction) where possible. When necessary, managers supplement or replenish sport fish stocks with fish from either hatcheries or aquaculture facilities. Subsequent yields vary depending on the amount of sport and commercial fishing pressure tempered by habitat quality, the effectiveness of fishing regulations, and the ability of resource agencies to fund improvements in aquatic habitat, increasing demands for stocking, and better hatchery facilities.

In this section, we briefly discuss harvest information and identify differences in legal definitions of sport and commercial fish. More limited information is available on commercial uses and values of crayfish species in the states of the assessment area. The legal harvest of mussel species among assessment area states has been under investigation for several years, especially in the mainstem Ohio River. The recent (1999) collapse in the export market for shells will be beneficial to mussels. For example, no commercial harvest for mussels has been reported in Illinois since the collapse of the market. We also present information on the stocking of nonindigenous fish species and the supplemental stocking of native fish species within the assessment area.

DATA SOURCES

Within constraints of time and the patterns and trends in the assessment area, we modeled the following section after the excellent chapters on *Commercially and Recreationally Important Species* (Standage 1999a), and *Management Indicator Species* (Standage 1999b) in *Ozark-Ouachita Highlands Assessment: Aquatic Conditions* (General Technical Report SRS-33 (1999), regarding the Ozark-Ouachita Ecological Assessment in Missouri, Arkansas, Kansas, and Oklahoma). We derived lists of species of legal sport and commercial fishes from the Wildlife Codes (hunting and fishing regulations) of each state or from its respective Web page. All of the lists, except Missouri, were vague in terms of taxonomy (e.g., use of the term “sucker” or “redhorse” for several species of *Moxostoma*), and we adjusted the names in table 10 to reflect our best professional judgment (from interviews with commercial fishermen over the last several years and visits to fish markets on the Mississippi and Ohio Rivers) of the species most often caught and sold at market. We found that in many cases fish family groups were listed as sport/game and/or commercial species, when in fact, a particular species in a group does not grow large enough to have angling or commercial value. We identified only those species within a given fish family that might have sport or commercial value. Thus, blue catfish are shown as both a sport and commercial species, whereas the smaller madtom catfish are not.

It is difficult to obtain statistical information on commercial harvest of fishes from natural populations in North America except for the Laurentian Great Lakes. The National Marine Fisheries Service publishes an annual summary entitled *Fisheries of the United States,* but freshwater landings were not listed separately until 1995. Some commercial data from State Natural Resource Agencies can be compared to a survey made in 1975.

We did not make an attempt to tabulate "minnows" that are captured for bait or sold by commercial fishermen because if caught in the wild any number of species might be involved. Sport fish were identified by examining the lists of record size fish caught on hook and line for each of the four states. Some states have listed their stocking records on their respective Web pages. Nearly all included largemouth bass, bluegill, and channel catfish, all of which are ubiquitous in the assessment area and are stocked in nearly all lentic habitats in the region. We have used some information about additional species raised in the State hatchery systems as an indicator of special areas being stocked with specific exotic or nonindigenous species.

General information regarding human consumption of crayfishes was summarized from Huner (1978), Lodge et al. (2000a), and Page (1985). Data on the commercial harvest of mussels were taken from Cummings (1991) for Illinois, Williams and Schuster (1989) for Kentucky, and Oesch (1984) for Missouri.

PATTERNS AND TRENDS

Commercial Fish Harvest

More than 50 species of fish make up the freshwater commercial harvest in North America (Heidinger 2000); this figure does not include the bait minnow industry. In North America, less than 1 percent of the total commercial harvest of finfish comes from fresh water. Average yearly harvest of selected freshwater fishes from 1982 to 1984 compared to the average yearly harvest from 1995 to 1997 indicates a 61 percent reduction in harvest in the United States (Heidinger 2000). In a 1994 survey, just over 66 percent of the total United States harvest was from either the Great Lakes (29.2 million pounds) or the State of Arkansas (29 million pounds). To place this freshwater harvest in perspective, one only needs to realize that the 1998 commercial harvest of salmon from Alaska was 713 million pounds (Heidinger 2000) and the channel catfish aquaculture industry produced 507 million pounds in 1996 (USDA 1997). The price paid for fish in the round varies both by species and by location. Prices paid for selected species in, for example, Illinois and Missouri, range from $0.07 to $0.75 per pound (table 7).

Species legally available for harvest in Missouri, Illinois, Indiana, and Kentucky are presented in table 8 which also includes species that some states categorize as "rough" fish (e.g., gars, bowfin, shads, redhorses, freshwater drum). We have observed all of these species in the catches of commercial fishermen in Illinois and Kentucky or being sold in the few fish markets

Table 7. Approximate price per pound (round) of selected species (in cents) of commercial fishes of the Hoosier-Shawnee Ecological Assessment Area.

Species	Illinois 1993 (Dufford 1994)	Missouri 1992 (Robinson 1994)
American eel	12-32	18
Blue catfish	36-75	54
Bowfin	7-15	7
Buffalofishes	19-35	24
Bullheads	23-50	24
Common carp	7-35	12
Channel catfish	44-75	55
Flathead catfish	35-75	54
Freshwater drum	9-40	15
Gars	15-50	10
Grass carp	7-25	21
Other Asian carp	7-25	---
Paddlefish	20-31	30
Quillback carpsucker	7-50	19
Shovelnose sturgeon	25-60	25
Suckers	7-20	---

still open on the bordering big rivers of the assessment area.

Except for the major rivers (i.e., Mississippi, Ohio, and Wabash) in the assessment area, freshwater commercial fishing often is banned and is usually unpopular with sport anglers. Anglers fear exploitation of sportfishes by commercial fishermen and interference from commercial gear. Sportfishes taken with commercial gear must be returned to the body of water from which they were captured. Sport anglers often destroy commercial fishing gear especially if their lures get entangled by it.

Waters open to commercial fishing in Missouri include the Missouri, Mississippi, and lower St. Francis Rivers (MO DC 1997). From 1993 through 1995, the number of licensed commercial fishers with gear was 340, 319, and 395, respectively. A commercial fish license is also required of mussel harvesters, but their nets and other fishing gear are not regulated. Most commercial fishers (94 percent) have reported harvesting fewer than 5,000 pounds of fish annually since the 1988 license period. This level of harvesting strongly indicates that few fishers make much money from commercial fishing (Robinson 1994). Even at the price of $0.54/pound (the greatest price in 1992 for any commercial fish species), maximum earnings are below the poverty level.

Removal of all catfish species from the commercial fish list on the Missouri River (effective in 1992) is also considered to have caused a drop in the number of commercial fishers (Robinson 1994). The commercial harvest in Missouri for 1993 through 1995 ranged from 541,000 to 668,000 pounds with nearly half of all catches in weight consisting of buffalofishes and common carp. The grass carp harvest grew from 8,787 pounds in 1993 to 15,330 pounds in 1994, and 21,366 pounds in 1995. The majority of the grass carp harvest was from the Missouri and Mississippi Rivers. Undoubtedly, similar increases have occurred for bighead and silver carp, but the data are preliminary at the time of this writing. Commercial fishing is anticipated to remain fairly constant on the big rivers unless: (1) license fees increase significantly; (2) consumption advisories are imposed; (3) further restrictions on the harvest of catfish are imposed; (4) further restrictions on the harvest of sturgeon for caviar are imposed; or (5) the market for fresh fish changes dramatically.

Excluding the bordering rivers and the Great Lakes, Illinois continues to allow commercial fishing in two of the three large U.S. Army Corps of Engineers' reservoirs, Rend and Carlyle Lakes. Rend Lake was open to commercial fishing from January 31 to March 24, 2000. A total of 365,589 pounds of commercial species, primarily bigmouth buffalo, were harvested. Carlyle Lake was opened to commercial fishing from December 28, 1999 to January 28, 2000. A total of 109,519 pounds of commercial species were harvested. Both of these lakes are located to the north and outside of the assessment area. Commercial fishing on the portion of the big rivers (i.e., Mississippi, Ohio, and Wabash Rivers) that lie within the assessment

Table 8. Sport and commercial fishes of the Hoosier-Shawnee Ecological Assessment Area, by State. List includes exotic and non-indigenous species.

			Illinois		Indiana		Kentucky		Missouri	
Family	**Scientific name**	**Common name**	**Sport**	**Comm.**	**Sport**	**Comm.**	**Sport**	**Comm.**	**Sport**	**Comm.**
Acipenseridae	*Acipenser fulvescens*	Lake sturgeon		x			x			
Acipenseridae	*Scaphirhynchus platorynchus*	Shovelnose sturgeon	x	x	x	x		x		
Amiidae	*Amia calva*	Bowfin	x	x	x	x	x	x	x	x
Anguillidae	*Anguilla rostrata*	American eel		x				x	x	x
Catostomidae	*Carpiodes carpio*	River carpsucker		x		x				x
Catostomidae	*Carpiodes cyprinus*	Quillback		x		x				x
Catostomidae	*Carpiodes velifer*	Highfin carpsucker		x		x				x
Catostomidae	*Catostomus commersoni*	White sucker		x				x	x	x
Catostomidae	*Cycleptus elongatus*	Blue sucker		x				x	x	x
Catostomidae	*Hypentelium nigricans*	Northern hog sucker		x					x	
Catostomidae	*Ictiobus bubalus*	Smallmouth buffalo	x	x	x	x		x	x	x
Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	x	x	x	x			x	x
Catostomidae	*Ictiobus niger*	Black buffalo	x	x		x			x	x
Catostomidae	*Minytrema melanops*	Spotted sucker		x						x
Catostomidae	*Moxostoma anisurum*	Silver redhorse		x					x	x
Catostomidae	*Moxostoma carinatum*	River redhorse						x	x	x
Catostomidae	*Moxostoma duquesnei*	Black redhorse		x						x
Catostomidae	*Moxostoma erythrurum*	Golden redhorse		x				x	x	x
Catostomidae	*Moxostoma macrolepidotum*	Shorthead redhorse		x					x	x
Centrarchidae	*Ambloplites rupestris*	Rock bass	x		x		x		x	
Centrarchidae	*Centrarchus macropterus*	Flier			x				x	
Centrarchidae	*Lepomis auritus*	Redbreast sunfish					x			
Centrarchidae	*Lepomis cyanellus*	Green sunfish	x		x		x		x	
Centrarchidae	*Lepomis gulosus*	Warmouth	x		x		x		x	
Centrarchidae	*Lepomis humilis*	Orangespotted sunfish								
Centrarchidae	*Lepomis macrochirus*	Bluegill	x		x		x		x	
Centrarchidae	*Lepomis megalotis*	Longear sunfish					x			
Centrarchidae	*Lepomis microlophus*	Redear sunfish	x		x		x		x	
Centrarchidae	*Lepomis symmetricus*	Bantam sunfish								
Centrarchidae	*Micropterus dolomieu*	Smallmouth bass	x		x		x		x	
Centrarchidae	*Micropterus punctulatus*	Spotted bass	x		x		x		x	
Centrarchidae	*Micropterus salmoides*	Largemouth bass	x		x		x		x	
Centrarchidae	*Pomoxis annularis*	White crappie	x		x		x		x	
Centrarchidae	*Pomoxis nigromaculatus*	Black crappie	x		x		x		x	
Clupeidae	*Alosa chrysochloris*	Skipjack herring					x			
Clupeidae	*Dorosoma cepedianum*	Gizzard shad		x						
Cyprinidae	*Carassius auratus*	Goldfish		x						
Cyprinidae	*Cyprinus carpio*	Common carp	x	x	x	x	x	x	x	x
Cyprinidae	*Ctenopharyngodon idella*	Grass carp	x	x	x	x	x	x	x	x
Cyprinidae	*Hypophthalmichthys molitrix*	Silver carp		x		x		x		x
Cyprinidae	*Hypophthalmichthys nobilis*	Bighead carp	x	x	x	x	x	x	x	x
Esocidae	*Esox americanus*	Grass pickerel					x		x	
Esocidae	*Esox lucius*	Northern pike	x		x		x		x	
Esocidae	*Esox masquinongy*	Muskellunge	x		x		x		x	
Esocidae	*Esox masquinongy* x *E. lucius*	Tiger musky	x		x		x		x	

(table continued on next page)

(table 8 continued)

Family	Scientific name	Common name	Illinois		Indiana		Kentucky		Missouri	
			Sport	Comm.	Sport	Comm.	Sport	Comm.	Sport	Comm.
Esocidae	*Esox niger*	Chain pickerel			x		x		x	
Gadidae	*Lota lota*	Burbot			x					
Hiodontidae	*Hiodon alosoides*	Goldeye	x	x					x	
Hiodontidae	*Hiodon tergisus*	Mooneye								
Hiodontidae	*Hiodon tergisus*	Mooneye		x						
Ictaluridae	*Ameiurus catus*	White catfish			x				x	
Ictaluridae	*Ameiurus melas*	Black bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ameiurus natalis*	Yellow bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ameiurus nebulosus*	Brown bullhead	x	x	x	x	x	x	x	x
Ictaluridae	*Ictalurus furcatus*	Blue catfish	x	x	x	x	x	x	x	
Ictaluridae	*Ictalurus punctatus*	Channel catfish	x	x	x	x	x	x	x	
Ictaluridae	*Pylodictis olivaris*	Flathead catfish	x	x	x	x	x	x	x	
Lepisosteidae	*Atractosteus spatula*	Alligator gar								x
Lepisosteidae	*Lepisosteus oculatus*	Spotted gar	x	x		x	x	x	x	
Lepisosteidae	*Lepisosteus osseus*	Longnose gar		x		x		x	x	x
Lepisosteidae	*Lepisosteus platostomus*	Shortnose gar	x	x		x		x		x
Moronidae	*Morone chrysops*	White bass	x		x		x		x	
Moronidae	*Morone mississippiensis*	Yellow bass	x		x		x		x	
Moronidae	*Morone saxatilis*	Striped bass	x		x		x		x	
Moronidae	*Morone saxatilisx M. chrysops*	Sunshine or Calico bass	x		x		x		x	
Percidae	*Perca flavescens*	Yellow perch	x		x		x		x	
Percidae	*Stizostedion canadense*	Sauger	x		x		x		x	
Percidae	*Stizostedion vitreum*	Walleye	x		x		x		x	
Percidae	*Stizostedion canadense* x *S. viterum*	Saugeye	x		x		x			
Polyodontidae	*Polyodon spathula*	Paddlefish		x	x	x	x	x	x	x
Salmonidae	*Oncorhynchus mykiss*	Rainbow trout	x		x		x		x	
Salmonidae	*Salmo trutta*	Brown trout	x		x		x		x	
Sciaenidae	*Aplodinotus grunniens*	Freshwater drum	x	x	x	x	x	x	x	x

area generally target buffalofishes, paddlefish, the large catfishes (channel, blue, and flathead), and all of the Asian carps. A contentious and contemporary issue involves native sturgeon populations and the caviar industry. The black eggs removed from sturgeon and paddlefish are sold to the caviar markets. Because the federally endangered pallid sturgeon may be taken incidentally along with shovelnose and lake sturgeon, various agencies have lobbied for a complete shutdown of any fishing for sturgeon species. At the time of this writing, the issue had not been resolved. Excluding Lake Michigan, Illinois commercial anglers harvested 5.4 million pounds of fish in calendar year 1999 valued at nearly $1.4 million. There was no reported mussel harvest in calendar year 1999 due to a collapse of the export market for shells.

Commercial fishing is allowed or has been allowed on the Ohio and Mississippi Rivers in Kentucky and the largest reservoirs including those near the assessment area—Kentucky Lake and Lake Barkley and Rough River and Nolin River reservoirs (Hoyt and Flynn 1974, Timmons et al. 1989). The commercial fishery of Kentucky Lake is especially important to the economy of western Kentucky. Renaker and Carter (1968) estimated the annual harvest and value of the trotline fishery in the Kentucky section of Kentucky Lake as 136,101 pounds and

$32,740 in 1965 and 575,301 pounds and $166,806 in 1966, whereas Timmons et al. (1985) reported a harvest of 913,560 pounds worth $448,620 in 1984. Bull (1985) estimated a trotline harvest of 379,191 pounds worth $172,000 in 1984 in the same section of Kentucky Lake. Species accounting for the bulk of the harvest included paddlefish, gars, American eels, common carp, buffalofishes, the large catfishes, and freshwater drum. The fate of harvested fish falls into three general categories: 1) fish sold alive, 2) fish sold dressed, and 3) fish for personal use. Few individual fishers or families earn a living above the poverty line if commercial fishing is their only source of income.

Recreational fisheries

Designated species of sport fish, by State, are listed in table 8. These listed species reflect named species of sport fish or members of families of sport fish sought by anglers and for which fishing records are maintained on an annual basis in each State. We distinguish between the terms "game" and "sport" fish and maintain that most recreational or "sport" fishing in the assessment area involves the return of individual fish to the body of water soon after capture. "Game" implies exploitation for food and is a term now often restricted to birds and mammals exploited for recreational hunting and consumption. The listings are similar for each State, ranging from 41 to 52 sport fishes depending on definition, angler preferences, geography, angler gear, and other factors. All of the States are maintaining angler records for four different hybrid forms: tiger musky, sunshine bass, calico bass, and saugeye. Some of the hybrids cannot be accurately distinguished from their parental species and require genetic tests for identification and establishment of a record fish. The full suite of sport fish listed for the four States reflects what recreational fishers seek. In addition, many—if not most—of the commercial species are also caught and harvested. While the four States may have different lists of sport fish, in practice, similar species are being managed through statewide creel limits (the number of fish than can be harvested) or more localized size limits.

In addition to the stocking of the standard largemouth bass, bluegill, and channel catfish, each of the States has programs for stocking or releasing exotic or nonindigenous species into reservoirs in or near the assessment area. For example, Illinois operates four hatcheries to annually produce more than 50 million fish of 19 species for stocking into Illinois waters. Indiana operates 6 State hatcheries and Missouri 11 with literally hundreds of thousands of fish produced and released into waters near or in the assessment area. Some fish are also provided by private industry and the Federal government (e.g., Fish and Wildlife Service). Examples of stockings in the assessment area include striped bass, muskellunge, northern pike, brown trout, and rainbow trout, only one (muskellunge) of which is native to the region. The stockings are conducted to 1) develop self-sustaining fisheries; 2) provide unique sport-fishing opportunities; and 3) encourage non-reproducing species to take advantage of unique habitats (e.g., reservoirs and their tailwater fisheries) and/or underutilized forage fish. Trout are stocked into many of the large reservoirs or their cold tailwaters. Striped bass, sunshine bass, and calico bass are stocked in many of the large reservoirs to prey upon shad. Muskellunge are stocked in Lake Kinkaid, Illinois, where a substantial fishery and musky guide livelihood have developed. Some States (e.g., Illinois) in the assessment area allow stocking of triploid grass carp (purportedly sterile) in farm ponds to control aquatic plant growth.

Recent research in the assessment States has concentrated on determining genetic stock of the region's sport fishes. Information gained provides for more effective management of, for example, largemouth bass that are native to the region rather than introduction of southern or Florida largemouth bass that have their own physiological adaptations for warmer environments. Hatcheries are raising native river-run stocks of walleye to protect their genetic integrity. There is a large and ongoing interstate study of paddlefish in the bordering big rivers emphasizing distribution and abundance. The growing aquaculture industry is having its activities closely monitored in all four States, and a comprehensive aquatic nuisance species management plan has been developed and submitted to the Federal task force dealing with these matters.

Commercial Mussel Importance

In the early part of the 20th century, large quantities of freshwater mussels were harvested commercially for the pearl button industry from the largest rivers in the Mississippi basin. Once mussels were collected, the soft tissues were cooked and removed, and the shells shipped to factories where they were cut into blanks, sorted, polished, and finished into buttons (Cummings 1991). Species that were most valuable to the button industry were those having white, unblemished nacres that were relatively large and of uniform thickness. The yellow sandshell was used primarily in the early years of the industry, followed by the plain pocketbook and black sandshell. As the industry progressed, additional species were used. For example, Williams and Schuster (1989) inspected several "dumps" on the lower Ohio River where drilled out shells had been discarded and found the following species to be common: ebonyshell, Wabash pigtoe, Ohio pigtoe, mapleleaf, monkeyface, pimpleback, wartyback, and mucket (table 9). Additional species considered valuable to the industry included the pistolgrip and the butterfly (Oesch 1984).

The pearl button industry flourished for nearly 75 years, then collapsed in the early 1950s following the development and widespread use of plastics (Parmalee and Bogan 1998). Although shells are no longer manufactured into buttons, a mussel industry and commercial harvest exists in the assessment area, especially on the mainstem Ohio River. Today, freshwater mussel shells are used in the Japanese cultured pearl industry. Shells harvested from rivers in the United States from Wisconsin to Alabama are exported to Japan where they are cut into small pellets that serve as nuclei for cultured pearls. The following species are most desired for pearl nuclei because of their size, thickness, and hardness: threeridge, washboard, ebonyshell, Wabash pigtoe, Ohio pigtoe, mapleleaf, monkeyface, wartyback, and pimpleback (table 9, Williams and Schuster 1989). Mussel shells are also used to a much lesser extent as specialty items (Oesch 1984). For example, there is still some small demand for the so-called "pinks"—spike, purple wartyback, and elephant ear (table 9), which have pink to purple nacre. These and other species are used primarily in the manufacture of jewelry and other novelty items such as inlaid furniture and knife handles (Williams and Schuster 1989).

Commercial Crayfish Importance

Except for those species in the genus *Cambarellus,* almost all crayfish species in the assessment area have the potential to reach sizes suitable for human consumption (table 10). However, midwesterners do not consume large quantities of crayfish as is customary among some of the Southern States—mainly Texas and Louisiana (Taylor et al. 1996). No publication summarizes the current crayfish harvest for human consumption in the Midwest, and we therefore judged it to be minimal. Internationally, crayfish are an important product of commerce (Moody 2000). The total annual commercial harvest of crayfish is more than 110,000 metric tons; the United States produces 55 percent of that volume, and the People's Republic of China produces 36 percent. *Procambarus clarkii* is the single most

Table 9. Primary habitat and commercial importance of native freshwater mussel species in the Hoosier-Shawnee Ecological Assessment Area.

			Occurrence		Preferred Habitat													Commercial importance		
Family Subfamily	Species	Common name	SNF	HNF	*Creek	*Headwater	*Small river	*Medium river	*Large river	*Impoundments	*Mud/ silt	*Sand	*Gravel	*Mixed sand & gravel	**Slow current	**Moderate current	**Swift current	Cultured Pearl	Button	***Polished chip
Margaretiferidae	*Cumberlandia monodonta*	Spectaclecase	X						X			X	X		X					
Unionidae																				
Ambleminae	*Amblema plicata*	Threeridge	X	X			X	X	X	X	X	X	X		X	X	X	X	X	X
Ambleminae	*Cyclonaias tuberculata*	Purple wartyback	X	X				X	X				X	X	X	X				
Ambleminae	*Elliptio crassidens*	Elephant ear	X	X					X		X	X	X				X			X
Ambleminae	*Elliptio dilatata*	Spike	X	X			X	X	X	X	X		X			X	X			X
Ambleminae	*Fusconaia ebena*	Ebonyshell	X	X					X					X		X	X	X	X	X
Ambleminae	*Fusconaia flava*	Wabash pigtoe	X	X	X	X	X	X	X		X	X	X		X	X	X		X	
Ambleminae	*Fusconaia subrotunda*	Long-solid		X					X				X				X	?	?	?
Ambleminae	*Hemistena lata*	Cracking pearlymussel						X	X		X	X	X			X				
Ambleminae	*Megalonaias nervosa*	Washboard	X	X				X	X		X	X	X			X		X	X	
Ambleminae	*Plethobasus cicatricosus*	White wartyback							X				X				X	?	?	?
Ambleminae	*Plethobasus cooperianus*	Orange-foot pimpleback	X	X					X				X	X			X			
Ambleminae	*Plethobasus cyphyus*	Sheepnose	X	X				X	X				X	X			X			
Ambleminae	*Pleurobema clava*	Clubshell		X				X	X				X	X			X	?	?	?
Ambleminae	*Pleurobema sintoxia*	Round pigtoe		X				X	X		X	X	X			X			X	X
Ambleminae	*Pleurobema cordatum*	Ohio pigtoe	X	X				X	X			X	X			X		X	X	
Ambleminae	*Pleurobema plenum*	Rough pigtoe		X				X	X			X	X			?		?	?	?
Ambleminae	*Pleurobema rubrum*	Pyramid pigtoe		X				X	X			X	X				X	?	?	?
Ambleminae	*Quadrula nobilis*	Southern mapleleaf (2)							X	X		X	X		X	X	X	?	?	?
Ambleminae	*Quadrula cylindrica*	Rabbitsfoot	X	X				X	X					X			X			
Ambleminae	*Qudrula metanevra*	Monkeyface	X	X				X	X				X	X		X	X	X	X	X
Ambleminae	*Quadrula nodulata*	Wartyback	X					X	X			X	X			?		X	X	X
Ambleminae	*Quadrula pustulosa*	Pimpleback	X	X				X	X		X	X	X		X	X	X	X	X	X
Ambleminae	*Quadrula quadrula*	Mapleleaf	X	X				X	X		X	X	X		X	X	X	X	X	X
Ambleminae	*Tritogonia verrucosa*	Pistolgrip	X	X				X	X		X	X	X			X		X	X	X
Ambleminae	*Uniomerus tetralasmus*	Pondhorn	X	X	X	X				X	X	X			X					
Anodontinae	*Alasmidonta marginata*	Elktoe					X	X					X	X		X	X			
Anodontinae	*Alasmidonta viridis*	Slippershell			X	X					X	X	X				X			
Anodontinae	*Anodonta suborbiculata*	Flat floater	X	X	X	X				X	X				X					
Anodontinae	*Anodontoides ferussacianus*	Cylindrical papershell		X	X	X					X	X			X					
Anodontinae	*Arcidens confragosus*	Rock-pocketbook	X	X				X	X		X	X			X					
Anodontinae	*Strophitus undulatus*	Squawfoot		X			X	X	X		X	X	X			?	?			
Anodontinae	*Utterbackia imbecillis*	Paper pondshell		X	X	X				X	X				X					
Lampsilinae	*Actinonaias ligamentina*	Mucket	X	X				X	X				X	X	X	X	X	X		X
Lampsilinae	*Cyprogenia stegaria*	Fanshell		X				X	X				X				X			
Lampsilinae	*Ellipsaria lineolata*	Butterfly	X	X					X			X	X				X	X	X	X
Lampsilinae	*Epioblasma archaeformis*	Sugarspoon						X	X				X	X			X			
Lampsilinae	*Epioblasma flexuosa*	Leafshell (3)							X				X	X			X			
Lampsilinae	*Epioblasma obliquata*	Catspaw						X	X				X				X			

(table continued on next page)

(table 9 continued)

Family Subfamily	Species	Common name	Occurrence: SNF	Occurrence: HNF	Preferred Habitat: *Creek	*Headwater	*Small river	*Medium river	*Large river	*Impoundments	*Mud/ silt	*Sand	*Gravel	*Mixed sand & gravel	**Slow current	**Moderate current	**Swift current	Commercial importance: Cultured Pearl	Button	***Polished chip
Unionidae																				
Lampsilinae	*Epioblasma propinqua*	Tennessee riffleshell(2)		X					X				X	X			X			
Lampsilinae	*Epioblasma rangiana*	Northern riffleshell		X				X	X				X				X			
Lampsilinae	*Epioblasma sampsonii*	Wabash riffleshell						?	?				?	?			?			
Lampsilinae	*Epioblasma torulosa*	Tubercled blossom		X				X	X				X				X			
Lampsilinae	*Epioblasma triquetra*	Snuffbox		X				X	X				X				X			
Lampsilinae	*Lampsilis abrupta*	Pink mucket	X						X			X	X				X			
Lampsilinae	*Lampsilis cardium*	Plain pocketbook	X	X	X		X	X	X		X	X	X		X	X	X	X	X	X
Lampsilinae	*Lampsilis fasciola*	Wavy-rayed lampmussel		X				X					X			X			?	?
Lampsilinae	*Lampsilis ovata*	Pocketbook	X						X			X	X		X	X	X			
Lampsilinae	*Lampsilis siliquoidea*	Fatmucket	X	X		X	X	X		X	X	X	X		X				X	X
Lampsilinae	*Lampsilis teres*	Yellow sandshell	X	X				X	X			X	X		X	X			X	X
Lampsilinae	*Leptodea fragilis*	Fragile papershell	X	X	X		X	X	X		X	X	X		X	X	X			
Lampsilinae	*Leptodea leptodon*	Scaleshell							X		X						X			
Lampsilinae	*Ligumia recta*	Black sandshell	X	X				X	X			X	X				X		X	X
Lampsilinae	*Ligumia subrostrata*	Pondmussel	X		X					X	X	X			X					
Lampsilinae	*Obliquaria reflexa*	Threehorn wartyback	X	X					X	X		X	X		X	X				X
Lampsilinae	*Obovaria olivaria*	Hickorynut	X	X					X			X		X		X	X			
Lampsilinae	*Obovaria retusa*	Ring pink	X						X			X	X			?	?			
Lampsilinae	*Obovaria subrotunda*	Round hickorynut	X	X				X				X	X			X				
Lampsilinae	*Potamilus alatus*	Pink heelsplitter	X	X				X	X		X	X	X	X	X	X	X			X
Lampsilinae	*Potamilus capax*	Fat pocketbook	X	X					X		X	X			X					
Lampsilinae	*Ptychobranchus fasciolaris*	Kidneyshell	X	X				X	X				X			X	X			
Lampsilinae	*Toxolasma lividus*	Purple lilliput					X	X		X			X		?					
Lampsilinae	*Toxolasma parvus*	Lilliput			X		X	X	X	X	X	X	X		?					
Lampsilinae	*Toxolasma texasensis*	Texas lilliput	X			X	X	X			X	X			X					
Lampsilinae	*Truncilla donaciformis*	Fawnsfoot	X	X				X	X			X	X		X	X	X			
Lampsilinae	*Truncilla truncata*	Deertoe	X	X				X	X		X	X	X		X	X	X			
Lampsilinae	*Villosa fabalis*	Rayed bean					X	X		X		X	X			?	?			
Lampsilinae	*Villosa iris*	Rainbow					X	X				X	X			X	X			
Lampsilinae	*Villosa lienosa*	Little spectaclecase		X			X	X				X	X		X					
Lampsilinae	*Villosa ortmanni*	Kentucky creekshell					?	?				?	?	?	?	?	?			
Unioninae	*Plectomerus dombeyanus*	Bankclimber					X	X			X		X		X	X				X

*Cummings and Mayer (1992)
**Parmalee and Bogan (1998)
***Polished chip (Oesch 1984); jewelry and specialty items (Williams and Schuster 1989)

Table 10. Primary habitat and commercial importance of native freshwater crayfish species in the Hoosier-Shawnee Ecological Assessment Area.

Family Subfamily	Scientific Name	Common Name	Occurence SNF	Occurence HNF	Preferred habitat ∆	Commercial importance
Cambaridae						
Cambarellinae	*Cambarellus puer*	Cajun dwarf crayfish	X		3º burrower	
Cambarellinae	*Cambarellus shufeldtii*	Shufeldt's dwarf crayfish	X		3º burrower	
Cambarinae	*Barbicambarus cornutus*	Bottlebrush crayfish			3º burrower	Potentially consumable
Cambarinae	*Cambarus bartonii*	Appalachian brook crayfish			3º burrower & troglophilic	
Cambarinae	*Cambarus diogenes*	Devil crayfish	X	X	1º burrower	Potentially consumable
Cambarinae	*Cambarus graysoni*	Nashville crayfish			3º burrower or Open water	
Cambarinae	*Cambarus ortmanni*	Lentic crayfish			2º burrower	
Cambarinae	*Cambarus rusticiformis*	Riffle crayfish	X		Open water	Potentially consumable
Cambarinae	*Cambarus tenebrosus*	Spring grayfish	X	X	Open water, springs & troglophilic	Potentially consumable
Cambarinae	*Fallicambarus fodiens*	Digger crayfish	X		1º burrower	Potentially consumable
Cambarinae	*Orconectes barrenensis*	Green River crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes bisectus*	Crittenden crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes illinoiensis*	Illinois crayfish*	X		Open water & 3º burrower	Potentially consumable
Cambarinae	*Orconectes immunis*	Papershell crayfish	X	X	3º burrower	Potentially consumable
Cambarinae	*Orconectes indianensis*	Indiana crayfish*	X	X	Open water & 3º burrower	
Cambarinae	*Orconectes inermis*	Subterranean crayfish		X	Troglobitic	
Cambarinae	*Orconectes kentuckiensis*	Kentucky crayfish*	X		Open water & 3º burrower	
Cambarinae	*Orconectes lancifer*	Shrimp crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes luteus*	Golden crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes margorectus*	Cobble crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes palmeri*	Gray-speckled crayfish			3º burrower & Open water	
Cambarinae	*Orconectes pellucidus*	Eyeless crayfish			Troglobitic	
Cambarinae	*Orconectes placidus*	Placid crayfish	X		Open water & 3º burrower	Potentially consumable
Cambarinae	*Orconectes putnami*	Disjunct crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes rafinesquei*	Rafinesque's crayfish*			Open water & 3º burrower	
Cambarinae	*Orconectes ronaldi*	Mud River crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes rusticus*	Rusty crayfish	X		Open water & 3º burrower	Potentially consumable**
Cambarinae	*Orconectes stannardi*	Little Wabash crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes tricuspis*	Headwater crayfish			Open water & 3º burrower	
Cambarinae	*Orconectes virilis*	Virile crayfish	X		Open water & 3º burrower	Potentially consumable***
Cambarinae	*Procambarus acutus*	White River crayfish	X		3º burrower	Potentially consumable
Cambarinae	*Procambarus clarkii*	Red swamp crayfish	X	X	3º burrower	Potentailly consumable****
Cambarinae	*Procambarus gracilis*	Prairie crayfish	X		1º burrower	
Cambarinae	*Procambarus viaeviridis*	Vernal crayfish	X		2º burrower	

See text for full description of the different habitats
1º = primary, 2º = secondary, 3º = tertiary, Troglophilic = lives in caves and surface waters, and Troglobitic = obligate cave dweller
∆ Most crayfish preferring flowing, open-water, burrow either in times of low water, to brood eggs, or to escape below the frost line in winter.
* endemic to the Hoosier-Shawnee Ecological Assessment Area.
** Has historically been sold as bait throughout the midwest and New England which lead to significant range expansion (Page 1985).
*** Has historically been harvested and eaten in Illinois (Page 1985).
**** Continues to be harvested commercially for human consumption and bait in more southern portions of its range (Pflieger 1996).

commercially important species in North America, making up more than 70 percent of all harvested species (Moody 2000). Significant crayfish harvest for human consumption, as well as bait, historically occurred in Wisconsin and Ohio (Huner 1978) with other Midwestern States either not reporting catches or not having significant harvests. Page (1985) mentioned that in Illinois, *Orconectes virilis*, an abundant and ubiquitous species, often was harvested for food historically, but does not appear to be harvested currently. Pflieger (1996) noted that *Procambarus clarkii*, found in the assessment area primarily in southern Illinois, was the most commonly harvested and cultured (for human consumption) species in the United States but largely in the extreme southern portions of its range—Texas and Louisiana. For the most part, however, crayfishes of the assessment area are not commercially harvested for human consumption.

Crayfishes are of potential importance in the commercial bait industry and as a food source for wild sportfish stocks. There is also a small but persistent interest in keeping crayfishes as aquarium pets. Although no literature was found that discussed crayfish harvest for the bait industry in or near the assessment area, harvest certainly occurs. Huner (1978) suggested that most North American crayfish species have been collected for bait historically. On a local level, numerous species are captured for bait throughout the assessment area, in part because the practice of harvesting and selling crayfishes as bait is legal in all four States in the assessment area. Certainly it is common practice for bass and catfish anglers to personally harvest crayfish to be used as bait on fishing outings. As noted earlier, crayfish abundance and species composition can have significant effects on sportfish populations (Lodge et al. 2000a). Crayfishes are indirectly important recreationally in this regard because they make up a significant portion of the biomass in a given aquatic system. This biomass becomes a food source for many life stages of numerous sportfish species, particularly basses and sunfishes (Lodge et al. 2000a).

Implications and Opportunities

The era of major reservoir construction in the assessment area is about over and it is unlikely that major changes will be made in management of existing reservoirs and their water releases. Species introductions and manipulation will still occur. The success of the introduced muskellunge fishery in southern Illinois may cause other States in the assessment area to consider a similar program. There was some natural reproduction in earlier years of management, but this seems to have disappeared in the most recent years. A major management problem now is escape of introduced sportfishes over the dams of reservoirs into streams that connect to the big rivers. This sort of behavior could pose ecological problems for native stream fishes and other sport fishes unaccustomed to having a large nonindigenous predator (e.g., muskellunge) in their midst. It is also costly to State resource agencies because considerable personnel time and effort are spent retrieving, for example, adult muskellunge, and returning them to the lake in which they were originally stocked.

We anticipate that fisheries managers will increasingly focus on maintaining or restoring significant warm-water and cool-water stream fisheries and improve sport-fish populations and angling in progressively smaller water bodies as time goes on. Most of the large cities now have active urban fishing programs. Emphasis on managing striped bass and other reservoir sport fish is not likely to diminish in the reasonable future. Considerable technical assistance is now available for the landowner with private pond waters. In the assessment area, largemouth, smallmouth, and spotted basses, bluegill, crappie, white and striped basses, walleye, and large catfishes are still the species of choice of most anglers.

Commercial mussel harvesting has been driven by the overseas demand for shell blanks for the cultured pearl industry. Mussel harvesting needs to be carefully monitored to ensure sustainability of the harvested species as well as other species that may be indirectly affected by harvest activities. Uniformity of harvest regulations (including harvest method [i.e., brailing versus diving], minimum shell sizes, season dates, and time of day open for harvest) and uniformity of reporting would support management of harvest within the assessment area and beyond.

Commercial fishing within the assessment area is primarily restricted to the big rivers at this time. Lack of analysis of required commercial fishers reports and lack of close monitoring of fishing are viewed here as a handicap for efficient fisheries management. A shutdown of the caviar industry would halt all fishing for the three sturgeon species and possibly the paddlefish. Commercial fishing is a lifestyle for some families in the region, but none are making a substantial living with fishing alone. Despite fears of sport fishers, commercial fishing is harvesting a renewable resource and can be compatible with general fishery management objectives in the region.

Management of recreational fishing is an ever-changing science. Significant progress has been made in improving habitats and fishery populations, particularly in reservoirs. Continued efforts with private landowners to help assess and manage the hundreds of small water bodies in the assessment area should yield quality fishing. Conserving native genetic stocks of sportfish is an important long-term goal to maintain the integrity of popular species including the largemouth bass, walleye, and bluegill. Development of high quality stream and river fisheries requires more research, attention, and funding in the near future. Some nearly unexploited river catfish fisheries could be developed into new tournaments, especially considering that most fishing records of any size will almost certainly be set with increased catfish angling. Restoration of many streams and rivers in the region would be required to address the degradation of many waters from mining and logging activities, outdated agricultural practices, and chemical pollution. Support of grassroots teams devoted to stream restoration and conservation by government agencies and private corporations (e.g., The Nature Conservancy) could help to restore and protect the fishing quality of assessment area waters.

As mentioned above, because crayfishes can make up a significant portion of the biomass in an aquatic ecosystem, and because they are often "dominant consumers of benthic invertebrates, detritus, macrophytes, and algae in lakes and streams," removals and additions of crayfish species "often lead to large ecosystem effects, in addition to changes in fish populations, and losses in biodiversity" (Lodge et al. 2000a). Although crayfishes naturally expand their ranges by moving both overland and underwater from drainage to drainage, anthropogenic mechanisms for range expansion are much more effective (Lodge et al. 2000a). Lodge et al. (2000a) recognized eight ways humans can expand the ranges of crayfishes: "(1) dispersal into new drainages via canals; …(2) legal and (3) illegal stocking in natural waters; …(4) escapes from aquaculture ponds, (5) live food vendors; …(6) the aquarium and pond trade; …(7) escapes or releases from students after studying live crayfishes obtained from biological supply houses; and (8) escapes from the live bait trade." In the assessment area, crayfishes escaping from the live bait trade are probably the most likely cause of human-induced range expansion. A secondarily important range expansion mechanism is probably escape from aquaculture ponds.

Probably the best North American example of the effects of a nonindigenous crayfish on newly encountered ecosystems is the progressive movement of *Orconectes rusticus* (rusty crayfish) across the upper Midwest, Canada, northern Appalachia, New England, and parts of the Southwestern United States (Lodge et al. 2000a, Page 1985). Rusty crayfish physically and ecologically outcompete smaller, slower growing, less aggressive native crayfish species, destroy macrophyte communities, and decimate benthic invertebrate communities (Lodge et al. 2000a, Page 1985). These detrimental ecosystem-wide changes affect numerous native aquatic species, in addition to crayfishes, and including sport and non-game fishes. Rusty crayfish also hybridize with native crayfish species, in effect genetically eliminating them from the ecosystem in addition to physically and ecologically outcompeting them (Perry et al. 2001). The rusty crayfish is native to the eastern and southern portions of the assessment area (Indiana and Kentucky) and could potentially invade surrounding areas.

An effective way to reduce the threat of nonindigenous crayfishes would be to place a ban on the practice of using live crayfishes as bait for sportfishing within the national forest boundaries. Furthermore, residents and businesses near the national forests could be encouraged to culture and sell bait minnows rather than nonindigenous crayfishes.

AQUATIC HABITATS

The diversity and abundance of aquatic organisms (e.g., fishes, mussels, crayfishes) and characteristics of their physical habitat (e.g., stream size, substrate type) are primary tools to assess the quality of habitats (Dolloff et al. 1993, Karr et al. 1986). In recent years it has become commonplace to assess aquatic systems by taking a series of measurements and samples at a particular site or series of sites on a stream. Such specific information is unavailable for large portions of the assessment area. The U.S. Environmental Protection Agency (USEPA) and the USEPA programs at the State level have initiated protocols to be used by their field personnel to assess physical and chemical qualities of aquatic habitats. Much of the field work in Illinois and Kentucky has been accomplished in a cooperative and consistent manner with the State Natural Resource Agency or State Nature Preserves Commission. Large-scale analyses in Illinois have linked water quality and other physical variables to fish diversity and abundance and stream ratings for the entire state are available (e.g., Illinois Biological Stream Characterization Work Group 1995). In previous sections, we were able to evaluate diversity of major aquatic groups across the assessment area. No comparable information base exists that can be used to directly examine the status of aquatic habitats in that same area.

The assessment area encompasses a number of major physiographic regions and a diversity of geologic features that, along with an abundance of water bodies, has produced a plethora of aquatic habitats suitable for fishes, mussels, and crayfishes. Habitat occupation varies considerably among the groups of aquatic organisms targeted in this study. For example, several crayfish species are burrowers that may spend much of their lives more than a yard deep in the mud along a stream or wetland. No comparable examples of this kind of habitat occupation are available among fishes or mussels in the area.

DATA SOURCES AND METHODS OF ANALYSIS

Fishes

We classified habitat diversity for fishes around a framework and definitions from Cowardin et al. (1979) and Jenkins et al. (1971). The primary purposes of this habitat classification are to allow the user a quick and accurate characterization of fish habitats known to occur in the assessment area and to allow analysis of affinities of groups of fishes to particular habitat types. The following definitions are provided as a guide to our concepts and use of terms in the characterization of major fish habitat systems and subsystems. The *Lacustrine System* includes permanently flooded lakes and reservoirs generally greater than 20 acres in surface area (except sinkhole ponds) with all of the following features: 1) situated in a dammed river channel or topographic depression; 2) lacking trees, shrubs, and emergent vegetation with greater than 30 percent areal coverage; and 3) the deepest part of the basin exceeds 2 m at low water (Cowardin et al. 1979). The subsystems are *Reservoir* (e.g., Lake of Egypt, Illinois), *Floodplain Lake and Oxbow* (e.g., Taylor Lake, Butler County, Kentucky), and Sinkhole Pond (e.g., Dripping Sinks, Lawrence County, Indiana).

The *Palustrine System* includes wetlands dominated by trees, shrubs, and/or emergent vegetation or those lacking such vegetation with both of the following features: 1) surface area less than 20 acres and 2) water depth in the deepest part of the basin less than 2 m at low water. This system includes vegetated wetlands variously known as swamps, oxbows, sloughs, ditches, marshes, or backwaters. It also encompasses a variety of small, shallow impoundments often called ponds (Cowardin et al. 1979). The subsystems are *Floodplain Lake and Oxbow* (e.g., Mud Lake, Hardin County, Illinois), *Pond* (i.e., farm ponds), and *Wetland* (e.g., Cypress Creek Wetland, Muhlenberg County, Kentucky).

The *Riverine System* includes a large majority of the aquatic habitats in the assessment area and is defined as all waters contained within a channel (sensu Cowardin et al. 1979) except for habitats dominated by trees, shrubs, and emergent plants. Water is usually flowing in this system. The modifiers *upland* and *lowland* characterize gradient and velocity in riverine subsystems. Upland is used to describe riverine subsystems in which the gradient is high and the velocity of water is rapid; water generally flows year round; substrates consist of bedrock, boulder, cobble, pebble, and gravel with occasional patches of sand; dissolved oxygen concentrations are near saturation; and the floodplain is little developed (Cowardin et al. 1979). The concept is also partly based on the presence of shoals or riffles within these subsystems constituting 5 to 10 percent or more of the length of the stream (Jenkins and others 1971). In contrast, lowland applies to those subsystems in which gradient and water velocity are low; flow may be negligible in late summer or early fall; substrates consist of sand, mud, or organic debris; oxygen deficits occur; and the floodplain is well developed. The occurrence of riffles and shoals is low, constituting less than 5 to 10 percent of the stream length.

Subsystems in the *Riverine System* are *Cave Stream, Spring, Headwater Creek, Stream and River,* and *Big River*. The distinction between *Cave Stream* and *Spring* subsystems is based on the larger size of a *Cave Stream* and its association with an obvious surface opening; nevertheless, the distinction in some cases may be arbitrary. We regard sinking streams, a common feature of karst topography, as a part of the *Cave Stream* subsystem. The *Headwater Creek* subsystem includes streams ranging up to about 30 feet in width (Jenkins et al. 1971). In forested areas, flow may be present all year; however, many headwater creeks typically consist of isolated pools or lack surface water during seasons of drought. The *Stream and River* subsystem applies to those waters ranging in size from about 30 to 200 feet in width (Jenkins et al. 1971), having water in the channels, and generally flowing year round (e.g., Green River, Kentucky). The *Big River* subsystem includes waters greater than 200 feet wide and follows the concept of Jenkins et al. (1971). This subsystem is used for the largest rivers of the area (e.g., Ohio River, Missouri River, Mississippi River), most of which are impounded by a series of locks and dams or single large dams, but have an admixture of slow-quiet pools and occasional fast-water shoals or tailwater reaches. Substrates are variable and the floodplain is generally well developed. This subsystem also includes the embayed mouths of streams and rivers that empty into big rivers.

Mussels

We used Cummings and Mayer (1992) and Parmalee and Bogan (1998) for descriptions of aquatic habitats occupied by mussel species in the assessment area. We followed the definitions as used above for fishes when assigning mussel species to specific habitat categories.

Crayfishes

We relied on Hobbs (1981), Page (1985), and Pflieger (1996) for descriptions, illustrations, and definitions of aquatic habitats of crayfishes, which can occupy smaller bodies of water (e.g., ditches) or more temporary bodies of water (e.g., vernal ponds, flooded backyards) more readily than either fishes or mussels. Definitions of the five major types of crayfish habitats as well as a few individual species accounts of habitat occurrence were thoroughly documented by Hobbs (1981). Habitat occurrence for most species was presented in either Page (1985) or Pflieger (1996).

Information on the ecological role and importance of crayfishes in aquatic and terrestrial habitats came mainly from Lodge et al. (2000a, 2000b) and Taylor et al. (1996). General information on cave ecology and conservation was supplied in the reviews by Culver et al. (1999) and Elliott (2000). Forest Service riparian regulations on logging and recreational activities within national forests were provided by Chad Stinson, Shawnee National Forest.

PATTERNS AND TRENDS

Fish Habitat

Flowing waters are the dominant habitat of fishes in the assessment area with nearly 150 species recorded from upland streams and rivers or big rivers. Additionally, most fishes are found over substrates of sand and gravel and in glides or raceways of the riverine system (table 11). Only six species are found in the cave stream subsystem, and a few others would be expected to occasionally enter the twilight zones of caves for limited times. Twelve species have been recorded from springs, but more field efforts are needed to consider this an accurate assessment of this uncommon habitat. Riffle and shoal habitats account for only about 5 to 10 percent of stream length and yet 52 species are recorded from that specific habitat, nearly always over a gravel or pebble substrate. Following definitions of the lacustrine system, it is clear that all "lakes" are artificial in the region and technically are human-made reservoirs that have effectively halted the flow and velocity of riverine systems. As a consequence, the fish communities of reservoirs are depauperate when compared to riverine systems, largely because habitat heterogeneity has been reduced or completely altered. Fish diversity in reservoirs is less than half that of rivers (table 11) and is artificially maintained, in part, by expensive stocking programs to meet the perceived demand of recreational fishers. Most palustrine habitats in the area consist of farm ponds and the few oxbows and wetlands that have not been converted to agricultural land. Nearly all accessible ponds are heavily managed for recreational fishing and have little fish diversity beyond the tailor-made fish populations of channel catfish, bluegill, and largemouth bass. Just over 50 species are associated with aquatic plants, a habitat feature that is rather rare in the assessment area.

Table 11. Primary habitat of native freshwater fishes in the Hoosier-Shawnee Ecological Assessment Area.

		Occurrence		Preferred habitat																									
Species	**Common name**	**SNF**	**HNF**	**Reservoir**	**Floodplain lake & oxbow**	**Sinkhole ponds**	**Ponds**	**Wetlands**	**Cave stream**	**Springs**	**Upland headwater creek**	**Upland stream & river**	**Lowland headwater creek**	**Lowland stream & river**	**Big river**	**Organic debris/mud**	**Sand/gravel (0.08-3 in.)**	**Pebble/cobble (3-24 in.)**	**Boulder/bedrock (>24 in.)**	**Emergent vegetation/cover**	**Aquatic bed**	**Scrub-shrub**	**Forested**	**Instream shelter**	**Riffles**	**Glides**	**Pools**	**Backwaters**	**Embayments**
Acipenser fulvescens	Lake sturgeon	X	X									X			X		X	X											
Scaphirhynchus albus	Pallid sturgeon	X													X		X	X											
Scaphirhynchus platorynchus	Shovelnose sturgeon	X	X												X		X	X											X
Amblyopsis spelaea	Northern cavefish		X						X							X	X										X		
Forbesichthys agassizi	Spring cavefish	X				X			X	X	X					X	X										X		
Typhlichthys subterraneus	Southern cavefish		X						X							X	X										X		
Amia calva	Bowfin	X	X		X		X					X		X	X	X	X			X	X		X	X					X
Anguilla rostrata	American eel	X	X									X		X	X	X	X							X					X
Aphredoderus sayanus	Pirate perch	X	X							X		X	X	X			X	X			X	X	X	X					
Labidesthes sicculus	Brook silverside	X	X	X	X							X		X	X		X	X											X
Menidia beryllina	Inland silverside	X		X	X									X	X	X	X												X
Carpiodes carpio	River carpsucker	X	X	X								X		X	X	X	X											X	X
Carpiodes cyprinus	Quillback	X		X								X		X	X	X	X											X	X
Carpiodes velifer	Highfin carpsucker	X	X	X								X		X	X	X	X											X	X
Catostomus commersoni	White sucker	X	X							X	X	X	X	X			X	X	X	X	X			X	X		X		
Cycleptus elongatus	Blue sucker	X	X									X			X		X	X											
Erimyzon oblongus	Creek chubsucker	X	X		X			X			X	X	X	X		X	X			X	X			X			X		
Erimyzon sucetta	Lake chubsucker	X	X		X			X								X	X			X	X	X	X						
Hypentelium nigricans	Northern hog sucker	X	X							X	X	X					X	X	X										
Ictiobus bubalus	Smallmouth buffalo	X	X	X	X			X				X			X	X	X											X	X
Ictiobus cyprinellus	Bigmouth buffalo	X	X	X	X			X				X		X	X	X	X											X	X
Ictiobus niger	Black buffalo	X		X	X							X		X	X	X	X											X	X
Minytrema melanops	Spotted sucker	X	X	X	X							X		X		X	X									X	X		
Moxostoma anisurum	Silver redhorse		X									X		X	X		X	X								X			
Moxostoma carinatum	River redhorse		X									X			X		X	X											
Moxostoma duquesnei	Black redhorse	X	X									X					X	X								X	X		
Moxostoma erythrurum	Golden redhorse	X	X								X	X		X	X		X	X	X							X	X		
Moxostoma macrolepidotum	Shorthead redhorse	X	X	X								X		X	X		X	X								X	X		
Ambloplites rupestris	Rock bass	X	X	X								X					X	X	X	X				X			X		
Centrarchus macropterus	Flier	X	X		X			X						X		X	X				X						X		
Lepomis auritus	Redbreast sunfish			X			X					X		X		X	X				X			X			X	X	
Lepomis cyanellus	Green sunfish	X	X	X	X		X	X			X	X	X	X	X	X	X	X						X			X	X	X
Lepomis gulosus	Warmouth	X	X	X	X		X	X				X		X	X	X	X			X	X			X			X		X
Lepomis humilis	Orangespotted sunfish	X	X	X	X			X				X		X	X	X	X										X		X
Lepomis macrochirus	Bluegill	X	X	X	X		X	X			X	X	X	X	X	X	X	X			X			X			X		X
Lepomis megalotis	Longear sunfish	X	X	X	X		X	X			X	X	X	X	X	X	X	X						X			X		X
Lepomis microlophus	Redear sunfishes	X	X	X	X		X					X		X	X	X	X			X	X			X			X		X
Lepomis miniatus	Redspotted sunfish	X			X			X						X		X	X			X	X		X	X					
Lepomis symmetricus	Bantam sunfish	X			X			X						X		X					X			X					
Micropterus dolomieu	Smallmouth bass	X	X	X								X			X		X	X	X					X		X	X		X

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Micropterus punctulatus	Spotted bass	X	X	X	X			X				X		X	X		X	X						X		X	X		X
Micropterus salmoides	Largemouth bass	X	X	X	X		X	X				X		X	X	X	X	X		X	X	X	X	X			X	X	X
Pomoxis annularis	White crappie	X	X	X	X		X	X				X		X	X	X	X			X	X	X	X	X			X	X	X
Pomoxis nigromaculatus	Black crappie	X	X	X	X		X	X				X		X	X	X	X			X	X	X	X	X			X	X	X
Alosa alabamae	Alabama shad														X		X									X			
Alosa chrysochloris	Skipjack herring	X	X	X								X		X	X		X												X
Dorosoma cepedianum	Gizzard shad	X	X	X	X							X		X	X	X	X												X
Dorosoma petenense	Threadfin shad	X	X	X								X			X	X	X												X
Cottus bairdi	Mottled sculpin		X								X	X					X	X							X	X			
Cottus carolinae	Banded sculpin	X	X						X	X	X	X					X	X							X	X			
Campostoma anomalum	Central stoneroller		X								X	X	X	X			X	X	X						X	X	X		
Campostoma pullum	Mississippi stoneroller	X									X	X	X	X			X	X	X						X	X	X		
Campostoma oligolepis	Largescale stoneroller	X									X	X					X	X	X						X	X			
Cyprinella lutrensis	Red shiner	X			X								X	X	X	X	X									X	X		
Cyprinella spiloptera	Spotfin shiner	X	X									X		X	X		X	X						X	X	X	X		
Cyprinella venusta	Blacktail shiner	X												X	X		X							X		X	X		
Cyprinella whipplei	Steelcolor shiner	X	X									X		X			X	X						X	X	X	X		
Ericymba buccata	Silverjaw minnow	X	X								X	X	X	X			X									X	X		
Erimystax dissimilis	Streamline chub											X					X								X	X			
Erimystax x-punctatus	Gravel chub		X									X					X								X	X			
Hybognathus argyritis	Western silvery minnow	X													X		X									X			
Hybognathus hayi	Cypress minnow	X	X		X			X						X		X					X	X	X	X			X	X	
Hybognathus nuchalis	Mississippi silvery minnow	X	X		X							X		X	X	X	X									X	X		
Hybognathus placitus	Plains minnow	X													X		X									X			
Hybopsis amblops	Bigeye chub	X	X									X					X									X	X		
Hybopsis amnis	Pallid shiner	X	X									X		X		X	X							X			X		
Luxilus chrysocephalus	Striped shiner	X	X								X	X		X	X		X	X							X	X	X		
Luxilus cornutus	Common shiner		X								X	X					X	X							X	X	X		
Luxilus zonatus	Bleeding shiner											X					X	X							X	X	X		
Lythrurus fasciolaris	Scarletfin shiner	X	X									X					X	X								X	X		
Lythrurus fumeus	Ribbon shiner	X	X											X		X	X										X	X	
Lythrurus umbratilis	Redfin shiner	X	X								X	X	X	X		X	X							X		X	X		
Macrhybopsis gelida	Sturgeon chub	X													X		X									X			
Macrhybopsis hyostoma	Speckled chub	X	X									X			X		X									X			
Macrhybopsis meeki	Sicklefin chub	X													X		X									X			
Macrhybopsis storeriana	Silver chub	X	X	X								X		X	X		X	X								X	X		
Nocomis biguttatus	Hornyhead chub	X	X									X					X	X								X	X		
Nocomis effusus	Redtail chub											X					X	X							X	X	X		
Notemigonus crysoleucas	Golden shiner	X	X	X	X		X	X				X		X	X	X	X				X	X	X	X					
Notropis ariommus	Popeye shiner		X									X					X	X		X						X	X		

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Notropis atherinoides	Emerald shiner	X	X	X	X						X			X	X	X	X	X								X	X		
Notropis blennius	River shiner	X	X	X	X										X	X	X									X	X	X	X
Notropis boops	Bigeye shiner	X	X									X					X	X		X						X	X		
Notropis buchanani	Ghost shiner	X	X									X		X	X	X	X										X	X	X
Notropis chalybaeus	Ironcolor shiner		X		X									X	X	X	X			X	X						X	X	X
Notropis dorsalis	Bigmouth shiner	X									X	X					X									X	X		
Notropis hudsonius	Spottail shiner	X													X		X									X	X		
Notropis ludibundus	Sand shiner	X	X									X		X			X									X	X		
Notropis maculatus	Taillight shiner	X	X		X									X		X	X				X		X	X			X	X	
Notropis nubilus	Ozark minnow	X										X			X		X	X								X	X		
Notropis photogenis	Silver shiner		X									X					X	X								X	X		
Notropis rubellus	Rosyface shiner		X									X					X	X								X	X		
Notropis shumardi	Silverband shiner	X	X											X	X		X									X			
Notropis texanus	Weed shiner				X									X	X	X	X			X	X						X	X	X
Notropis volucellus	Mimic shiner	X	X									X		X			X			X	X					X	X		
Notropis wickliffi	Channel shiner	X	X												X	X	X			X						X	X	X	X
Opsopoeodus emiliae	Pugnose minnow	X	X		X			X				X		X		X	X				X	X	X	X			X	X	
Phenacobius mirabilis	Suckermouth minnow	X	X								X	X	X	X	X		X	X							X	X			
Phenacobius uranops	Stargazing minnow											X					X	X							X	X			
Phoxinus erythrogaster	Southern redbelly dace	X	X						X	X	X	X				X	X				X			X		X	X		
Pimephales notatus	Bluntnose minnow	X	X								X	X	X	X	X	X	X	X			X			X		X	X		X
Pimephales promelas	Fathead minnow	X	X		X		X				X	X	X	X	X	X	X							X			X	X	
Pimephales vigilax	Bullhead minnow	X	X	X								X		X	X		X	X	X					X		X	X		
Platygobio gracilis	Flathead chub	X													X		X									X		X	
Pteronotropis hubbsi	Bluehead shiner	X			X											X					X	X	X	X					
Rhinichthys atratulus	Blacknose dace	X	X							X	X	X					X	X						X	X	X			
Rhinichthys cataractae	Longnose dace	X										X						X							X				
Semotilus atromaculatus	Creek chub	X	X			X			X	X	X	X	X	X		X	X	X	X		X			X		X	X		
Elassoma zonatum	Banded pygmy sunfish	X			X			X								X	X				X	X	X	X			X		
Esox americanus	Grass pickerel	X	X	X	X		X	X				X		X		X	X	X		X	X	X	X	X			X		
Esox lucius	Northern pike	X	X	X			X									X	X			X	X			X			X		
Esox masquinongy	Muskellunge		X	X								X					X	X	X	X	X			X			X		
Esox niger	Chain pickerel			X	X			X						X		X	X				X		X	X			X		
Fundulus catenatus	Northern studfish	X									X	X					X	X		X							X		
Fundulus dispar	Starhead topminnow	X			X			X								X	X				X								
Fundulus notatus	Blackstripe topminnow	X	X		X			X			X	X	X	X	X	X	X				X						X	X	X
Fundulus olivaceus	Blackspotted topminnow	X			X			X			X	X	X	X			X				X						X		
Lota lota	Burbot											X		X	X	X	X	X						X			X		X
Hiodon alosoides	Goldeye	X		X										X	X		X									X	X		X
Hiodon tergisus	Mooneye	X	X	X								X		X	X		X									X	X		X

(table continued on next page)

(table 11 continued)

Species	Common name	Occurrence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Ameiurus melas	Black bullhead	X	X	X	X		X	X				X	X	X	X	X	X				X			X			X	X	X
Ameiurus natalis	Yellow bullhead	X	X	X	X		X	X			X	X	X	X	X	X	X				X			X			X	X	X
Ameiurus nebulosus	Brown bullhead	X	X	X	X		X	X				X		X	X	X	X				X			X			X	X	X
Ictalurus furcatus	Blue catfish	X		X								X		X	X	X	X							X		X	X	X	X
Ictalurus punctatus	Channel catfish	X	X	X	X		X					X		X	X	X	X	X						X		X	X	X	X
Noturus elegans	Elegant madtom											X					X	X							X	X			
Noturus eleutherus	Mountain madtom		X									X			X		X	X							X	X			
Noturus exilis	Slender madtom	X										X					X	X							X	X			
Noturus flavus	Stonecat	X	X									X			X		X	X	X						X	X			
Noturus gyrinus	Tadpole madtom	X	X	X	X							X		X		X	X			X	X			X			X		
Noturus miurus	Brindled madtom	X	X									X		X		X	X							X	X		X		
Noturus nocturnus	Freckled madtom	X	X									X		X	X	X	X							X	X		X		
Noturus stigmosus	Northern madtom		X									X			X	X	X	X			X			X	X	X			
Pylodictis olivaris	Flathead catfish	X	X	X								X		X	X	X	X	X						X					
Atractosteus spatula	Alligator gar	X			X									X	X	X	X												
Lepisosteus oculatus	Spotted gar	X		X	X			X						X	X	X	X				X	X	X	X			X		
Lepisosteus osseus	Longnose gar	X	X	X	X							X		X	X	X	X			X	X			X			X		
Lepisosteus platostomus	Shortnose gar	X	X	X	X									X	X	X	X			X	X			X			X		
Morone chrysops	White bass	X		X								X		X	X		X	X									X		
Morone mississippiensis	Yellow bass	X	X	X	X							X		X	X		X	X											
Ammocrypta clara	Western sand darter	X										X			X		X									X			
Ammocrypta pellucida	Eastern sand darter		X									X		X			X									X			
Crystallaria asprella	Crystal darter											X			X		X									X			
Etheostoma asprigene	Mud darter	X			X			X						X	X	X	X							X	X	X			
Etheostoma barbouri	Teardrop darter										X	X					X	X								X	X		
Etheostoma bellum	Orangefin darter											X					X	X							X	X			
Etheostoma blennioides	Greenside darter		X									X					X	X		X	X				X	X			
Etheostoma caeruleum	Rainbow darter	X	X								X	X					X	X							X	X			
Etheostoma camurum	Bluebreast darter		X									X					X	X							X				
Etheostoma chlorosoma	Bluntnose darter	X	X		X			X					X	X		X	X				X			X			X		
Etheostoma crossopterum	Fringed darter										X	X					X	X								X	X		
Etheostoma flabellare	Fantail darter	X	X								X	X					X	X							X	X			
Etheostoma flavum	Saffron darter											X						X								X	X		
Etheostoma gracile	Slough darter	X	X		X			X					X	X		X	X			X	X			X		X	X		
Etheostoma histrio	Harlequin darter											X		X		X	X							X	X	X			
Etheostoma kennicotti	Stripetail darter	X									X	X					X	X								X	X		
Etheostoma maculatum	Spotted darter											X					X	X	X						X				
Etheostoma microperca	Least darter									X	X					X	X				X			X			X		
Etheostoma nigrum	Johnny darter	X	X								X	X					X	X						X		X	X		
Etheostoma oophylax	Guardian darter										X	X					X	X							X	X			

(table continued on next page)

(table 11 continued)

Species	Common name	Occur-rence		Preferred habitat																									
		SNF	HNF	Reservoir	Floodplain lake & oxbow	Sinkhole ponds	Ponds	Wetlands	Cave stream	Springs	Upland headwater creek	Upland stream & river	Lowland headwater creek	Lowland stream & river	Big river	Organic debris/mud	Sand/gravel (0.08-3 in.)	Pebble/cobble (3-24 in.)	Boulder/bedrock (>24 in.)	Emergent vegetation/cover	Aquatic bed	Scrub-shrub	Forested	Instream shelter	Riffles	Glides	Pools	Backwaters	Embayments
Etheostoma proeliare	Cypress darter							X		X			X			X	X				X			X					
Etheostoma rafinesquei	Kentucky darter										X	X					X	X		X					X		X		
Etheostoma proeliare	Cypress darter	X																											
Etheostoma smithi	Slabrock darter			X							X						X	X							X		X		
Etheostoma spectabile	Orangethroat darter	X	X								X	X	X	X			X								X	X	X		
Etheostoma squamiceps	Spottail darter	X									X	X						X							X		X		
Etheostoma stigmaeum	Speckled darter											X					X	X								X	X		
Etheostoma tecumsehi	Shawnee darter										X						X	X			X				X	X	X		
Etheostoma tippecanoe	Tippecanoe darter		X									X					X	X							X				
Etheostoma variatum	Variegate darter		X									X					X	X							X	X			
Etheostoma virgatum	Striped darter										X	X					X	X								X	X		
Etheostoma zonale	Banded darter		X									X					X	X			X				X	X			
Perca flavescens	Yellow perch		X	X											X	X	X				X						X	X	X
Percina caprodes	Logperch	X	X	X	X							X		X	X	X	X	X								X	X		
Percina copelandi	Channel darter		X									X			X		X									X			
Percina evides	Gilt darter											X			X		X	X							X	X			
Percina maculata	Blackside darter	X	X								X	X	X	X		X	X	X								X	X		
Percina phoxocephala	Slenderhead darter	X	X									X			X		X	X							X	X			
Percina sciera	Dusky darter	X	X									X		X		X	X							X		X	X		
Percina shumardi	River darter	X	X									X		X			X	X	X		X				X	X			
Percina stictogaster	Frecklebelly darter											X					X	X		X				X		X			
Percina vigil	Saddleback darter											X		X			X								X	X			
Stizostedion canadense	Sauger	X	X	X								X		X	X		X	X						X		X			
Stizostedion vitreum	Walleye	X		X								X		X	X		X	X						X		X	X		
Percopsis omiscomaycus	Trout-perch	X	X									X					X									X	X		
Ichthyomyzon bdellium	Ohio lamprey		X	X								X		X		X	X	X						X	X	X	X		
Ichthyomyzon castaneus	Chestnut lamprey	X	X	X								X		X		X	X	X						X	X	X	X		
Ichthyomyzon fossor	Northern brook lamprey		X									X				X	X	X						X	X	X	X		
Ichthyomyzon unicuspis	Silver lamprey	X	X	X								X		X		X	X	X						X	X	X	X		
Lampetra aepyptera	Least brook lamprey	X	X					X		X	X	X	X	X		X	X	X						X	X	X			
Lampetra appendix	American brook lamprey											X				X	X	X						X	X	X			
Polyodon spathula	Paddlefish	X		X	X							X		X	X	X	X	X									X	X	X
Aplodinotus grunniens	Freshwater drum	X	X	X	X							X		X	X	X	X										X	X	X
Umbra limi	Central mudminnow	X	X		X			X		X						X	X				X			X					

Unique and rare aquatic habitats for fishes in the area include cave streams, springs, wetlands, and floodplain lakes and oxbows. An outstanding example of all these habitats in one location is the LaRue-Pine Hills Research Natural Area, Union County, Illinois. Other especially scenic sites and those with excellent water quality and high aquatic diversity and found within the two national forests include the middle Blue River system and portions of the East Fork White River in the Hoosier, and the upper Clear Creek system and Big and Lusk Creeks in the Shawnee.

Mussel Habitat

Most freshwater mussels inhabit permanent flowing bodies of water (i.e., riverine system) but some vary considerably with respect to their microhabitat occurrences (Parmalee 1967, Cummings and Mayer 1992). The aquatic assessment area encompasses a variety of local habitats and environments that support a diverse native freshwater mussel fauna. Those hydrologic units (e.g., lower Ohio, lower Ohio Bay, and lower Ohio-Little Pigeon) that border major ecotones of physiographic regions provide a mixture of hilly upland areas and broad alluvial valleys. Within these areas, habitats ranging from small upland streams to large and small rivers, sloughs, and impoundments (artificial ponds and reservoirs) support a variety of mussel species adapted to different habitat types.

Habitat occurrences of native mussel species recorded within the assessment area are presented in table 9. Species diversity was greatest in those hydrologic units containing portions of medium and large rivers (e.g., lower Tennessee, lower Cumberland, upper Green, and lower Ohio). In fact, 64 percent of the mussel species reported from the assessment area inhabit primarily medium and large rivers. Examples of this riverine mussel fauna include snuffbox, fanshell, plain pocketbook, threehorn wartyback, hickorynut, ring pink, sheepnose, mapleleaf, elephant ear, and ebonyshell. These and other riverine species are generally most successful in sand, gravel, or mixed sand-gravel substrates (table 9). Riverine species (most species in Ambleminae and Lampsilinae, table 9) that live in swift current develop thick shells, heavy hinge teeth, and well-developed muscle insertion scars (Parmalee 1967). In larger rivers, mussel distributions vary with depth, current velocity, substrate composition, and other physical factors affecting their development. For example, according to Parmalee (1967), in fast flowing sections of the Mississippi River, mussels can be found at depths of greater than 15 feet. Williams and Schuster (1989) reported that most mussels in large rivers prefer habitat that has a substrate of sand and fine to coarse gravel in depths of 8 to 20 feet in enough current to prevent excessive siltation.

Native freshwater mussels reported from the assessment area that are particular to creek, headwater, slough, or pond habitats with little or no flow include pondhorn, flat floater, cylindrical papershell, paper pondshell, white heelsplitter, giant floater, and pondmussel (table 9). These species (most species in Anodontinae, table 9) differ morphologically from the riverine species in having thin shells, shallow muscle scars, and reduced or absent hinge teeth (Parmalee 1967). Mussels occurring in lentic habitats in mud or silt substrates also are often limited to shallow water (above the epilimnion) because of their relatively poor tolerance of hypoxia (McMahon 1991). Other mussels are ubiquitous throughout the assessment area and occur in a variety of different habitat types: Wabash pigtoe, threeridge, plain pocketbook, fatmucket, and fragile papershell (table 7). These species have been reported to be adaptable to varying water depths and can tolerate impoundments (Cummings and Mayer 1992, Parmalee 1967).

Crayfish Habitat

Crayfishes in the assessment area occupy all five major habitat types defined and outlined in Hobbs (1981). The assessment area has species that occupy open water habitats, species exhibiting all three types of burrowing behaviors, and those that dwell in cave streams—both troglobites and troglophiles (table 10).

According to Hobbs (1981), open-water dwellers can be found in permanent or nearly permanent lentic and lotic environments. Most construct simple burrows out of benthic debris or seek cover under rocks or coarse woody debris. Although these crayfishes are generally found in the main body of water, all will burrow in the substrate down to the water table to seek cover in the event of loss of standing water due to drought. They also may burrow to avoid freezing in winter. This burrowing behavior is similar to tertiary burrowers (see below). In the assessment area, 18 species of crayfish occupy open-water habitats: 16 of the genus *Orconectes* and 2 of the genus *Cambarus* (table 10). Eight open-water crayfish species are found in the watersheds that drain the Shawnee National Forest. The watersheds draining the Hoosier National Forest are home to only two crayfish species that have been recorded from open-water habitats.

Primary burrowers are crayfish species that excavate a complex system of tunnels that generally contact the water table in at least one place. These species rarely leave their burrows that seldom come into contact with permanent bodies of surface water. Burrows can be located well inland from such bodies of water, a location that may preclude them from protection by forested filter strips designed to minimize the impacts of logging and recreation on national forest watersheds (see below for description of filter strips). Three primary burrowers occur in the assessment area—*Cambarus diogenes*, *Fallicambarus fodiens*, and *Procambarus gracilis* (table 10). All three of these species are found in the watersheds that drain the Shawnee National Forest. Only *C. diogenes* has been reported in watersheds that drain the Hoosier National Forest.

Secondary burrowers dig simple, straight-shafted tunnels in areas that are prone to flood during certain times of the year such as roadside ditches, borrow pits, swamp pools, and other depressions. These burrowers seldom live in saturated areas where the water table is at or near the soil surface for most of the year. The tunnels of secondary burrowers often do not contact the water table but generally are excavated in moist soils ensuring that the relative humidity of the air in the burrow remains near 100 percent. These species may remain torpid in their burrows during times of drought. They also leave their burrows and spend much of the year in open-water habitats, particularly when the low-lying areas in which they live flood. There are two secondary burrowing species in the assessment area—*Cambarus ortmanni* and *Procambarus viaeviridis* (table 8). The latter species is found in the watersheds that drain the Shawnee National Forest. There are no secondary burrowers in the watersheds of the Hoosier National Forest.

Tertiary burrowing crayfishes are those that spend most of their lives in open water but retreat to burrows during periods of inactivity, to hide from predators, to avoid freezing in the winter, to lay and brood eggs, or to avoid desiccation during low water periods. In contrast to the limited burrowing activities of open-water species, tertiary burrowers may construct elaborate burrows that may or may not come into direct contact with open water. Tertiary burrowers maintain their burrows for most of the year whereas open-water species burrow only when absolutely necessary. The demarcation between open-water species and tertiary burrowers can at times be very narrow, hence most species in table eight are listed as both. Nine tertiary burrowing species are found in the assessment area—two in the genus *Cambarellus*, one in the genus *Barbicambarus*, two in the genus *Cambarus*, two in the genus *Orconectes*, and two in the genus *Procambarus* (table 10). Five of those species are found in watersheds that drain the Shawnee National Forest and two are found in the watersheds of the Hoosier National Forest.

Four species of crayfish in the assessment area either must live in caves (troglobitic) or frequent caves (troglophilic) during their lifetimes (table 10). *Orconectes pellucidus* and *O. inermis* are eyeless, non-pigmented, troglobitic species found in caves of karst formations in western Kentucky and south-central Indiana. *Cambarus tenebrosus* is a troglophilic species that frequents rocky headwater streams and springs, hence its common occurrence in caves. *Cambarus bartonii* is found in a diversity of habitats including caves, springs, riffles, stream pools, and rarely impoundments. *Cambarus tenebrosus* is the only cave-dwelling species found in the Shawnee National Forest. *Cambarus tenebrosus* and *O. inermis* are found in watersheds of the Hoosier National Forest. Eberly (1955) listed *O. pellucidus* as occurring in several counties that overlap the Hoosier National Forest, but Hobbs et al. (1977) reported no valid records of this species in Indiana.

Implications and Opportunities

Habitat degradation has been a major factor involved in the decline of freshwater mussel and fish populations. For example, construction of dams, channelization, and improper maintenance of riparian zones have resulted in changes to stream environments that are unfavorable to most mussel and some fish species, including increased sedimentation, changed stream hydrology, and reduced habitat heterogeneity. The use of best management practices for timber harvest and road building would minimize impacts to adjacent streams. To be effective, habitat protection and good conservation practices must also extend beyond the boundaries of Federal lands to include entire watersheds. This requires the cooperation of all agencies that share responsibilities for public watersheds and their faunas, as well as riparian landowners. Empirical studies directed at crayfishes are needed to determine the effects of habitat degradation on them.

The activities and home ranges of both primary and secondary burrowing crayfishes can occur great distances from surface bodies of permanent flowing or standing water. Maintenance of vegetative filter strips of varying widths adjacent to lakes, wetlands, perennial streams, and intermittent streams in which logging, road construction, and recreational activities occur will help minimize the potential negative effects those practices might have on aquatic environments and their inhabitants. Primary and secondary burrowing crayfishes, although aquatic species, should perhaps be considered terrestrial species because of their potential to live well beyond the relative protection of designated filter strips. If these species are not considered terrestrial, specific concessions could be made to ensure monitoring and conservation. Restrictions on road building, logging activities, and recreational activities in areas where crayfish burrows are present might benefit these species. Frequent burrow destruction and soil compaction could hinder crayfish burrowing activity, forcing populations to move or trapping them below ground for potentially lethal lengths of time.

As noted earlier, there are no federally listed crayfishes in the assessment area, but three crayfishes in the Shawnee National Forest are listed as endangered in the State of Illinois—*O. indianensis, O. kentuckiensis*, and *O. placidus*. The Forest Service has specific policies for creating stream and river fords (in association with road building and logging activities) within the national forests to minimize the negative effects of the fords on aquatic ecosystems. Crayfishes are relatively immobile compared to other aquatic organisms (e.g., fishes) and are less able to evade fording vehicles.

Much of the assessment area is underlain by karst formations with numerous caves in limestone and other soluble rock (Culver et al. 1999). Cave ecosystems are fragile and complex and can be severely damaged by: (1) water projects such as damming, diverting, and well drilling; (2) land development such as paving, excavating, and filling; (3) nutrient loss from exclusion or loss of important species; (4) nutrient enrichment from sewage, agricultural runoff, slash from forest cutting, and excessive runoff from logged areas; (5) introduction of exotic and pest species; (6) chemical pollution; (7) overcollection; (8) overvisitation; and (9) isolation caused by fragmentation of cave networks from all factors mentioned previously (Elliot 2000). Although many other terrestrial and aquatic organisms depend on cave habitats for survival, the troglophilic and troglobitic fishes and crayfishes in the assessment area could serve as relatively conspicuous and easily monitored indicator species representing the relative health of the caves of the assessment area. Currently, neither of the two cave-associated crayfish species (i.e., *Orconectes inermis* and *O. pellucidus*), only one of which is documented to occur in the Hoosier National Forest, is listed as a Management Indicator Species (MIS) (table 5). These species could be monitored as an indicator of the effects of logging and recreational activities on caves of the assessment area.

LITERATURE CITED

Abell, R.A.; Olson, D.M.; Dinerstein, E.; Hurley, P.T.; et al. 2000.
Freshwater ecoregions of North America: a conservation assessment. World Wildlife Fund (U.S.). Washington, DC: Island Press. 319 p.

Allan, J.D.; Flecker, A.S. 1993.
Biodiversity conservation in running waters. Bioscience. 43(1): 32-43.

Angermeier, P.L. 1995.
Ecological attributes of extinction-prone species: loss of freshwater fishes of Virginia. Conservation Biology. 9(1): 143-158.

Angermeier, P.L.; Karr, J.R. 1994.
Biological integrity versus biological diversity as policy directives. Bioscience. 44(10): 690-697.

Baker, F.C. 1906.
A catalogue of the Mollusca of Illinois. Bulletin of the Illinois State Laboratory of Natural History. 7(6): 53-136 + 1 map.

Becker, G.C. 1983.
Fishes of Wisconsin. Madison, WI: The University of Wisconsin Press. 1,052 p.

Bull, L.A. 1985.
A creel survey of the commercial and sport trotline fishermen of the Kentucky sections of Kentucky Lake and Lake Barkley. Murray, KY: Murray State University. 64 p. Unpubl. M.S. thesis.

Burr, B.M.; Mayden, R.L. 1992.
Phylogenetics and North American freshwater fishes. In: Mayden, R.L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 18-75.

Burr, B.M.; Page, L.M. 1986.
Zoogeography of fishes of the lower Ohio-upper Mississippi River basin. In: Hocutt, C.H.; Wiley, E.O., eds. The zoogeography of North American freshwater fishes. New York, NY: John Wiley & Sons, Inc.: 287-324.

Burr, B.M.; Page, L.M. 1993.
A new species of Percina (Odontopholis) from Kentucky and Tennessee with comparisons to Percina cymatotaenia (Teleostei: Percidae). Bulletin of the Alabama Museum of Natural History. 16: 15-28.

Burr, B.M.; Stewart, J.G. 1999.
Status review, distribution, and aspects of life history of the threatened least brook lamprey, Lamptera aepyptera (Pisces: Petromyzontidae), in Illinois. Final Rep. Springfield, IL: Illinois Department of Natural Resources, Division of Natural Heritage. 25 p.

Burr, B.M.; Warren, M.L., Jr. 1986.
A distributional atlas of Kentucky fishes. Sci. .Tech. Ser. 4. Frankfort, KY: Kentucky Nature Preserve Commission. 398 p.

Burr, B.M.; Cook, K.M.; Eisenhour, D.J.; Piller, K. R.; et al. 1996.
Selected Illinois fishes in jeopardy: new records and status evaluations. Transaction of the Illinois State Academy of Science. 89(3-4): 169-186.

Call, R.E. 1900.
A descriptive illustrated catalog of the Mollusca of Indiana. Indiana Department of Geology and Natural Resources, 24th annual report 1899: 335-535, 1013-1017 [index], pls. 1-78.

Ceas, P.A. 1997.
Systematic studies of the orangethroat darter, Etheostoma spectabile, complex (Percidae; Subgenus Oligocephalus). Urbana-Champaign, IL: University of Illinois, Urbana-Champaign. 161 p. Unpubl. Ph.D. dissertation.

Ceas, P.A.; Page, L.M. 1997.
Systematic studies of the Etheostoma spectabile complex (Percidae; Subgenus Oligocephalus), with descriptions of four new species. Copeia. 1997(3): 496-522.

Cicerello, R.R.; Warren, M.L., Jr.; Schuster, G.A. 1991.
A distributional checklist of the freshwater unionids of KY. American Malacological Bulletin. 8(2): 113-129.

Cicerello, R.R. 2001.
Unpublished spot-distributions maps for the freshwater mussels of Kentucky. Frankfort, KY: Kentucky State Nature Preserves Commission.

Clarke, A.H.; Hovingh, P.; Clarke, J.J. 1999.
A freshwater mussel inventory of four tributary watersheds of the east Fork of White River, Hoosier National Forest, Indiana, with notes on other freshwater mollusks and on amphibians and leeches. Final Rep. Bedord, IN: U.S. Department of Agriculture, Forest Service, Hoosier National Forest, Brownstown Ranger District. 33 p. + maps and field notes.

Cowardin, L.M.; Carter, V.; Golet, F.C.; LaRoe, E.T. 1979.
Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Washington, DC: U.S. Department of the Interior, Office of Biological Services, Fish and Wildlife Service. 131 p.

Culver, D.C.; Master, L.L.; Christman, M.C.; Hobbs, H.H., III. 1999.
Obligate cave fauna of the 48 contiguous United States. Conservation Biology. 14(2): 386-401.

Cummings, K.S. 1991.
The aquatic Mollusca of Illinois. In: Page, L.M.; Jeffords, M.R., eds. Our living heritage: the biological resources of Illinois. Illinois Natural History Survey Bulletin. 34(4): 428-438.

Cummings, K.S. 2001.
Unpublished spot-distribution maps for the freshwater mussels of Illinois and Indiana. Champaign, IL: Illinois Natural History Survey. [maps]

Cummings, K.S.; Mayer, C.A. 1992.
Field guide to freshwater mussels of the Midwest. Illinois Natural History Survey Bulletin Manual 5. 194 p.

Cummings, K.S.; Mayer, C.A. 1997.
Distributional checklist and status of Illinois freshwater mussels (Mollusca: Unionacea). In: Cummings, K.S.; et al., eds. Conservation and management of freshwater mussels II: initiatives for the future: Proceedings of a UMRCC symposium; 1995 October 16-18; St. Louis, MO. Rock Island, MS: Upper Mississippi River Conservation Committee: 129-145.

Cummings, K.S.; Mayer, C.A.; Page, L.M. 1992.
Survey of the freshwater mussels (Mollusca: Unionidae) of the Wabash River drainage. Tech. Rep. 6. Final Report prepared for Indiana Department of Natural Resources. Indianapolis, IN: Illinois Natural History Survey, Center for Biodiversity: iii + 201 p.

Daniels, L.E. 1903.
A check list of Indiana Mollusca, with localities. Indiana Geological Survey Annual Report. 26: 629-652.

Dimmick, W.W.; Fiorino, K.L.; Burr, B.M. 1996.
Reevaluation of the Lythrurus ardens (Cypriniformes: Cyprinidae) complex with recognition of three evolutionary species. Copeia. 1996(4): 813-823.

Dolloff, C.A.; Hankin, D.G.; Reeves, G.H. 1993.
Basin-wide estimation of habitat and fish populations in streams. Gen. Tech. Rep. SE-83. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 25 p.

Dufford, D.W. 1994.
Illinois 1993 commercial catch report exclusive of Lake Michigan. Springfield, IL: Illinois Department of Conservation. 15 p.

Eberly, W.R. 1955.
Summary of the distribution of Indiana crayfishes, including new state and county records. Proceedings of the Indiana Academy of Science. 64: 281-283.

Eisenhour, D.J. 1997.
Distribution and systematics of Notropis wickliffi (Cypriniformes: Cyprinidae) in Illinois. Transactions of the Illinois State Academy of Science. 90(1-2): 65-78.

Elliot, W.R. 2000.
Conservation of the North American cave and karst biota (Chapter 34). In: Wilkens, H.; et al., eds. Ecosystems of the world, volume 30: subterranean ecosystems. London, UK: Elsevier: 665-689.

Forbes, S.A.; Richardson, R.E. 1909.
The fishes of Illinois. Illinois State Laboratory of Natural History. cxxxi + 357 p. plus separate atlas of 103 maps.

Gerking, S.D. 1945.
Distribution of the fishes of Indiana. Investigations of Indiana Lakes and Streams. 3: 1-137.

Gilbert, C.R. 1969.
Systematics and distribution of the American cyprinid fishes Notropis ariommus and Notropis telescopus. Copeia. (3): 474-492.

Goodrich, C.; van der Schalie, H. 1944.
A revision of the Mollusca of Indiana. American Midland Naturalist. 32(2): 257-326.

Harmon, J.L. 1998.
Finalization of freshwater mussel (Bivalvia: Unionidae) survey of Indiana's East Fork White River Drainage. Final Rep. Indianapolis, IN: Indiana Department of Natural Resources, Division of Fish and Wildlife. 166 p.

Harris, J.L. 1999.
Status of aquatic resources—diversity of mussels. In: Ozark-Ouachita highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Argriculture, Forest Service, Southern Research Station: 115-132.

Hay, W.P. 1896.
The crustacea of Indiana. Proceedings of the Indiana Academy of Science. 1: 147-151.

Heidinger, R.C. 2000.
Commercial harvest and biology of major freshwater finfish species. In: Martin, R.E.; et al., eds. Marine and freshwater products handbook. Lancaster, PA: Technomic Publishing Co., Inc.: 209-252.

Herkert, J.R., eds. 1992.
Endangered and threatened species of Illinois: status and distribution, volume 2: animals. Springfield, IL: Illinois Endangered Species Protection Board. 142 p.

Hobbs, H.H., Jr. 1981. T
he crayfishes of Georgia. Smithsonian Contributions to Zoology 318. 549 p.

Hobbs, H.H., Jr.; Hobbs, H.H., III; Daniel, M.A. 1977.
A review of the troglobitic decapod crustaceans of the Americas. Smithsonian Contributions to Zoology 244. 183 p.

Hoyt, R.E.; Flynn, R.B. 1974.
Commercial fishery investigations of Rough River and Nolin River reservoirs, Kentucky. Final Rep. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources, Division of Fisheries. 31 p.

Huner, J.V. 1978.
Exploitation of freshwater crayfishes in North America. Fisheries. 3(6): 2-5.

Illinois Biological Stream Characterization Work Group. 1995.
[Map of] Biological stream characterization of Illinois streams. Champaign, IL: Illinois Natural History Survey. 1 map.

Illinois Endangered Species Protection Board. 2000.
Checklist of endangered and threatened animals and plants of Illinois. Springfield, IL: Endangered Species Protection Board. 20 p.

Illinois Natural History Survey Database of Crayfishes. 2001.
Champaign, IL: Illinois Natural History Survey.

Indiana Department of Fish and Wildlife Resources Web site. Viewed March, 2001.
http://www.in.gov/dnr. Web site a service of the Indiana Department of Natural Resources.

Jenkins, R.E.; Burkhead, N.M. 1994.
Freshwater fishes of Virginia. Bethesda, MD: American Fisheries Society. 1,079 p.

Jenkins, R.E.; Lachner, E.A.; Schwartz, F.J. 1971.
Fishes of the central Appalachian drainages: their distribution and dispersal. In: Holt, P.C., ed. The distributional history of the biota of the southern Appalachians, Part III: Vertebrates. Res. Div. Monogr. 4. Blacksburg, VA: Virginia Polytechnic Institute and State University: 43-117.

Johnson, R.I. 1980.
Zoogeography of the North American Unionacea (Mollusca: Bivalvia) north of the maximum Pleistocene glaciation. Museum of Comparative Zoology Bulletin. 149(2): 77-189.

Karr, J.R.; Fausch, K.D.; Angermeier, P.L.; et al. 1986.
Assessing biological integrity in running waters: a method and its rationale. Spec. Publ. 5. Champaign, IL: Illinois Natural History Survey. 28 p.

Kentucky State Nature Preserve Commission Web site. Viewed October, 2001.
http://www.kynaturepreserves.org/reports.html. Endangered, threatened, special concern, and historic plants and animals of Kentucky. [A pdf file].

Layman, S.R. 1994.
Phylogenetic systematics and biogeography of darters of the subgenus Doration (Percidae: Etheostoma). Tuscaloosa, AL: University of Alabama. Ph.D. dissertation.

Lee, D.S.; Gilbert, C.R.; Hocutt, C.H.; Jenkins, R.E.; et al. 1980 et seq.
Atlas of North American freshwater fishes. North Carolina State Museum of Natural History. 867 p.

Lodge, D.M.; Taylor, C.A.; Holdich, D.M.; Skurdal, J. 2000a.
Nonindigenous crayfishes threaten North American freshwater biodiversity: lessons from Europe. Fisheries. 25(8): 7-20.

Lodge, D.M.; Taylor, C.A.; Holdich, D.M.; Skurdal, J. 2000b.
Reducing impacts of exotic crayfish introductions: new policies needed. Fisheries. 25(8): 21-23.

Maxwell, J.R.; Edwards, C.J.; Jensen M.E.; et al. 1995.
A hierarchical framework of aquatic ecological units in North America (Nearctic zone). Gen. Tech. Rep. NC-176. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 72 p.

Mayden, R.L. 1987.
Pleistocene glaciation and historical biogeography of North American central highland fishes. In: Johnson, W.C., ed. Quaternary environments of Kansas. Kansas Geological Survey Guidebook Series 5: 141-151.

Mayden, R.L. 1988.
Vicariance biogeography, parsimony, and evolution in North American freshwater fishes. Systematic Zoology. 37(4): 329-355.

Mayden, R.L.; Burr, B.M.; Page, L.M.; Miller, R.R. 1992.
The native freshwater fishes of North America. In: Mayden, R.L., ed. Systematics, historical ecology, and North American freshwater fishes. Stanford, CA: Stanford University Press: 825-863.

McComish, T.S.; Brown, F.C. 1980.
Distribution and life history notes for fishes of the Hoosier National Forest, Indiana. [Report to agency not indicated]. 225 p.

McMahon, R.F. 1991.
Mollusca: Bivalvia. In: Thorpe, J.H.; Covich, A.P., eds. Ecology and classification of north american freshwater invertebrates. San Diego, CA: Academic Press: 315-399.

Meyer, E.R. 1974.
Unionid mussels of the Wabash, White, and East Fork White rivers, Indiana. Virginia Journal of Science. 25: 20-25.

Missouri Department of Conservation (MO DC). 1997.
Wildlife code of Missouri. Jefferson City, MO: Missouri Department of Conservation. 145 p.

Missouri Natural Heritage Program. 2000.
Missouri species of conservation concern checklist. Jefferson City, MO: Missouri Department of Conservation. vi + 28 p.

Moody, M.W. 2000.
Handling and processing crawfish. In: Martin, R.E.; et al., eds. Marine and freshwater products handbook. Lancaster, PA: Technomic Publishing Co., Inc: 309-322.

Natureserve Web site. Viewed October 2001.
http://www.natureserve.org/. Web site a service of the Association for Biodiversity Information.

Oesch, R.D. 1984.
Missouri Naiads. A guide to the mussels of Missouri. Jefferson City, MO: Missouri Department of Conservation. 270 p.

Page, L.M. 1985.
The crayfishes and shrimps (Decapoda) of Illinois. Illinois Natural History Survey Bulletin. 33(4): 35-448.

Page, L.M. 1991.
Streams of Illinois. In: Page, L.M.; Jeffords, M.R., eds. Our living heritage: the biological resources of Illinois. Illinois Natural History Survey Bulletin. 34(4): 439-446.

Page, L.M.; Burr, B.M. 1991.
A field guide to freshwater fishes. Boston, MA: Houghton Mifflin Co. 432 p.

Page, L.M.; Mottesi, G.B. 1995.
The distribution and status of the Indiana crayfish, Oconectes indianensis, with comments on the crayfishes of Indiana. Proceedings of the Indiana Academy of Science. 104: 103-111.

Page, L.M.; Ceas, P.A.; Swofford, D.L.; Buth, D.G. 1992.
Evolutionary relationships within the Etheostoma squamiceps complex (Percidae; subgenus Catonotus) with descriptions of five new species. Copeia. (3): 615-646.

Parmalee, P.W. 1967.
The fresh-water mussels of Illinois. Illinois State Museum, Popular Science Series 8. 108 p.

Parmalee, P.W.; Bogan, A.E. 1998.
The freshwater mussels of Tennessee. Knoxville, TN: The University of Tennessee Press. 328 p.

Pearson, W.D.; Boston, C.H. 1995.
Distribution and status of the northern cavefish, Amblyopsis spelaea. Final Report to Indiana Department of Natural Resources, Division of Fish and Wildlife, Nongame and Endangered Wildlife Program. 101 p.

Perry, W.L.; Feder, J.L.; Dwyer, G.; Lodge, D.M. 2001.
Hybrid zone dynamics and species replacement between Orconectes crayfishes in a northern Wisconsin lake. Evolution. 55(6): 1153-1166.

Pflieger, W.L. 1971.
A distributional study of Missouri fishes. University of Kansas Publications, Museum of Natural History. 20(3): 225-570.

Pflieger, W.L. 1996.
The crayfishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 152 p.

Pflieger, W.L. 1997.
The fishes of Missouri. Jefferson City, MO: Missouri Department of Conservation. 372 p.

Poly, W.J. 2001.
Distribution of the alligator gar, Atractosteus spatula (Lacépède,1803), in Illinois. Transactions of the Illinois State Academy of Science. 94(3): 185-190.

Poly, W.J.; Wilson, A.K. 1998.
The fringed darter, Etheostoma crossopterum, in the Cache River basin of southern Illinois (Percidae: Subgenus Catonotus). Ohio Journal of Science. 98(2): 6-9.

Renaker, R.; Carter, B.T. 1968.
The commercial fish harvest in Kentucky during 1965 and 1966. Rep. 25. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources. 25 p.

Robinson, J.W. 1994.
Missouri's commercial fishery harvest, 1992. Jefferson City, MO: Missouri Department of Conservation. 14 p.

Smith, P.W. 1971.
Illinois streams: a classification based on their fishes and an analysis of factors responsible for disappearance of native species. Biol. Notes 76. Champaign, IL: Illinois Natural History Survey. 14 p.

Smith, P.W. 1979.
The fishes of Illinois. Urbana, IL: University of Illinois Press. 314 p.

Standage, R.W. 1999a.
Status of aquatic resources—commercially and recreationally important species (Chapter 2). In: Ozark-Ouachita highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 162-171.

Standage, R.W. 1999b.
Status of aquatic resources—management indicator species. In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 171-176.

Strange, R.M.; Burr, B.M. 1997.
Intraspecific phylogeography of North American highland fishes: a test of the Pleistocene vicariance hypothesis. Evolution. 51(3): 885-897.

Taylor, C.A. 2000.
Systematic studies of the Orconectes juvenilis complex (Decapoda: Cambaridae), with descriptions of two new species. Journal of Crustacean Biology. 20(1): 132-152.

Taylor, C.A. 2002.
A new crayfish of the genus Orconectes Cope, 1872 from the lower Ohio River drainage of western Kentucky (Crustacea: Decapoda: Cambaridae). Proceedings of the Biological Society of Washington. 115(1): 129-137.

Taylor, C.A.; Anton, T.G. 1999.
Distribution and ecological notes on some of Illinois' burrowing crayfishes. Transactions of the Illinois State Academy of Science. 92(1-2): 137-145.

Taylor, C.A.; Schuster, G.A. 2001.
Unpublished spot-distribution maps for the crayfishes of Kentucky. Champaign, IL: Illinois Natural History Survey and Richmond, KY: Eastern Kentucky University.

Taylor, C.A.; Warren, M.L., Jr.; Fitzpatrick, J.F., Jr.; et al. 1996.
Conservation status of the crayfishes of the U.S. and Canada. Fisheries. 22(4): 25-38.

Taylor, R.W. 1982.
The freshwater mussels (naiads) of Big Indian Creek, a small southern Indiana tributary of the Ohio River (Bivalvia: Unionidae). Nautilus. 96(2): 66-68.

Timmons, T.J.; Bull, L.A.; Johnson, R.L. 1985.
Trotline fishery survey of the Kentucky sections of Kentucky Lake and Lake Barkley. Project 2-409-R-1, Final Rep. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources, Federal Aid in Fish Restoration. 22 p.

Timmons, T.J.; Hoffnagle, T.; Hale, R.C.; Soldo, J.B. 1989.
Incidence of sport fishes in the commercial fish catch from Kentucky Lake, Kentucky and Tennessee. North American Journal of Fisheries Management. 9: 209-212.

U.S. Department of Agriculture, Forest Service (USDA FS). 1997.
Rare invertebrates, North America. Rep. 15, Washington, DC: U.S. Department of Agriculture, Forest Service, Threatened, Endangered, and Special Concern Program, 212 p. [Based on the report of The Nature Conservancy and the Natural Heritage Central databases].

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997a.
Endangered and threatened species: review of plant and animal taxa. Federal Register. 62(182): 49,397-49,411.

U.S. Department of the Interior, Fish and Wildlife Service (USDI FWS). 1997b.
List of endangered and threatened wildlife and plants, May 13, 1997. Washington, DC: U.S. Department of the Interior, Fish and Wildlife Service, Division of Endangered Species. 42 p.

van der Schalie, H.; van der Schalie, A. 1950.
The mussels of the Mississippi River. American Midland Naturalist. 44: 448-466.

Warren, M.L., Jr.; Burr, B.M. 1988.
Reassessment of the Illinois ranges of the bigeye chub, Hybopsis amblops, and the pallid shiner, Notropis amnis. Ohio Journal of Science. 88(5): 181-183.

Warren, M.L., Jr.; Burr, B.M. 1994.
Status of freshwater fishes of the United States: overview of an imperiled fauna. Fisheries. 19(1): 6-18.

Warren, M.L., Jr.; Hlass, L. 1999.
Status of aquatic resources—diversity of fishes (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 100-115.

Warren, M.L., Jr.; Tinkle, K. 1999.
Status of aquatic resources—endangered, threatened, and other aquatic species of special concern (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen. Tech. Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 153-162.

Warren, M.L., Jr.; Robison, H.W.; Tinkle, K. 1999.
Status of aquatic resources—diversity of crayfishes (Chapter 2). In: Ozark-Ouachita Highlands assessment: aquatic conditions. Gen Tech Rep. SRS-33. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station: 132-140.

Warren, M.L., Jr.; Burr, B.M.; Etnier, D.A.; Starnes, W.C. 1991.
Fishes of Kentucky and Tennessee: a hierarchical classification of drainages. Journal of the Tennessee Academy of Science. 66(4): 135-140.

Warren, M.L., Jr.; Burr, B.M.; Walsh, S.J.; et al. 2000.
Diversity, distribution, and conservation status of the native freshwater fishes of the southern U.S. Fisheries. 25(10): 7-29.

Watters, G.T. 2000.
Freshwater mussels: a complicated resource to conserve. In: Abell, R.A.; Olson, D.M.; Dinerstein, E.; et al. 2000. Freshwater ecoregions of North America: a conservation assessment. World Wildlife Fund (U.S.). Washington, DC: Island Press: 37-38.

Weilbaker, C.; Baker, C.D.; Forsyth, B.J.; Christenson, C.M.; Taylor, R.W. 1985.
The freshwater naiads, Bivalvia: Unionidae, of the Blue River, a Southern Indiana tributary of the Ohio River. Proceedings of the Indiana Academy of Science. 94: 687-691.

Weitzell, R.E.; Stewart, J.G.; Burr, B.M. 1998.
Status survey of the least brook lamprey, Lamptera aepyptera (Pisces: Petromyzontidae), a threatened species in Illinois. Final Rep. Springfield, IL: Illinois Department of Natural Resources, Division of Natural Heritage. 26 p.

Wiley, E.O.; Mayden, R.L. 1985.
Species and speciation in phylogenetic systematics, with examples from the North American fish fauna. Annals of the Missouri Botanical Gardens. 72: 596-635.

Williams, F.E.; Neves, R.J. 1992.
Introducing the elements of biological diversity in the aquatic environment. In: Williams, J.E.; Neves, R.J., eds. Reprint of special session 6, biological diversity in aquatic management. Transactions of the 57th North American wildlife and natural resources conference, Wildlife Management Institute. Washington, DC: Wildlife Management Institute: 345-354.

Williams, J.C.; Schuster, G.A. 1989.
Freshwater mussel investigations of the Ohio River: mile 317.0 to mile 981.0. Frankfort, KY: Kentucky Department of Fish and Wildlife Resources. 57 p.

Williams, J.D.; Warren, M.L., Jr.; Cummings, K.S.; et al. 1993.
Conservation status of freshwater mussels of the U.S. and Canada. Fisheries. 18(9): 6-22.

http://endangered.fws.gov/wildlife. 2001.
U.S. listed invertebrate animal species report by taxonomic group. U.S. Fish and Wildlife Service.

http://www.in.gov/dnr/fishwild/endangered/mollusks.htm. 2001.
Indiana endangered Mollusks. Indiana Department of Natural Resources, Division of Fish and Wildlife.

http://www.conservation.state.mo.us. 2001.
Endangered species checklist. Missouri Department of Conservation.

Great Trinity Forest Management Plan

Wetlands

Freshwater Mussels of the Delta National Forest, Mississippi

MLW

Freshwater Mussels of the Delta National Forest, Mississippi

USDA Forest Service
Southern Research Station
Center for Aquatic Technology Transfer
Center for Bottomland Hardwoods Research
Forest Hydrology Laboratory
Oxford, Mississippi 38655

Freshwater mussels of the Delta National Forest, Mississippi

Final Report

Submitted to:

National Forests in Mississippi
100 W. Capitol Street, Suite 1141
Jackson, MS 39269

and

FS/BLM National Aquatic Monitoring Center
860 N 1200 E
Logan, UT 84321

By:

Wendell R. Haag and Melvin L. Warren, Jr.
USDA Forest Service
Southern Research Station
Center for Bottomland Hardwoods Research
1000 Front Street
Oxford, MS 38655

December 1998

Summary

Twenty-three species of freshwater mussels were collected during a survey of aquatic habitats in the Delta National Forest, Mississippi. An additional 6 species not encountered in this survey were reported by an earlier study in the Big Sunflower River near the northern proclamation boundary of the Forest. These species are included here, bringing the total species list for the Forest to 29 species. These species are distributed unequally among aquatic habitats in the Forest. Twenty-four species occurred only in large river habitats represented by the Big and Little Sunflower Rivers. Three other habitat types, bayous and small permanent streams, intermittent streams and ditches, and palustrine wetlands, had mussel faunas that were similar to each other but differed from the large river fauna. Two species occurred only in these habitats and not in large rivers. An additional three species were widely distributed among all habitat types.

Most species found in large river habitats showed little or no evidence of recent recruitment; most individuals were greater than 10 years old. Five species unique to large stream sites were found only as relict shells, indicating that these species are now rare or extirpated from these sites. In contrast, all species found in bayous and small permanent streams, intermittent streams and ditches, and palustrine wetlands showed evidence of recent recruitment.

The continued existence of the diverse and distinctive large stream mussel fauna in the Forest is contingent on: 1) maintaining the habitat integrity of the Little Sunflower and the Big Sunflower rivers; 2) determining factors that are limiting recruitment and eliminating species; and 3) identifying management alternatives that may mitigate these factors. The current conditions for freshwater mussels in the Little Sunflower and Big Sunflower rivers of the Forest are inexorably influenced by upstream watershed conditions. From that perspective, the continued existence of the diverse mussel fauna of the Delta National Forest is also contingent on the cooperation and coordination of 'state and federal management and regulatory activities in the Big and Little Sunflower rivers.

Introduction

Freshwater mussels of the family Unionidae are an important part of stream, lake, and wetland ecosystems in the southeastern United States, In many areas, mussels account for a large proportion of the biomass in streams (Negus 1966, others) and serve as an important food resource for fish and other animals (Neves and Odum 1988, Daiber 1952). Dense populations of mussels also contribute to the functioning of aquatic ecosystems by filtering large volumes of water (McMahon 1991). Different aquatic habitats·support different mussel species assemblages and stream communities are usually different than communities found in lentic habitats such as lakes and wetlands (Parmalee and Bogan 1998).

Many large streams in the Mississippi River Embayment support diverse, abundant mussel communities. Species composition of these communities is distinctive from other large streams in the southeast, as well as from other aquatic habitats within the Mississippi River Embayment. Examples in this region include the Big Black River, MS, with 31 species (Hartfield and Rummel 1985), the Hatchie River, TN, with 33 species (Manning 1989), the St. Francis River, AK, with 35 species (Ahlstedt and Jenkinson 1991, Jenkinson and Ahlstedt 1994), and the Cache River, AK, with 19 species (Jenkinson and Ahlstedt 1994). Mussel assemblages of these rivers are.characterized by a predominance of long-lived, heavy-shelled species including a mixture of southern species such as the Round pearshell (*Glebula rotundata),* Bankclimber (*Plectomerus dombeyanus*), Bleufer (*Potamilus purpuratus),* Southern mapleleaf *(Quadrula apiculata*), Texas lilliput (*Toxolasma* texasensis), and the Tapered pondhorn *(Uniomerus declivus),* and more widespread Interior Basin species such as the Three-ridge (*Amblema plicata),* Wabash pigtoe *(Fusconaia flava),* Washboard *(Megalonaias nervosa),* Three-horned wartyback (*Obliquaria reflexa),* Pimpleback *(Quadrula pustulosa),* and at least 15 other species.

Lentic habitats such as lakes and wetlands support less diverse but similarly distinctive mussel communities. These assemblages are characterized by a predominance of short-lived, thin-shelled species such as the Flat floater *(Anodonta suborbiculata),* Pondmussel (*Ligumia* subrostrata), Giant floater *(Pyganodon grandis),* Pondhorn (Uniomerus *tetralasmus*), and the Paper pondshell *(Utterbackia imbecillis).* These species are widespread in lentic habitats of the southern and central United States.

Mussel populations in the United States have declined precipitously in the last 50 years due to a variety of human-induced modifications to aquatic habitats such as channelization, impoundment, and water pollution. Currently, 72 percent of the freshwater mussel fauna of North America is considered threatened, endangered, or of special concern (Williams et al. 1993). National Forests contain some of the highest quality aquatic habitat remaining in the southeast and represent important refugia for remnants of the southern mussel fauna.

The Delta National Forest (NF) contains a wide variety of aquatic habitats including large rivers, small lowland streams and bayous, and wetlands. The proclamation boundary of the Forest encompasses 47,885 ha in the Yazoo Delta physiographic region in west-central Mississippi. The Delta NF is drained entirely by the Sunflower River system of the Yazoo drainage. Information on mussel distributions within the Delta NF was limited to one site, on the Big Sunflower River immediately upstream from the Delta NF (Miller et al. 1992). No information on mussel occurrences was available for other sections of this river or for other aquatic habitats in the Forest (Haag and Warren 1995).

The goal of this study is to fully document the mussel fauna of the Delta National Forest. We present a comprehensive species list for the Forest and document species assemblages occurring in different aquatic habitats. We also provide information on mussel densities and length-frequencies that can be used as baseline information for future monitoring of mussel resources in the Delta National Forest.

Methods

We surveyed freshwater mussel populations in waters of the Delta National Forest during low-water conditions in August 1997 and November 1998. Water bodies were located by examining USGS 7.5 minute topographic maps and the USFS 15 minute Delta NF district map. We made an attempt to visit representatives of all major aquatic habitat types occurring on the Forest. Only sites with standing water or evidence of recent standing water were surveyed. Sites that appeared to be dry for most of the year were not sampled. At all sites with water, live mussels were located by feeling along the bottom and sifting through the substrate. We augmented our survey results with information from previously published studies on mussel distributions in the Delta NF to provide a complete list of mussel species in the area.

In addition to searching for live mussels, at all sites shorelines were searched for empty shells which were bagged and returned to the laboratory for identification. All shells encountered were classified as freshly dead, weathered dead, or relict shells. Freshly dead shells were defined as those which had traces of soft tissue remaining in the shell or had a lustrous nacre (mother-of-pearl layer) inside the shell; these traits indicate that the animal died recently and the species probably continues to exist at the site. Weathered dead shells were defined as those without traces of soft tissue and with a non-lustrous nacre, but for which the periostracum (the outer, proteinaceous layer of the shell) and prismatic layer (the calcium-based structural element of the shell) were not decomposed and were structurally sound; these traits indicate that the animal died within approximately the last five years and the species may continue to exist at the site. Relict shells were defined as those for which the periostracum and prismatic layers were partially decomposed, resulting in a chalky, easily broken shell; these traits indicate that the animal likely died greater than 5 years ago. Representation of a species only by relict shells at a site indicates that the species may no longer occur at that site. Relict shells may persist for many years and when present, they provide a record of the historical fauna of the site.

At sites surveyed during 1998, we made quantitative estimates of mussel abundance at most sites by conducting a series of timed searches. At each site, two different observers each made from one to five 5-10 minute searches and mussel abundances were expressed as mean number of mussels encountered/hour.

We made observations on ages and lengths of most live mussels encountered to assess the extent of recent recruitment. At intermittent stream and ditch sites and palustrine wetland sites, we made age observations on freshly dead shells because of the rarity of live mussels at these sites. Mussels deposit annual growth rings in the shells similar to those found in trees, and ages can be estimated by counting these rings. However, in older individuals, shell erosion or mineral deposits obscure growth rings, making accurate estimation of age difficult. Therefore, we estimated ages of mussels by counting growth rings where possible and each individual was classified into one of two age groups: 1) less than 10 years old or 2) greater than 10 years old. In this way, we were able to evaluate the extent to which recruitment has occurred 'in the past 10 years.

We also measured the length of all live individuals encountered at quantitatively sampled sites. Because mussels have indeterminate growth, length can be used as a surrogate measure to estimate age. In order to estimate age, length measurements must be calibrated against individuals of known ages. This information is lacking for this region. However, our measurements serve as baseline information for future comparisons of size distributions of mussels.

We described the habitat of all sites sampled for mussels according to the guidelines set forth by the U.S. Fish and Wildlife Service (Cowardin et al. 1979). We analyzed mussel occurrence in each habitat type in order to identify fauna1 assemblages characteristic of these habitats.,

Results

We sampled thirty-two sites for mussels during this study (Figure 1). We visited 38 sites but three appeared to be dry for much of the year and were not sampled. Two sites visited on the Big Sunflower River and one site on Six-mile Cutoff were too deep for sampling using our methodology. Twenty-one (66%) of the sampled sites had at least one species of mussel. Two sites had only *Corbicula fluminea,* a small bivalve introduced from Asia, or fingernail clams (family Sphaeriidae).

We classified sites in Delta NF with permanent water into 4 major aquatic habitat types: large rivers, bayous and small permanent streams, intermittent streams and ditches, and palustrine wetlands (Table 2). Nine large river sites, 1 bayou and small permanent stream site, 14 intermittent stream and ditch sites, and 8 palustrine wetland sites were sampled. Mussels occurred in all habitat types, but species composition and abundance varied among habitats (Table 1).

Mussel communities of large river sites were distinctive from all other habitat types and had the highest species diversity (27 species) (Table 1) and mean mussel abundance (74 mussels/hour, standard error (SE) = 29). Twenty-four species were found only in large river habitats. These communities were dominated by the Three-ridge (*Amblema plicata*) (28 individuals/hour, SE = 17), Bankclimber (*Plectomerus dombeyanus)* (18 individuals/hour, SE = 8), and Pimpleback *Quadrula pustulosa* (5 individuals/hour, SE = 3). Three species (Flat floater, *Anodonta suborbiculata;* Giant floater, *Pyganodon grandis;* and Texas lilliput, *Toxolasma texasensis)* found at large river sites also were widely distributed among other habitat types.

Bayous and small permanent streams, intermittent small streams, and palustrine wetlands were similar in species diversity (2-5 species), species composition, and mussel abundance. Two species, the pondhorn (*Uniomerus tetralasmus*) and the paper pondshell, (*Utterbackia imbecillis*) were found only in these habitat types and were not found at large river sites. Mussel density was low in bayous, intermittent streams, and palustrine wetlands (less than 1 mussel/hour).

Large excavated drainage canals represent an additional habitat type present in the Forest, but we did not sample these habitats. This habitat type is represented in Delta NF by Holly Bluff Cutoff and Six-mile Cutoff.

Age structure of mussel populations varied among habitat types. At large-river sites, age structure of most species was biased strongly toward older individuals (>10 years old), and there was little evidence of recent recruitment (Tables 3 and 4). Of 16 species found alive in large river habitats, individuals less than 10 years old were found for only 7 species. For 6 of these seven species, young individuals comprised less than 27% of the total. The dominant species in this habitat all showed extremely low levels of recent recruitment (*Amblema plicata, 5%* of total individuals were less than 10 years old; Plectomerus *dombeyanus* and *Quadrula pustulosa,* no individuals were less than 10 years old). In bayous and small permanent streams, intermittent streams and ditches, and palustrine wetlands, age structure of all species was biased towards individuals less than 10 years old. With the exception of one species, all individuals encountered were less than 10 years old.

Discussion

The Delta National Forest supports a diverse mussel fauna of at least 29 species (Table 1). We collected 23 species during this survey. Eighteen species were collected alive and 5 species were collected only as relict shells. Mussels were widely distributed throughout the waters of the Forest and were found in a wide variety of aquatic habitats. At several sites, diverse and abundant communities were present. Six species previously reported from the Delta NF (Miller et al. 1992) were not encountered in the present study (Table 1). Mussels are widely distributed throughout a variety of aquatic habitat types in the Forest. Most species are found only in large stream habitats and this habitat type supports the most diverse species assemblages (27 species). Small permanent streams, intermittent streams, and wetlands support a less diverse, but distinctive fauna of 5 species.

The mussel fauna of the Delta NF supports several species considered imperiled and that have conservation status at some level. Two species, the rock pocketbook *(Arcidens confragosus)* and the pyramid pigtoe (*Pleurobema pyramidatum*) appear on the National Forests in Mississippi Sensitive Species List. Three species, the butterfly (*Ellipsaria lineolata*), wartyback *(Quadrula nodulata),* and the tapered pondhorn (*Uniomerus declivus*) appear on the Mississippi Natural Heritage Program's Locally Rare Species List. One species, the deertoe (*Truncilla* *truncata*), not encountered in our survey but reported by an earlier study (Miller et al. 1992) appears on the Mississippi Natural Heritage Program Locally Rare Species List. *Pleurobema pyramidatum* and *Ellipsaria lineolata* are considered threatened, and of special concern, respectively, by the American Fisheries Society (Williams et al. 1993). All of these species occur only in large river habitats in the Delta NF.

Most species of large river habitats depend on stable habitat conditions. These species are usually long-lived, and reproduction can be infrequent (Payne and Miller 1989). However, we observed an almost complete lack of reproduction for most species in this habitat. Low recruitment has been observed throughout the lower Sunflower River' (Miller et al. 1995). Furthermore, the presence of 5 species as relict shells only suggests that some species may have been lost from the fauna in recent years. At least two of these species, the ebonyshell (*Fusconaia ebena*) and the pyramid pigtoe (*Pleurobema pyramidatum*), appear to once have been common, judging by the abundant valves of both species found at several sites. Cut-offs and other recently dredged water bodies may provide poor habitat for many large river species due to the unstable nature of the substrate (Ahlstedt and Jenkinson 1991).

In contrast to large river mussel species, wetland species are adapted to ephemeral, dynamic habitats. Most species common in these habitats are relatively short-lived and reproduce at an early age. Further, some species, notably the pondhorn

(Uniomerus tetralasmus), are thought to able to survive periods of drought by burying in the mud (Cummings and Mayer 1992, Parmalee and Bogan 1998). Other species such as the flat floater (*Anodonta suborbiculata),* Giant floater *(Pygandon grandis),* and the Paper pondshell *(Utterbackia imbecillis*) are host-generalists that can use a'wide variety of fishes as hosts (Watters 1994). Some evidence suggests that the Paper pondshell may be able to reproduce without a fish host (Watters 1994). These traits allow these species to rapidly colonize new habitats. Thus, most areas of newly-created aquatic habitat in the Delta NF that hold water for extended periods, such as beaver ponds, may be colonized by one or all of these species in a relatively short time period.

Our survey indicates a diverse and viable freshwater mussel fauna in the Delta National Forest. At least 18 species are currently living in the Forest out of a historical fauna of 29 species. Species found in wetland habitats all showed some evidence of recent recruitment and are adapted to the extremes in the hydrological regime of these Forest habitats. In contrast, many species restricted to large river habitats are not reproducing or recruitment is occurring at an extremely low level, and formerly common species are now rare or extirpated from the Forest. Low recruitment and species extirpations portend further declines in the large river mussel fauna. The causes for low recruitment and species extirpations have not been identified.

The continued existence of the diverse and distinctive large stream mussel fauna in the Forest is contingent on: 1) maintaining the habitat integrity of the Little Sunflower and the Big Sunflower rivers; 2) determining factors that are limiting recruitment and'eliminating species; and 3) identifying management alternatives that may mitigate these factors. The current conditions for freshwater mussels in the Little Sunflower and Big Sunflower rivers of the Forest are inexorably influenced by upstream watershed conditions. From that perspective, the continued existence of the diverse mussel fauna of the Delta National Forest is also contingent on the cooperation and coordination of state and federal management and regulatory activities in the Big and Little Sunflower rivers.

Acknowledgments

We would like to thank the following people for their help in completing this study. Dagmar Thurmond assisted with field work and was an excellent guide to aquatic habitats in the Delta NF. Gordon McWhirter assisted with field work, summarizing and editing field data, and production of the map. Gayle Henderson assisted with production of the map. Larry Moore provided information about aquatic habitats on the Delta NF. Rick Dillard and Glenn Chen coordinated funding. This study was supported by the USDA Forest Service, National Forests in Mississippi, National Aquatic Monitoring Center, and the Southern Research Station.

Literature cited

Ahlstedt, S.A. and J.J. Jenkinson. 1991. Distribution and abundance of *Potamilus capax* and other freshwater mussels in the St. Francis River system, Arkansas and Missouri, U.S.A. Walkerana 5:225-261.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States. FWS/OBS-79/31. Office of Biological Services, Fish and Wildlife Service, U.S. Department of the Interior, Washington, DC.

Cummings, K.S. and C. A. Mayer. 1992. Field guide to the freshwater mussels of the midwest. Manual 5, Illinois Natural History Survey, Champaign, IL.

Haag, W.R. and M.L. Warren, Jr. 1995. Current distributional information on freshwater mussels (family Unionidae) in Mississippi National Forests. General Technical Report SO-119. New Orleans, LA: U.S. Department of Agriculture, Forest Service, Southern Forest Experiment Station.

Hartfield, P.D. and R.G. Rummel. 1985. Freshwater mussels (Unionidae) of the Big Black River, Mississippi. The Nautilus 99:116-119.

Jenkinson, J.J. and S.A. Ahlstedt. 1994. A search for additional populations of *Potamilus capax* in the St. Francis and Cache River system, Arkansas and Missouri, U.S.A. Walkerana 7:71-157.

Manning, D. 1989. Freshwater mussels (Unionidae) of the Hatchie River, a tributary of the Mississippi River, in west Tennessee. Sterkiana 72:11-18.

McMahon, R.F. 1991. Mollusca: Bivalvia. *In* Ecology and classification of North American freshwater invertebrates. Edited by J.H. Thorp and A.P. Covich. Academic Press, San Diego, Calif. pp.315-399

Miller, A.C., B.S. Payne, and P.D. Hartfield. 1992. Characterization of a freshwater mussel (Unionidae) community in the Big Sunflower River, Sharkey County, Mississippi;. Journal of the Mississippi Academy of Sciences 37:8-11.

Parmalee, P.W. and A.E. Bogan. 1998. The freshwater mussels of Tennessee. University of Tennessee Press, Knoxville, TN.

Payne, B.S. and A.C. Miller. 1989. Growth and survival of recent recruits to a population of *Fusconaia ebena* (Bivalvia:Unionidae) in the lower Ohio River. American Midland Naturalist 121:99-104.

Watters, G.T. 1994. An annotated bibliography of the reproduction and propagation of the Unionidae. Ohio Biological Survey Miscellaneous Contribution No. 1, Ohio Biological Survey, Ohio State University, Columbus, OH.

Williams, J.D., M.L. Warren, Jr., K.S. Cummings, J.L Harris, and R.J. Neves. 1993. Conservation status of freshwater mussels of the United States and Canada. Fisheries 18:6-22.

Figure 1. Map of Delta National Forest, Mississippi showing location of sites sampled for freshwater mussels, 1997-1998.

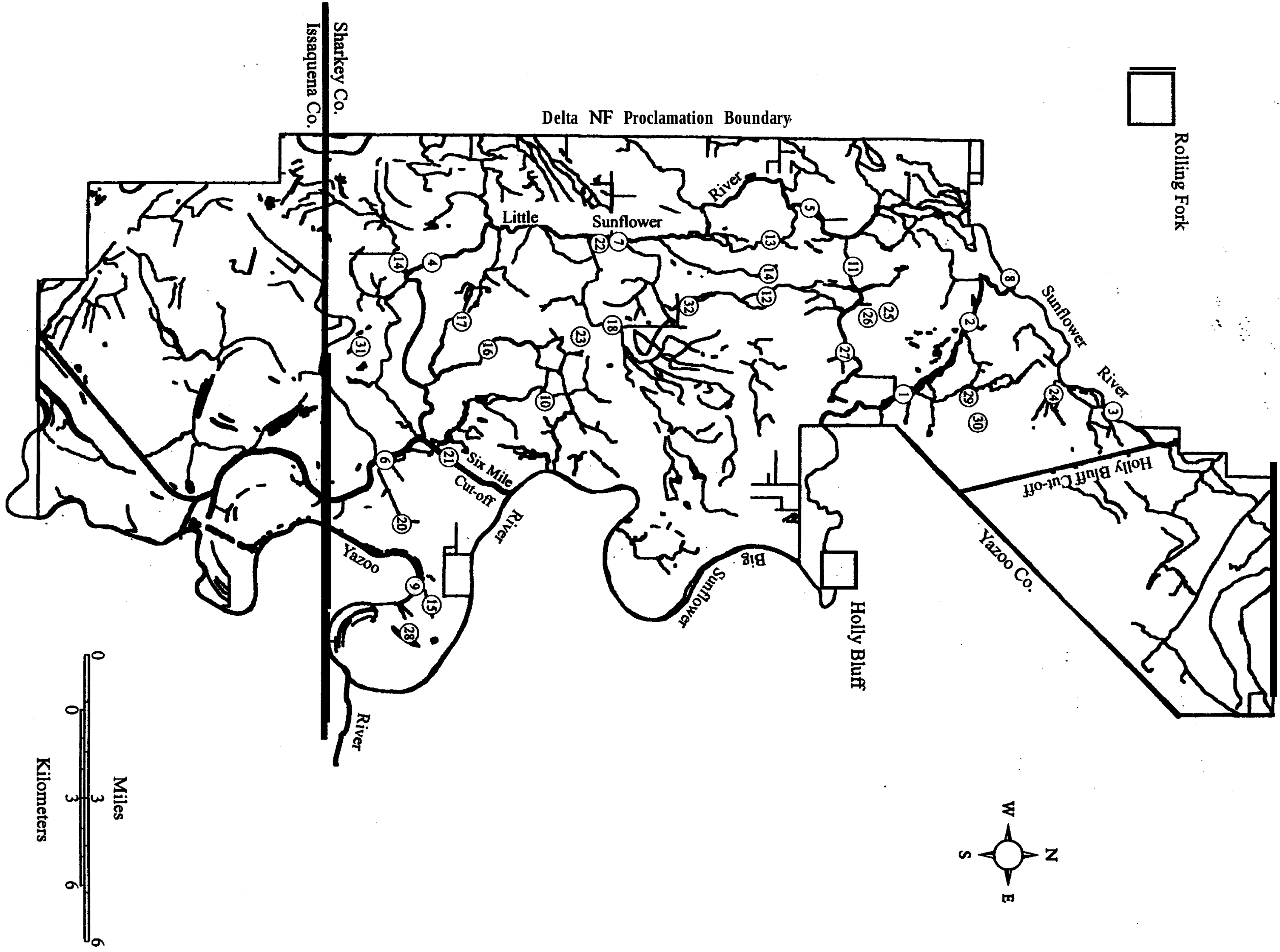

Delta NF Proclamation Boundary
Sharkey Co.
Issaquena Co.
Rolling Fork
Little Sunflower River
Sunflower River
Six Mile Cut-off
Yazoo River
Big Sunflower
Holly Bluff
Holly Bluff Cut-off
Yazoo Co.
Miles
Kilometers
0
3
6
W
N
S
E

Table 1. Mussel fauna of Delta National Forest, Mississippi. Habitat types are: 1) large rivers; 2) bayous and small permanent streams; 3) intermittent streams and ditches; 4) palustrine wetlands. "X" denotes that the species has been found in a particular habitat-type, "-" denotes that the species has not been found in that habitat type.

Species	Common name	Habitat type 1	2	3	4
Actinonaias ligamentina	Mucket	X[1]	-		
Amblema plicata	Three-ridge	X	-		
Andodonta suborbiculata	Flat floater	X	-	X	X
*Arcidens confragosus**	Rock pocketbook	X	-		
Ellipsaria lineolata+#	Butterfly	X[2]	-		
Elliptio crassidens	Elephant-ear	X[1]	-		
Fusconaia ebena	Ebonyshell	X[2]	-		
F. flava	Wabash pigtoe	X	-		
Glebula rotundata	Round pearlshell	X[1]	-		
Lampsilis siliquoidea	Fatmucket	X[2]	-		
L. teres	Yellow sandshell	X	-		
Leptodea fragilis	Fragile papershell	X	-		
Megalonaias nervosa	Washboard	X	-		
Obliquaria reflexa	Three-horned wartyback	X	-		
Plectomerus dombeyanus	Bankclimber	X	-		
Pleurobema pyramidatum'"	Pyramid pigtoe	X[2]	-		
Potamilus ohiensis	Pink papershell	X[1]	-		
P. purpuratus	Bleufer	X	-		
Pyganodon grandis	Giant floater	X	-	X	X
Quadrula nodulata'	Wartyback	X	-	-	
Q. pustulosa	Pimpleback	X	-	-	
Q. quadrula	Mapleleaf	X	-	-	
Toxolasma texasensis	Texas lilliput	X	X	X	X
Tritogonia verrucosa	Pistolgrip	X[2]	-	-	
Truncilla donaciformis	Fawnsfoot	X[1]	-	-	
T. truncata+	Deertoe	X[1]	-	-	
Unionmerus declivus'	Tapered pondhorn	X	-	-	
U. tetralasmus	Pondhorn	-	-	X	X
Utterbackia imbecillis	Paper pondshell	-	X	X	X

[1] Species was reported in an earlier study from this habitat type, but was not encountered in the present study

[2] Species was found only as relict shells

* National Forests in Mississippi Sensitive Species

+ Mississippi Natural Heritage Program Locally Rare Species

Considered of Special Concern by the American Fisheries Society

° Considered Threatened by the American Fisheries Society

Table 2. Classification of aquatic habitats for mussels in the Delta National Forest, Mississippi (Based on Cowardin et al. 1979).

1. Large Rivers. System: Riverine, subsystem: lower perennial, class: unconsolidated, subclass: mud, also some sand in places. Water regime: permanent, flow all year.
2. Bayous and small permanent streams. System: Riverine, subsystem: lower perennial, class: unconsolidated, subclass: mud. Water regime: permanent, but may not flow in summer.
3. Intermittent small streams and ditches. System: riverine, subsystem: intermittent, class: streambed, subclass: mud, vegetated. Water regime: intermittently to semipermanently flooded.
4. Palustrine wetlands. system: Palustrine, class: unconsolidated bottom, subclass mud, organic; class: aquatic bed, subclass: floating vascular; class: unconsolidated shore, subclass: mud, vegetated, broad-leaved scrub-shrub wetland, broad-leaved and needle-leaved deciduous forested wetland. Water regime: permanently to intermittently flooded.

Table 3. Proportion of live or freshly dead mussels that were estimated to be less than 10 years old in four habitat types in Delta National Forest, Mississippi. Proportions for large rivers and bayous are based on live individuals. Proportions for intermittent stream and wetland habitats are based on both live individuals and freshly dead shells.

Species	Habitat type			
	Large Rivers	Bayous	Inter-mittent	Wetlands
Amblema plicata	0.05	-	-	-
Anodonta suborbiculata	1.00	-	1.00	-
Arcidens confragosus	0	-	-	-
Fusconaia flava	0	-	-	-
Lampsilis teres	0	-	-	-
Leptodea fragilis	0.25*	-	-	-
Megalonaias nervosa	0	-	-	-
Obliquaria reflexa	0	-	-	-
Plectomerus dombeyanus	0	-	-	-
Potamilus purpuratus	0*	-	-	-
Pyganodon grandis	0.06	-	1.00	1.00
Quadrula nodulata	0	-	-	-
Q. pustulosa	0	-	-	-
Q. quadrula	0.27	-	-	-
Toxolasma texasensis	0	0.60	1.00	1.00
Uniomerus declivus	0	-	-	-
U. tetralasmus	-	-	1.00	1.00
Utterbackia imbecillis	-	1.00	1.00	1.00

* Although few or no young individuals of these species were found alive, freshly dead shells of individuals less than 10 years old were found.

Table 4. Minimum (Min.), maximum (Max.), mean, and standard errors (SE) for lengths of live mussels collected from large river habitats in Delta National Forest, MS, 1998. All measurements are in millimeters.

Species	N	Min.	Max.	Mean	SE
Amblema plicata	86	27	116	97	1
Arcidens confragosus	7	98	119	111	2
Fusconaia flava	8	42	78	65	4
Lampsilis teres	4	95	106	102	2
Leptodea fragilis	3	40	122	93	22
Megalonaias nervosa	8	120	158	140	4
Obliquaria reflexa	5	43	56	51	2
Plectomerus dombeyanus	59	95	118	109	1
Potamilus purpuratus	3	100	132	113	8
Pyganodon grandis	9	95	145	132	5
Quadrula nodulata	8	40	59	50	2
Q. pustulosa	16	52	66	57	1
Q. quadrula	11	35	75	59	

Appendix 1. List of sites by habitat type and mussel species present in Delta National Forest, Mississippi. 'Table entries in parentheses represent the number of individuals that were estimated to be less than 10 years old. For entries with no values in parentheses, all individuals were estimated to be greater than 10 years old.

Large Rivers

Site 1, Big Sunflower River at the boat launch on MS highway 16. 7.5 mi. SE of Rolling Fork, 4.0 mi. WNW of Holly Bluff. T12N, R6W, Sec. 36. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Quantitative site: six 5-minute searches

Species	Number of live mussels							
	Search							
	1	2	3	4	5	6	Totals	No./hour
Amblema plicata	3	0	0	1	5	2	11(1)	22
*Arcidens confragosus**	0	2	0	0	0	0	2	4
Lampsilis teres'	0	0	0	0	0	0	0	0
Leptodea fragilis[2]	0	0	0	0	0	0	0	0
Megalonaias nervosa	0	0	0	0	0	1	1	2
Obliquaria reflexa	1	0	0	0	0	0	1	2
Plectomerus dombeyanus	7	1	0	4	4	0	16	32
Potamilus purpuratus[2]	0	0	0	0	0	0	0	0
Pyganodon grandis	0	1	0	1	1	0	3	6
Quadrula nodulata'	2	1	0	0	0	0	3	6
Q. pustulosa	3	2	0	1	1	0	7	14
Q. quadrula	1	2	0	0	2	0	5(2)	10
Toxolasma texasensis	0	0	0	0	1	0	1	2
Totals								**100**

[1] Freshly dead shells only
[2] Weathered shells only
* National Forests in Mississippi Sensitive Species
\+ Mississippi Natural Heritage Program Locally Rare Species

Site 2, Big Sunflower River 0.5 mi. NW of the junction of MS Highway 16 and FS road 715, 5.75 mi. SE of Rolling Fork, and 5.75 mi. NW of Holly Bluff. T12N, R6W, Sec. 27. Sharkey Co., MS. 2 Nov 1998. W.R. Haag and J.G. McWhirter.

Quantitative site: nine lo-minute searches

Species	Number of live mussels										
	Search										
	1	2	3	4	5	6	7	8	9	Totals	No./hour
Amblema plicata	0	2	3	7	3	1	7	2	0	25(1)	17
*Arcidens confragosus**	0	0	2	0	1	0	0	0	0	3	2
Fusconaia ebena[3]	0	0	0	0	0	0	0	0	0	0	0
F. flava	1	0	0	1	0	0	0	0	0	2	1
Lampsilis teres	0	0	1	1	0	0	0	0	0	2	1
Leptodea fragilis[1]	0	0	0	0	0	0	0	0	0	0	0
Megalonaias nervosa	0	0	0	1	0	1	3	0	0	5	3
Obliquaria reflexa .	0	0	1	1	0	0	1	0	0	3	2
Plectomerus dombeyanus	2	10	0	5	1	1	3	1	1	24	16
*Pleurobema pyramidatum**[3]	0	0	0	0	0	0	0	0	0	0	0
Potamilus purpuratus'	0	0	2	0	0	0	0	0	0	2	1
Pyganodon grandis	0	0	1	1	0	0	0	1	0	3	2
Quadrula nodulata'	0	0	0	1	2	0	1	0	0	4	3
Q. pustulosa	0	0	3	2	0	0	0	0	0	5	3
Q. quadrula	0	1	0	2	0	0	0	0	0	3(1)	2
Toxolasma texasensis'	0	0	0	0	0	0	0	0	0	0	0
Totals	3	13	13	22	7	3	15	4	1	81	53

[1] Freshly dead shells only
[3] *Relict* shells only
• National Forests in Mississippi Sensitive Species
+ Mississippi Natural Heritage Program Locally Rare Species

Site 3. Big Sunflower River at the end of FS road 717-A, N of Green Ash Greentree Reservoir. 6.0 mi. E of Rolling Fork, 6.25 mi. NW of Holly Bluff. T12N, R6W, Sec. 12. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Quantitative site: Six 5-minute searches

Species	Number of live mussels							
	Search							
	1	2	3	4	5	6	Totals	No./hour
Amblema plicata[4]	3	5	8	1	17	12	46(1)	92
Ellipsaria lineolata[*3]	0	0	0	0	0	0	0	0
Fusconaia ebena[1]	0	0	0	0	0	0	0	0
F. flava	0	0	0	0	5	0	5	10
Lampsilis siliquoidea[3]	0	0	0	0	0	0	0	0
L. teres	0	0	0	0	0	2	2	4
Leptodea fragilis	0	0	0	1	0	0	1	2
Megalonaias nervosa	0	0	0	0	2	0	2	4
Obliquaria reflexa[*]	0	0	1	0	0	0	1	2
Plectomerus dombeyanus	0	0	0	0	9	9	18	36
Pleurobema pyramidatum[*3]	0	0	0	0	0	0	0	0
Potamilus purpuratus[1]	0	0	0	0	0	0	0	0
Pyganodon grandis	0	0	0	1	0	0	1	2
Quadrula nodulata[*3]	0	0	0	0	0	0	0	0
Q. pustulosa	0	0	0	0	3	1	4	8
Q. quadrula	0	0	0	0	1	1	2	4
Tritogonia verrucosa[3]	0	0	0	0	0	0	0	0
Uniomerus declivus[3]	0	0	0	0	0	0	0	0
Totals	3	6	8	3	37	25	82	164

[1] Freshly dead shells only
[3] Relict shells only
[4] One live individual found outside of timed searches
* National Forests in Mississippi Sensitive Species
\+ Mississippi Natural Heritage Program Locally Rare Species

Site 4. Little Sunflower River at Dummy Line road bridge, 4.5 mi NE Valley Park, 10.5 mi SW Holly Bluff. T10N, R6W, sec. 21. Sharkey Cc., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site (ages not estimated at this site)

Amblema plicata	1 Live
Quadula quadrula	3 Live
Pyganodon grandis	4 Live
Toxolasma texasensis	3 Live

Site 5. Little Sunflower River at end of FS ATV trail 703-F, at end of FS road 703-W, 3.5 mi W Delta NF Work Center, 7.5 mi SSE Rolling Fork, 7.7 mi. WSW of Holly Bluff. T11N, R6W, sec. 17. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Amblema plicata	2 live (1 < 10 yr old)
Anodonta suborbiculata	2 live (2 < 10 yr old)
Lampsilis siliquoidea	1 relict shell
Lampsilis teres	1 freshly dead shell
Leptodea fragidis	1 weathered shell
Pyganodon grandis	6 live (1 < 10 yr old)
Quadrula quadrula	1 weathered shell
Toxolasma texasensis	4 live
Uniomerus declivis	2 live

Site 6, Little Sunflower River at South Greentree reservoir pump station, about 1 mile downstream of the confluence of the Little Sunflower River and Six-Mile Cutoff. 17.3 mi. SE of Rolling Fork, and 10.2 mi. SSW of Holly Bluff. T10N, R5W, Sec. 30. Sharkey Co. MS.
3 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Non-quantitative site (ages not estimated at this site)

Amblema plicata	1 freshly dead shell
Lampsilis teres	2 weathered shells
Leptodea fragilis	2 freshly dead shells
Plectomerus dombeyanus	1 freshly dead shell
Potamilus purpuratus	1 weathered shell
Pyganodon grandis	1 freshly dead shell
Toxolasma texasensis	2 live

Site 7. Little Sunflower River at the end of FS road 707-H. 11.5 mi. SSE of Rolling Fork, 8.8 mi. SE of Holly Bluff. **T10N, R6W**, Sec. 4. Sharkey Co., MS. 3 Nov. 1998. W.R. Haag, D. Thurmond, J.G. McWhirter. . .

Quantitative site: eight S-minute searches

Species	Number of live mussels									
	Search									
	1	2	3	4	5	6	7	8	Totals	NO./hour
Pyganodon grandis	0	0	0	0	0	0	1	0	1	2
Totals	**0**	**0**	**0**	**0**	**0**	**0**	**1**	**0**	**1**	**2**

Site 8, Little Sunflower River at MS highway 16 bridge. mi SE of Rolling Fork, 7.0 mi NW of Holly Bluff. **T12N, R6W**, Sec. 21. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Quantitative site: Six S-minute searches

Species	Number of live mussels							
	Search							
	1	2	3	4	5	6	Totals	No. /hour
Amblema plicata	1	1	0	0	1	1	4	8
*Arcidens confragosus**	1	0	1	0	0	0	2	4
Fusconaia ebena[1]	0	0	0	0	0	0	0	0
F. flava	0	1	0	0	0	0	1	2
Lampsilis teres[1]	0	0	0	0	0	0	0	0
Leptodea fragilis	0	1	0	1	0	0	2(1)	4
Megalonaias nervosa[3]	0	0	0	0	0	0	0	0
Plectomerus dombeyanus	0	0	1	0	0	0	1	2
*Pleurobema pyramidatum**[3]	0	0	0	0	0	0	0	0
Potamilus purpuratus	1	0	0	0	0	0	1	2
Pyganodon grandis	0	1	0	0	0	1	2	4
Quadrula nodulata[1]	0	1	0	0	0	0	1	2
Q. pustulosa[1]	0	0	0	0	0	0	0	0
Q. quadrula	0	1	0	0	0	0	1	2
Toxolasma tesasensis[1]	0	0	0	0	0	0	0	0
Totals	**3**	**6**	**2**	**1**	**1**	**2**	**15**	**30**

[1] Freshly dead shells only
[3] Relict shells only
[4] One live individual found outside of timed searches
* National Forests in Mississippi Sensitive Species
\+ Mississippi Natural Heritage Program Locally Rare **Species**

Site 9. Yazoo River at the end of FS Road 710-A. E of Rolling Fork, 9.25 mi. S of Holly Bluff. T10N, R5W, Sec. 27. Sharkey Co., MS. 3 Nov. 1998. W.R. Haag, D. Thurmond, J.G. McWhirter. . .

Non-quantitative site

Lampsilis teres	21 freshly dead shells (17 < 10 yr old)
Leptodea fragilis	1 weathered shell
Corbicula fluminea	present

Permanent bayous and small streams.

Site 10. Cypress Bayou at Dummy Line road bridge, 6.5 mi SW Holly Bluff, 13.75 mi. SSE of Rolling Fork. T10N, R6W, sec. 12. Sharkey Co., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Toxolasma texasensis	5 Live (3 < 10 yr old)
Utterbackia imbecillis	3 Live (all < 10 yr old)

Internuttent streams and ditches

Site 11, Howlett Bayou at FS road 715 bridge. 7.0 mi SE Rolling Fork, 6.0 mi. W of Holly Bluff. T11N, R6W, junction of sections 3,4,9,10. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found

Site 12, unnamed slough at FS road 703-W bridge, 0.7 mi W junction of FS roads 703 and 707, first culvert W of junction, 9.0 mi SSE Rolling Fork, 6.0 mi. WSW of Holly Bluff. T11N, R6W, sec. 15/22. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found
Sphaeriidae present

Site 13. unnamed slough at FS road 703-W bridge, 1.65 mi W junction of FS roads 703 and 707, 8.0 mi SSE Rolling Fork, 7.0 mi. WSW of Holly Bluff. T11N, R6W, sec. 16. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Uniomerus tetralasmus	1 Live (< 10 yr old)
Sphaeriidae	

Site 14. unnamed slough at FS road 703-W bridge, 1.1 mi W junction of FS roads 703 and 707, 0.1 mi W of junction of sections 15, 16, 21, 22, 8.0 mi SSE Rolling Fork, 6.5 mi. WSW of Holly Bluff. T11N, R6W, sec. 16/21. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found

Site 15. unnamed tributary to Yazoo River at FS road 710 crossing, 1.0 mi WNW Clark Lake, 8.5 mi. S of Holly Bluff. T10N, R5W, sec. 22. Sharkey Co., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found
Corbicula fluminea present

Si e 6. Six-mile Bayou at *Dummy* Line road bridge, 6.5 mi NE Valley Park, 9.0 mi SW Holly Bluff. T10N, R6W, sec. 14. Sharkey co., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found

Site 17, unnamed tributary to Six-mile Bayou and roadside drainage ditch at Dummy Line road bridge, 6.0 mi NE Valley Park, 10.0 Mi SW Holly Bluff. T10N, R6W, sec. 22. Sharkey Co., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Toxolasma texasensis	1 freshly dead shell (< 10 yr old)
Utterbackia imbecillis	2 freshly dead shells (all < 10 yr old)
Sphaeriidae	present

Site 18. unnamed bayou at the SE corner of Long Bayou Greentree Reservoir on FS road 707-H. 12.0 mi. SSE of Rolling Fork, and 7.0 mi. SW of Holly Bluff. T11N, R6W, Sec. 34. Sharkey Co., MS. 2 Nov 1998. W.R. Haag and J.G. McWhirter.

Non-quantitative site

Uniomerus tetralasmus	1 freshly dead shell (< 10 yr old)
Toxolasma texasensis	1 freshly dead shell (< 10 yr old)
Sphaeriidae	present

Site 19. unnamed slough at the crossing of FS road 720, about 0.25 mi. upstream of the confluence with the Little Sunflower River. 16.0 mi. SSE of Rolling Fork, and 11.2 mi. SE of Holly Bluff. T10N, R6W, Sec. 28. Sharkey Co., MS. 2 Nov. 1998. W.R. Haag and J.G. McWhirter.

Quantitative site: two S-minute searches

No mussels found.

Site20. roadside ditch along FS road 710-B, at the entrance to South Greentree Reservoir. 17.5 mi. SE of Rolling Fork, and 9.5 mi. SSW of Holly Bluff. T10N, R5W, Sec. 28&29. Sharkey Co., MS. 3 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Quantitative site: four S-minute searches

No live mussels found

Anodonta suborbiculata	27 freshly dead shells (all < 10 yr old)
Pyganodon grandis	10 freshly dead shells (all < 10 yr old)
Uniomerus tetralasmus	13 freshly dead shells (all < 10 yr old)

Site ... roadside ditch along FS road 710-B, between Six-Mile Cutoff and FS 710-B. 16.3 mi. SE of Rolling Fork, and 8.75 mi. SSW of Holly Bluff. T10N, R5W, Sec. 19. Sharkey Co., MS. 3 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Non-quantitative site

Pyganodon grandis	1 weathered shell (< 10 yr old)

Site 22. ditch along FS road 707-H, near the SW corner of Long Bayou Greentree Reservoir. 11.7 mi. SSE of Rolling Fork, 8.9 mi. SE of Holly Bluff. T10N, R6W, Sec. 4. Sharkey Co., MS. 3 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Non-quantitative site

No mussels found

Site 23. roadside ditch along FS road 707, about 0.75 mi. S of the SE corner of Long Bayou Greentree Reservoir. 12.5 mi. SSE of Rolling Fork, 7.5 mi. SE of Holly Bluff. T10N, R6W, Sec. 2&3. Sharkey Co., MS. 3 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Non-quantitative site

No mussels found

Site 24. unnamed slough/drainage ditch along FS road 717-A, S of Green Ash Greentree Reservoir. 6.4 mi. ESE of Rolling Fork, 5.2 mi. NW of Holly Bluff. T12N, R6W, Sec. 13. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Quantitative site: four S-minute searches

No live mussels found

Pyganodon grandis	1 weathered shell (< 10 yr old)

Palustrine wetlands

Site 25. Blue Lake at boat ramp and campground, 7.5 mi SE Rolling Fork, 5.5 mi. W of Holly Bluff. T11N, R6W, sec. 10. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Toxolasma texasensis	1 freshly dead shell (< 10 yr old)
Sphaeriidae	present

Site 26. Lost Lake at end of FS road 715-C. 8.0 mi SE Rolling Fork, 5.5 mi. W of Holly Bluff. T11N, R6W, sec. 10. Sharkey Co., MS. 26 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Anodonta suborbiculata	1 weathered shell
Pyganodon grandis	1 weathered shell
Toxolasma texasensis	1 live (< 10 yr old)
Utterbackia *imbecillis*	1 live (< 10 yr old)

Site 27, Fish Lake at end of FS road 703-A: 8.0 mi SE Rolling Fork, 4.4 mi. W of Holly Bluff. T11N, R6W, sec. 11. Sharkey Co., MS. 26'August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

Toxolasma texasensis	1 freshly dead shell (< 10 yr old)
Sphaeriidae	present

Site 28. Clark Lake at end of FS ATV trail 710-A, 1.5 mi NW confluence of Big Sunflower and Yazoo Rivers, 10.0 mi S Holly Bluff, 11.0 mi. ENE of Valley Park. T10N, R5W, sec. 26. Sharkey co., MS. 27 August 1997. W.R. Haag and D. Thurmond.

Non-quantitative site

No mussels found

Site 29, unnamed slough just downstream of series of small lakes, 3.25 mi NNW Jct SR 16 and FS 703, 2.25 mi ESE point where Big and Little Sunflower Rivers split, approximately 6.75 mi SE Rolling Fork. T12N, R6W, Sec. 25. Sharkey Co., MS. 1998. D. Thurmond

Non-quantitative site

Uniomerus *tetralasmus*	1 weathered shell

Site 30. unnamed lake along the E side of FS road 717. 7.3 mi. SE of Rolling Fork, 4.0 mi. NW of Holly Bluff. T12N, R6W, Sec. 25. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Non-quantitative site

Uniomerus *tetralasmus*	2 freshly dead shells (all < 10 yr old)

Site 31. unnamed lake S of FS road 720. 17.2 mi. SSE of Rolling Fork, 11.5 mi. SE of Holly Bluff. T10N, R6W, Sec. 35, NW1/4. Sharkey Co., MS. 3 Nov 1998. W.R. Haag, J.G. McWhirter.

Quantitative site:" two 5-minute searches

No mussels found

Site 32. unnamed cypress slough on North Boundary of Long Bayou Greentree Reservoir on FS Road 707-C. 9.5 mi. SE of Rolling Fork, and 6.5 mi. SW of Holly Bluff. T11N, R6W, Sec. 27. Sharkey Co., MS. 2 Nov 1998. W.R. Haag and J.G. McWhirter.

Quantitative site: four 5-minute searches

No mussels found

Appendix 2. Lengths (mm) of individual mussels encountered in quantitative sampling in the Delta National Forest, MS.

Site. 1, Big Sunflower River at the boat launch on MS highway 16. 7.5 mi. SE of Rolling Fork, 4.0 mi. WNW of Holly Bluff. T12N, R6W, Sec. 36. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Search 1.

Species	Lengths (mm)
Amblema plicata	110, 92, 94
Obliquaria reflexa	49
Plectomerus dombeyanus	109, 106, 103, 95, 112, 114, 106
Quadrula nodulata	46, 53
Q. pustulosa	56, 53, 66
Q. quadrula	56

Search 2.

Species	Lengths (mm)
Arcidens confragosus	113, 118
Plectomerus dombeyanus	113
Pyganodon grandis	145
Quadrula nodulata	59
Q. pustulosa	59, 56
Q. quadrula	48*, 38*

*estimated less than 10 years old based on growth rings

Search 3. No mussels.

Search 4.

Species	Lengths (mm)
Amblema plicata	103
Plectomerus dombeyanus	110, 96, 118, 99
Pyganodon grandis	138
Q. pustulosa	54

Search 5.

Species	Lengths (mm)
Amblema plicata	100, 102, 109, 113, 72*
Plectomerus dombeyanus	102, 117, 118, 112
Pyganodon grandis	132
Q. pustulosa	58
Q. quadrula	71, 75
Toxolasma texasensis	51

*estimated less than 10 years old based on growth rings

Search 6.

Species	Lengths (mm)
Amblema plicata	109, 107
Megalonaias nervosa	120

Appendix 2, cont. Lengths (mm) of individual mussels encountered in quantitative sampling in the Delta National Forest, MS.

Site 2. Big Sunflower River 0.5 mi. NW of the junction of MS Highway 16 and FS road 715, 5.75 mi. SE of Rolling Fork, and 5.75 mi. NW of Holly Bluff. T12N, R6W, Sec. 27. Sharkey Co., MS.
2 Nov 1998. W.R. Haag and J.G. McWhirter.

Search 1.

Species	Lengths (mm)
Fusconaia flava	59
Plectomerus dombeyanus	108, 117

Search 2.

Species	Lengths (mm)
Amblema plicata	82, 86
Plectomerus dombeyanus	98, 104, 109, 103, 106, 107, 117, 114, 113, 117
Q. quadrula	65

Search 3.

Species	Lengths (mm)
Amblema plicata	94, 103, 97
Arcidens confragosus	109, 119
Lampsilis teres	106
Obliquaria reflexa	56
Potamilus purpuratus	100, 132
Pyganodon grandis	130
Q. pustulosa	55, 52, 56

Search 4.

Species	Lengths (mm)
Amblema plicata	85, 88, 98, 107, 90, 97, 95
Fusconaia flava	59
Lampsilis teres	95
Megalonaias nervosa	150
Obliquaria reflexa	43
Plectomerus dombeyanus	111, 106, 103, 113, 108
Quadrula nodulata	41
Q. pustulosa	52, 58
Q. quadrula	35*, 63

*estimated less than 10 years old based on growth rings

Search 5.

Species	Lengths (mm)
Amblema plicata	94, 91, 103
Arcidens confragosus	98
Plectomerus dombeyanus	110
Quadrula nodulata	52, 52

Appendix 2, cont. 'Lengths (mm) of individual mussels encountered in quantitative sampling in the Delta National Forest, MS.

Site 2, cont.

Search 6.

Species	Lengths (mm)
Amblema plicata	85
Megalonaias nervosa	158
Plectomerus dombeyanus	118

Search 7.

Species	Lengths (mm)
Amblema plicata	90, 99, 98, 98, 114, 102, 109
Megalonaias nervosa	153, 125, 126
Obliquaria reflexa	54
Plectomerus dombeyanus	107, 110, 117
Quadrula nodulata	58

Search 8.

Species	Lengths (mm)
Amblema plicata .	90, 27*
Plectomerus dombeyanus	111
Pyganodon grandis	133

*estimated less than 10 years old based on growth rings

Search 9.

Species	Lengths (mm)
Plectomerus dombeyanus	111

7

Appendix 2, cont. Lengths (mm) of individual mussels encountered in quantitative sampling in the Delta National Forest, MS.

Site 3. Big Sunflower River at the end of FS road 717-A, N of Green Ash Greentree Reservoir. 6.0 mi. E of Rolling Fork, 6.25 mi. NW of Holly Bluff. T12N, R6W, Sec. 12. Sharkey Co., MS.
4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Search 1.

Species	Lengths (mm)
Amblema plicata	98, 98, 92

Search 2.

Species	Lengths (mm)
Ainblema plicata	90, 93, 98, 95, 101
Obliquaria reflexa	51

Search 3.

Species	Lengths (mm)
Amblema plicata	96, 96, 89, 79, 102, 107, 95, 95

Search 4.

Species	Lengths (mm)
Amblema plicata	99
Leptodea fragilis	122
Pyganodon grandis	95

Search 5.

Species	Lengths (mm)
Amblema plicata	93, 97, 107, 101, 112, 108, 104, 113, 116, 100, 99, 100, 97, 108, 96, 97, 102
Fusconaia flava	69, 78, 73, 68, 42"
Megalonaias nervosa	140, 131
Plectomerus dombeyanus	105, 112, 111, 111, 107, 109, 98, 113, 106
Q. pustulosa	62, 58, 56
Q. quadrula	70

*estimated less than 10 years old based on growth rings

Search 6.

Species	Lengths (mm)
Amblema plicata	90, 107, 104, 95, 98, 97, 100, 99, 100, 98, 93, 39"
Lampsilis teres	103, 102
Plectomerus dombeyanus	108, 100, 107, 117, 113, 109, 97, 113, 107
Q. pustulosa	55
Q. quadrula	73

*estimated less than 10 years old based on growth rings

Appendix 2, cont. Lengths (mm) of individual mussels encountered in quantitative sampling in the Delta National Forest, MS.

Site 7. Little Sunflower River at the end of FS road 707-H. 11.5 mi. SSE of Rolling Fork, 8.8 mi. SE of Holly Bluff. T10N, R6W, Sec. 4. Sharkey Co., MS. 3 Nov. 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Searches 1-6,8. No mussels.

Search 7.

Species	Lengths (mm)
Pyganodon grandis	160

Site 8. Little Sunflower River at MS highway 16 bridge. 4.25 mi. SE of Rolling Fork, 7.0 mi NW of Holly Bluff. T12N, R6W, Sec. 21. Sharkey Co., MS. 4 Nov 1998. W.R. Haag, D. Thurmond, J.G. McWhirter.

Search 1.

Species	Lengths (mm)
Amblema plicata	98
Arcidens confragosus	110
Potamilus purpuratus	106

Search 2.

Species	Lengths (mm)
Amblema plicata	99
Fusconaia flava	68
Leptodea fragilis	117
Pyganodon grandis	137
Quadrula nodulata	40
Q. quadrula	58

Search 3.

Species	Lengths (mm)
Arcidens confragosus	111
Plectomerus dombeyanus	100

Search 4.

Species	Lengths (mm)
Leptodea fragilis	40*

*estimated less than 10 years old based on growth rings

Search 5.

Species	Lengths (mm)
Amblema plicata	95

Appendix a, cont. Lengths' (mm) of individual mussels encountered in quantitative, sampling in the Delta National Forest, MS.

Site 8, cont.

Search 6.

Species	Lengths (mm)
Amblema plicata	93
Pyganodon grandis	139

Literature Cited

Aquatic Nuisance Species (ANS) Task Force. 2007. General Prevention Procedures for Stopping Aquatic Hitchhikers: A Must Read for all Recreational Users. <http://www.protectyourwaters.net/prevention/prevention_generic.php> Accessed 18 Sept 2007.

Argonne National Laboratory. 2001. Peconic River Remedial Alternatives: Wetlands Restoration/ Constructed Wetlands. Brookhaven National Laboratory Technology Fact Sheet. <http://www.bnl.gov/erd/Peconic/Factsheet/Wetlands.pdf> Accessed 7 Nov 2007.

Brooks, M. B., J.T. Sipiorski, M.R. Thomas, K.S. Cummings and C.A. Taylor. 2004. Fishes, mussels, crayfishes, and aquatic habitats of the Hoosier-Shawnee ecological assessment area Gen. Tech. Rep. NC-244. U.S. Department of Agriculture, Forest Service, North Central Research Station. 267 p.. <http://www.treesearch.fs.fed.us/pubs/12417> Accessed 09 Oct 2008.

Chilton II, E.D. 2007. Aquatic Vegetation Management in Texas: A Guidance Document. Texas Parks and Wildlife Department, Inland Fisheries Division. <http://www.tpwd.state.tx.us/landwater/water/environconcerns/nuisance_plants/> Accessed 10 Sept 2007.

Cross, D., and P. Vohs, editors. 1988. Waterfowl Management Handbook. U.S. Fish and Wildlife Service. <http://www.nwrc.usgs.gov/wdb/pub/wmh/contents.html> Accessed 21 Aug 2007.

Environmental Laboratory. 1987. Corps of Engineers Wetlands Delineation Manual. Wetlands Research Program Technical Report Y-87-1. <http://el.erdc.usace.army.mil/elpubs/pdf/wlman87.pdf> Accessed 20 May 2008.

Flood, J. 2007. Focus on Fusconaia. The Dragonflyer Volume 13, Texas Master Naturalist. <http://ntmn.org/new/index.php?option=com_frontpage&Itemid=1> Accessed 09 Oct 2008.

Ground Water Advocates Coalition. 2007. Basic Ground Water Hydrology. <http://www.issaquah.org/COMORG/gwac/Hydro.htm> Accessed 8 Nov 2007.

Haag, W.R. and M.L. Warren, Jr. 1998. Freshwater mussels of the Delta National Forest. Mississippi Final Report, National Forests in Mississippi. <http://www.treesearch.fs.fed.us/pubs/2823> Accessed 09 Oct 2008.

May, M.E. 2007. Mussels Make Good Habitat. The Texas Nature Tracker Newsletter, Texas Parks and Wildlife. <http://www.tpwd.state.tx.us/publications/newsletters/texas_nature_tracker/> Accessed 09 Oct 2008.

May, M.E. 2007. 2006 Texas Mussels Watch. The Texas Nature Tracker Newsletter, Texas Parks and Wildlife. <http://www.tpwd.state.tx.us/publications/newsletters/texas_nature_tracker/> Accessed 09 Oct 2008.

Moore, S.E. 1999. Forests, Hydrology, and Water Quality: Impacts of Silvicultural Practices. University of

Florida/Institute of Food and Agricultural Sciences (IFAS) Extension CIR 1185. <http://edis.ifas.ufl.edu/FR009 > Accessed 10 Sept 2007.

Natural Resources Conservation Service (NRCS). 2001. Wetland Mammals. NRCS Wildlife Habitat Management Institute and Wildlife Habitat Council, Fish and Wildlife Habitat Management Leaflet Number 21. <http://www.whmi.nrcs.usda.gov/technical/leaflet.htm> Accessed 29 Aug 2007.

Natural Resources Conservation Service (NRCS). 2005. Wading Birds. NRCS Wildlife Habitat Management Institute and Wildlife Habitat Council, Fish and Wildlife Habitat Management Leaflet Number 16. <http://www.whmi.nrcs.usda.gov/technical/leaflet.htm> Accessed 29 Aug 2007.

Natural Resources Conservation Service (NRCS). 2007. Riparian Systems. NRCS Wildlife Habitat Management Institute and Wildlife Habitat Council, Fish and Wildlife Habitat Management Leaflet Number 45. <http://www.whmi.nrcs.usda.gov/technical/leaflet.htm> Accessed 29 Aug 2007.

Nelson, S.A. 2003. Streams and Drainage Systems. Tulane University. <http://www.tulane.edu/~sanelson/geol111/streams.htm > Accessed 18 Oct 2007.

North Carolina State University. 1995. WATERSHEDSS: Information on Wetlands. North Carolina State University NCSU Water Quality Group and Pennsylvania State University Biological Engineering Department. <http://www.water.ncsu.edu/watershedss/info/wetlands/index.html> Accessed 20 Nov 2007.

North Carolina Division of Forest Resources. 2003. Riparian Buffers in Forest Management: Establishment, Effectiveness and Recommendation. North Carolina Department of Environment and Natural Resources, Division of Forest Resources, Forestry NPS Unit and Forest Management and Development Section. <http://www.dfr.state.nc.us/water_quality/wq_htriparianpaper.htm> Accessed 1 Aug 2007.

Strader, R.W. and P.H Stinsion. 2005. Moist-soil Management Guidelines for the U.S. Fish and Wildlife Service Southeast Region. <http://www.fws.gov/auburnwildlife/MoistSoilReport.pdf> Accessed 2 Aug 2007.

Texas Aquatic Plant Management Society. 2003. Beneficial Native Aquatic Plants of Texas. <http://www.tapms.org/aquatic%20plants%20of%20texas2.pdf> Accessed 8 Nov 2007.

Texas Aquatic Plant Management Society. 2003. Harmful Non-Native Aquatic Weeds of Texas. <http://www.tapms.org/aquatic%20plants%20of%20texas2.pdf> Accessed 8 Nov 2007.

Texas Forest Service. 2007. Forestry Best Management Practices for Water Quality. <http://txforestservice.tamu.edu/main/article.aspx?id=74> Accessed 18 Sept 2007.

Texas Forest Service. 2007. Forestry, Wetlands and Water Quality. <http://txforestservice.tamu.edu/main/article.aspx?id=74> Accessed 18 Sept 2007.

Texas Forest Service. 2007. Streamside Management Zones.

<http://txforestservice.tamu.edu/main/article.aspx?id=74> Accessed 18 Sept 2007.

Vanderwel, D. and S. Abday. 2001. An Introduction to Water Erosion Control. Alberta Agriculture and Food. <http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex2074> Accessed 18 Oct 2007.