Chapter 3

Wetland Values and the Importance of Wetlands to Man

Illustration credit: U.S. Fish and Wildlife Service, Alderson Magee

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Wetland Values and the Importance of Wetlands to Man

CHAPTER SUMMARY

Some people value wetlands for their ***intrinsic qualities.*** They may wish to protect wetlands simply out of a desire to preserve natural areas for future generations or because they are often the last areas to be developed. Others value the varied and abundant flora and fauna that may be found in wetlands, and the opportunities for hunting, fishing, and boating and other recreational activities. While these recreational benefits can be quantified to some extent, the other intrinsic values of wetlands are, for the most part, intangible. For this reason, the justification for protecting wetlands has often focused on the importance of the ecologicalservices or resource values that wetlands provide, which are more scientifically and economically demonstrable than intrinsic qualities. These ecological services include floodpeak reduction, ground water recharge, water quality improvement, food and habitat, food-chain support, and shoreline stabilization.

The intrinsic values and ecological services provided by wetlands can vary significantly from one wetland to another and from one region of the country to another. Some wetlands provide benefits that primarily are local or regional in nature; other benefits may be national or even international in scope. ***Because of the wide variation among individual wetlands, the significance of their ecological services and intrinsic values must be determined on an individual or regional basis.***

The dollar value of the ecological services that wetlands provide sometimes can be quantified. The U.S. Army Corps of Engineers, for instance, estimated that the loss of the entire 8,422 acres of wetlands within the Charles River Basin, Mass., would produce average annual flood damage of over$17 million. However, because the many intrinsic qualities of wetlands cannot be quantified, it is difficult to place generally accepted dollar values on wetlands.

ATTITUDES TOWARD WETLANDS

The use of wetlands has become a public policy issue because of conflicts between those who wish to develop them and those who wish to preserve them. Developers, for instance, regard wetlands as prime locations for development because of their typical proximity to open water. Farmers drain or clear wetlands to plant crops in their rich organic soil. While there also are private gains involved, the creation of new jobs or the production of food that results from the development of wetlands directly benefits society.

On the other hand, undeveloped wetlands have important intrinsic qualities that are esthetically pleasing and provide numerous ecological services, such as flood control, that benefit society. The conflict between developers and conservationists over wetlands often is viewed as an issue that "involves questions of public good as opposed to private gain' (21). However, the issue is not simply a matter of public versus private interests but of conflicting public interests.

The values associated with wetlands were not always widely recognized. For example, in the 19th century when a national priority was placed on settling the country, wetlands were considered a menace, the cause of malaria, and a hindrance to land development. Through the Swamp Land Acts of 1849, 1850, and 1860, Congress granted to States all swamps and overflow lands for reclamation to reduce the destruction caused by flooding and eliminate mosquito-breeding swamps. A total of 65 million acres of wetlands were granted to 15 States for reclamation (81).

With increasing concerns about preserving different ecosystems, the public's perception of and attitude toward wetlands has changed gradually over the last half century. An inventory of wetlands conducted by the U.S. Fish and Wildlife Service (FWS) in the mid-1950's perhaps did the most to change attitudes about wetlands over the past three decades (81). The introduction to the inventory stated: "So long as this belief prevails (that wetlands are wastelands), wetlands will continue to be drained, filled, diked, impounded, or otherwise altered, and thus will lose their identity as wetlands and their value as wildlife habitat. The inventory created the lasting perception that wetlands rapidly were disappearing-a perception that galvanized certain groups to preserve wetlands.

Since the ***intrinsic values-recreation*** and a sense of the need to preserve the unique flora and fauna of scenic, natural areas—that motivated wetland protection at the outset were not appreciated universally, proponents began to investigate more tangible, ecological services provided by wetlands. Initially, these other services were suggested in the FWS wetland inventory report:

> . . . the storage of ground water, the retention of surface water for farm uses, the stabilization of runoff, the reduction or prevention of erosion, the production of timber, the creation of firebreaks, the provision of an outdoor laboratory for students and scientists, and the production of cash crops, such as minnows (for bait), marsh hay, wild rice, blackberries, cranberries and peat moss (81).

In his 1977 environmental message, President Carter conveyed an attitude about wetlands that stood in sharp contrast to the attitude of the early 1900's:

> The Nation's coastal and inland wetlands are vital natural resources of critical importance to the people of this country. Wetlands are areas of great natural productivity, hydrological utility, and environmental diversity, providing natural flood control, improved water quality, recharge of aquifers, flow stabilization of streams and rivers, and habitat for fish and wildlife resources. Wetlands contribute to the production of agricultural products and timber and provide recreational, scientific, and esthetic resources of national interest.[1]

Knowledge of the importance of the ecological services provided by wetlands has increased steadily, especially over the past two decades. As wetlands research continues, knowledge about the values of individual and different types of wetlands will, in all likelihood, improve. For example, some wetland services, such as ground water recharge, have been found to be less significant than once thought. On the other hand, the ecological services of inland freshwater wetlands with the exception of wildlife habitat are not widely recognized by the general public. It is quite possible that some wetlands may provide ecological services that are as yet unknown or poorly documented. In addition, the overall significance of continuing, incremental losses of wetlands is well known only in a few cases. Waterfowl managers, for example, use the number of prairie potholes in the Midwest to predict fall duck populations; without these wetlands, North American duck populations would decrease by about half. On the other hand, the importance of wetland-derived detritus for estuarine fish and shellfish populations relative to other sources of food, such as algae and detritus from upland areas, is not well known. Future research may resolve many of these uncertainties.

[1] Statement by the President accompanying Executive Order 11990; 42 FR 26961 (1977).

INTRINSIC VALUES OF WETLANDS

In recent years, the case for preserving wetlands has been based more and more on the ecological services provided by wetlands[2] and on the availability of scientific evidence documenting these services. For example, in a recent paper, William Reilly stated:

> Every bit of evidence that does exist suggests that our interior wetlands are vital elements of national estate. But there are many challenging voices—questioning voices. These will become stronger in future years. They will demand to be shown the scientific evidence behind wetland conservation decisions (81).

This situation perhaps has obscured one fundamental motivation of some for preserving wetlands—the desire to preserve, intact and unspoiled, unique natural ecosystems. For many personal reasons, whether ethical, religious, esthetic, or recreational in nature, people value wetlands for their intrinsic qualities. Because these intrinsic values are intangible and thus difficult to express in quantitative and economic terms, they are often overlooked in a society where decisions are based on numerical cost-benefit analyses. Although there have been attempts to quantify these values, this discussion simply identifies those characteristics of wetlands that people value.

Wetlands as Natural Areas

Some people are attracted to an environment that essentially is untouched by man's presence,[3] which is an attraction akin to the lure of wilderness. One scientist, for instance, writes in the preface to a wetland study:

> The river swamps are, for many of us in the Southeast, the last wilderness. True, they are narrow, even the mighty Altamaha swamp scarcely exceeds 5 miles in width; yet in length they are large indeed, often stretching more than half the length of the state. Narrow as they are, many provide a true wilderness experience. Where else in this mechanized, modern world can we so quickly lose ourselves in wildness without evidence of the massive civilization that surrounds us? (97).

Part of the reason that marshes, swamps, bogs, and other wetlands are associated with natural, undisturbed environments is that they are often the last areas to be developed. The difficulty and expense of draining wetlands for development have encouraged people to develop other areas first.

Various studies have found that wetlands rank high in esthetic quality in comparison to other landscape types (82). One particular value of wetlands is the attraction of the land-water interface. Many people find the edge between land and sea, lake, or stream scenically appealing, and such areas often include wetlands as well as beaches and banks. Small wetlands are capable of being surveyed in a glance or traversed in a few minutes and offer a contrast to the adjoining land or water. Seen from a passing car or hiking trail, wetland edges buffer commercially or agriculturally developed lands, providing scenic variety. Small wetlands also contrast with other types of natural areas, such as upland forests or open water.

Large wetlands have a similar "variety" value along their edges but may have other esthetic attributes as well. Of all natural areas, the most mysterious and haunting in appearance are the large cypress swamps draped with Spanish moss. Less exotic are wooded swamps, which are full of different shapes, textures, plants, and animals. Access and visibility are important factors; for example, pleasing wooded swamps should not be choked with underbrush that greatly impedes passage by foot or canoe. A large, open, grassy marsh can present quite an esthetic contrast and a feeling of open space.

In addition to the esthetic qualities of wetlands themselves, wetland flora and fauna lend a special esthetic attraction to wetlands. Waterbirds are a good example: herons, egrets, storks, terns, pelicans, and cranes all are found commonly or pri-

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[2]Massachusetts, for instance, the first State to enact a wetland law, recognizes seven wetland values: flood control, prevention of pollution, prevention of storm damage, protection of the public and private drinking water supply, protection of ground water supply, protection of fisheries 1978-79; Act of Mar. 25, 1965; ch. 220, 1965; Massachusetts Acts 116; Act of May 22, 1963; ch. 426, 1963; Massachusetts Acts 240.

[3]In the following discussion, examples illustrating these characteristics of wetlands are presented. Unless otherwise noted, these examples are taken from J, Perry and J. G. Perry, *Guide to Natural Areas of the Eastern United Stares (New* York: Random House Publishers).

Photo credit: U.S. Fish and Wildlife Service, C. Kenneth Dodd, Jr,

Draped with Spanish moss, the haunting Santee-Cooper River Swamp in South Carolina provides an uncommon wilderness experience

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marily in wetland habitats. Other species are more unusual. Five genera of insectivorous plants can be found in a North Carolina pocosin, including round-leaved sundew, butterworts, Venus fly traps, bladderworts, and two species of pitcher plants. In addition, wetlands, particularly those whose origins were glacial, often provide habitat for "relict' plants and animals, that is, those that were once, but are no longer, endemic to an area. Cranesville Swamp in West Virginia has a number of relict species, including Tamarack, Swainson's, and hermit thrushes; Nashville and mourning warblers; and purple finch, that typically are found much farther north.

Overall, wetlands are characterized by many different kinds of flora and fauna relative to other ecosystems. For example, approximately 5,000 species of plants, 190 species of amphibians, and approximately one-third of all bird species are thought to occur in wetlands across the United States (18, 22,45). A single, freshwater tidal marsh may have from 20 to 50 plant species. Over 100 woody plant species may inhabit bottom lands. (19). This diversity of plant types creates, in turn, a diversity of habitats for animals. Living in the Okefenokee Swamp in Georgia are over 200 species of birds, 41 species of mammals, 54 species of amphibians and reptiles, and all duck species found along the Atlantic flyway. In the Bombay Hook National Wildlife Refuge in Delaware, an area of 12,000 acres of brackish tidal marsh, over 300 bird species have been recorded. Tinicum Marsh, a national environmental education center outside of Philadelphia, has more than 300 plant species and over 250 bird species.

In addition to the many different kinds of flora and fauna, abundant populations of wildlife, especially waterfowl and waterbirds, make wetlands even more attractive as natural areas, The Merrit Island National Wildlife Refuge in Florida, an area with over 34,000 acres of freshwater and saltwater marshes and swamps, has a wintering waterfowl population of nearly 70,000 ducks and 120,000 coots. Hundreds of thousands of robins arrive at the Okefenokee Swamp each year. Mass nestings of wood storks—as many as 6,000 pairs—occur at the Corkscrew Swamp Sanctuary in Florida.

Wetlands for Recreation and Education

Wetlands provide direct enjoyment to inhabitants, visitors, and passers-by in many ways. Recreational activities in or around wetlands, including hiking, boating, fishing, hunting, and the observation of wildlife are pursued by millions of people and amount to billions of dollars in expenditures each year. For example, 19 of the 25 most visited National Wildlife Refuges (out of 309 refuge

Photo credit: U.S. Fish **and Wildlife** *service, Lawrence S. Smith*

A Youth Conservation Corps group is instructed in marsh ecology at a National Wildlife Refuge. Environmental education is a major theme in many parks and public areas established around wetland areas

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units) have substantial wetland components (90). These 19 refuges represent approximately 50 percent of the total visitation to all U.S. National Wildlife Refuge units. Several of these refuges are predominantly wetland environments: J. N. Ding Darling Refuge in Florida, considered one of the best birdwatching sites in the United States, had 671,000 visitors in 1981 (8th overall); Loxahatchee Refuge in Florida had 333,329 visitors (19th); Okefenokee Refuge, one of the oldest, largest, and wildest swamps in the United States, had 257,927 visitors (21st); the Great Swamp Refuge, more than half of which is wilderness within the New York City Metropolitan Area, had 250,756 visitors (23d). Recreational use of the Everglades National Park in Florida averaged 675,000 from 1979 to 1981 (60).

Wetlands also may provide learning opportunities for the general public or sites for educational and scientific purposes. Research on such subjects as botany, ornithology, and anthropology frequently is carried out in wetland areas. Environmental education is a major theme in many parks and public areas established around wetlands. For example, the environmental center at Tinicum Marsh on the outskirts of Philadelphia coordinates numerous public education programs. In 1981 it had 32,730 visitors (60).

From a purely scientific standpoint, the concept of the ecosystem has played an important role in environmental research and in the formal teaching of ecology. Because of the importance of water to the biosphere, most ecosystem study areas are selected to include water bodies such as streams, lakes, and wetlands. Wharton, (97) for instance, describes the scientific opportunities available through the Alcovy River Swamp:

> The Alcovy River is ideally suited for educational uses: it is essentially unpolluted, it is located within easy driving distance of a large metropolitan area but is unaffected by it; and it contains a unique swamp ecosystem found nowhere else in the Georgia Piedmont.
>
> The river swamp has a diversity of habitats and a corresponding diversity of plants and animals. It offers aquatic communities of all types of water, both flowing and still. The periodically high biomass of certain plant and animal groups offers an approach to community ecology and productivity. The drying up of bodies of water imitates both Paleozoic and monsoonal climatic effects on life and can illustrate the evolutionary transition from water to land. The swamp shows rapid changes in physiochemical conditions.
>
> The yearly import of decomposed mineral matter can involve both geological and cultural (agricultural) concepts. The processes of photosynthesis and decomposition can be readily demonstrated. Both the aquatic and the terrestrial segments of this ecosystem are subject to an annual series of plant and animal communities (succession), rapidly enforced by the regimen of the hydrocycle. Invertebrates such as clams, snails, leeches, adult aquatic insects, and larvae of aerial forms are extremely abundant—some of the species are "indicators' of the degree of pollution present.
>
> Much of the swamp fauna (invertebrates, fish, salamanders, mammals, birds) are present in midwinter, when other habitats are barren, Many of the vertebrate groups are yearly renewable by inundation (fish), are fossorial (salmanders), or are extremely plentiful (frogs). Thus, the animal community is not easily damaged or overcollected. There are few subsurface runways to crush, or delicate layers of litter and humus to compress, as in a terrestrial forest. Most of the mammals are renewable by migration from the river corridor if accidentally killed; the tracks, droppings, or other evidence of most are readily observable on the bare swamp floor (raccoon, otter, mink, wildcat, beaver, rodents, shrews). The ecosystem is adjusted to what might be called "annual catastrophism."Even the forest floor is changed and renewed to some extent annually.

Other Intrinsic Values

In addition to those values previously discussed, there may be other less obvious but just as important reasons for preserving natural areas, including wetlands (28). Many plants and animals may have great potential resource value for food, chemicals, drugs, and so forth, but are as yet undiscovered or undeveloped. Some scientists believe that all species are an integral part of the natural environment and contribute in some, perhaps unknown, way to its natural order and stability. The conservative belief is that excessive manmade impact on this natural system could cause irreversible changes in the natural order of the environment that may carry an unknown risk of serious damage to humans and their civilization. Natural systems can provide baseline conditions that help determine the extent to which the environment has been affected by man's activities and pollution. They may provide models for restoring or replacing habitats that have been significantly affected or even models of long-term survival for redesigning greatly modified, man-dominated systems that typically have not worked reliably over long periods of time.

Many people believe that unaltered natural areas, including wetlands, are valuable in and of themselves, regardless of any tangible benefits or ecological services society may receive from them. The reassurance that wetlands and other types of natural areas exist for both present and future generations can be a strong motivation to preserve wetlands in an undisturbed state. The Nature Conservancy, an organization whose goal is "the preservation of natural diversity by protecting lands containing the best examples of all components of the natural world, has devoted 50 percent of its past preservation efforts to the protection of wetlands. In the future, it plans to expand this to approximately 75 percent (53). Similarly, the North Carolina Natural Heritage Program gives top priority to protection of Carolina bays (bog swamps), bottom land swamps, and peat bogs (80). Under the South Carolina Heritage Trust Program, 60 percent of the areas preserved are shallow impoundments, marshes, flood plains, and wetland depressions (80). In the Wisconsin Scientific Areas Program, which inventories unique natural areas, approximately 50 percent of all inventoried areas are wetlands (36).

ECOLOGICAL SERVICES OR RESOURCE VALUES OF WETLANDS

The interaction between the hydrologic regime and the wetland topography, saturated soil, and emergent vegetation largely controls the general characteristics and the significance of the processes that occur in wetlands. The processes are in turn responsible for the ecological services the wetland may perform (fig. 4).

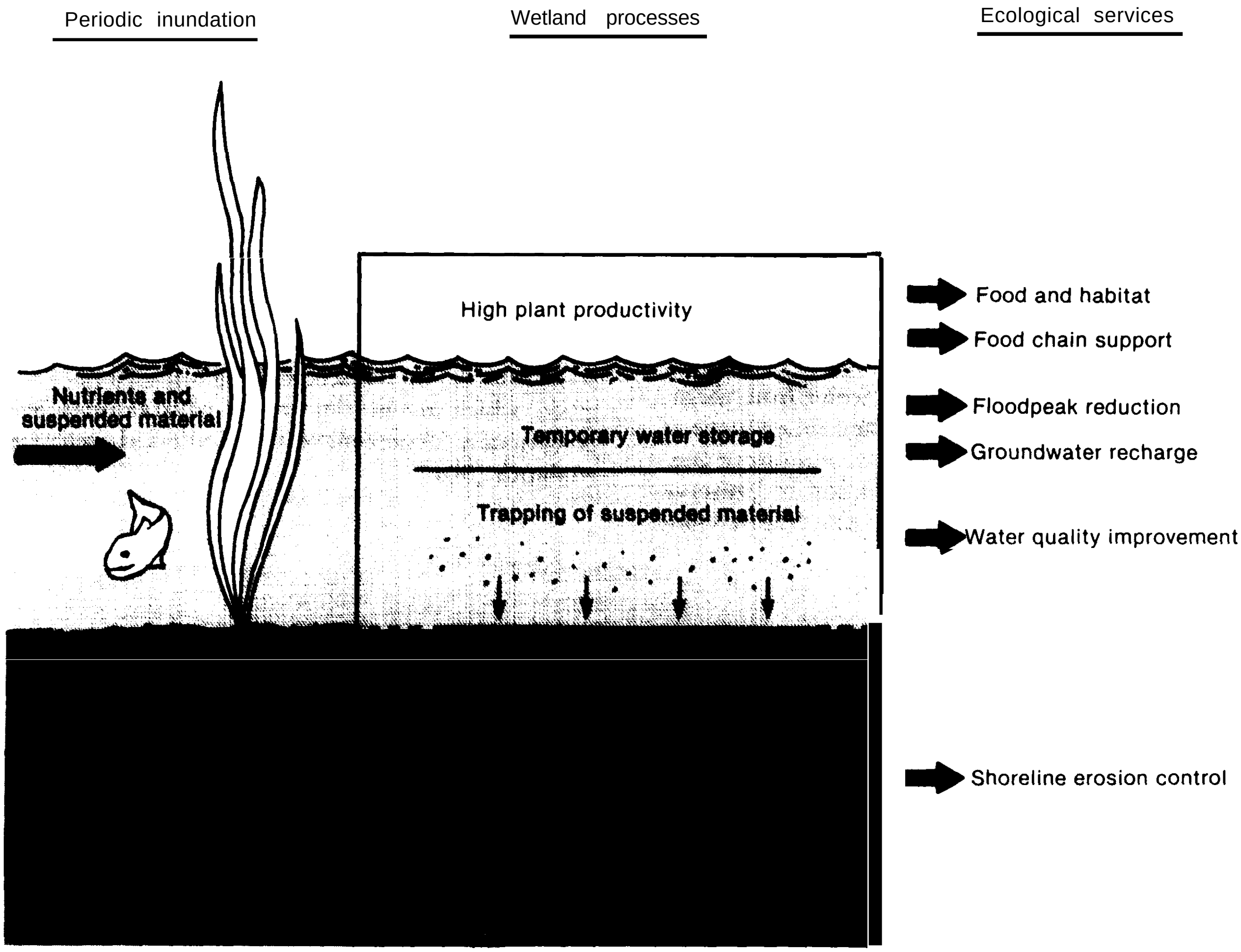
Isolated wetlands may ***temporarily store runoff,*** and flood plain wetlands may provide additional conveyance capacity for flood waters, thereby reducing floodpeaks in downstream areas. During periods of inundation, water flows over and through the wetland, depositing nutrient-rich organic and inorganic material suspended in the water. This ***suspended material is "trapped"*** along with any toxic materials that may be bound onto this suspended material. The nutrients and their substances thus become involved in many complex ***biochemical cycles*** within the wetland system. These nutrients help fuel the relatively high ***plant productivity*** characteristic of most wetlands during the growing season. The leaves of plants provide food and habitat for many forms of wildlife and endangered species during the growing season. At the end of the growing season, when the vegetation dies back, some of the leaf material remains in the wetland to support future plant growth in the coming season. Other leaf material is flushed into adjacent water bodies where it provides a nutrient-rich source of food for many aquatic organisms in the food chain. The ***plant roots anchor*** the wetland soils and prevent their erosion in some flood plain and coastal environments. The ecological services of wetlands are described in more detail below.[4]

Floodpeak Reduction

The ability of wetlands to store and convey floodwater is primarily a function of their topography. Many isolated freshwater and river wetlands are

[4]Recent reviews of the scientific literature have been completed by: 1) P. R. Adamus and L. T. Stockwell, "A Method for Wetland Functional Assessment, U.S. Department of Transportation, Federal Highway Administration, Office of Research, Environmental Division, Washington, D. C., 1983, p. 176; and 2) J. H. Sather and R. P. Smith, ' 'An Overview of Major Wetland Functions, " U.S. Fish and Wildlife Service, Washington, D. C., 1983.

Figure 4.—Relationship Between Wetland Processes and Values



SOURCE: Office of Technology Assessment.

topographic depressions that retain runoff flowing into them, at least until they are full. Also, during flooding, the river overflows its banks and spreads laterally across the flood plain, increasing its cross-sectional area and conveyance capacity. By temporarily storing storm water and providing capacity to convey floodwaters, wetlands can reduce floodpeaks and the frequency of flooding in downstream areas. Vegetation in flood plain wetlands further reduces the flow velocity of the river, thereby reducing potential floodpeaks in downstream areas and riverbank erosion. If the soil in a wetland is unsaturated, the soil itself will provide some storage capacity during periods of flooding. While the value of some wetlands for flood storage and conveyance is well known, analytical techniques for predicting the magnitude of this service still are being developed, The value of inland wetlands to reduce flooding in downstream areas generally depends on the area of the wetland, its location downstream, the magnitude of flooding, and the degree of encroachment on the wetland (16,31 ,67,88).

Inflow-Outflow Measurements

Only two studies were found that actually determined the storage capacity of a wetland during flood conditions. One study measured water levels of a cypress-tupelo swamp adjacent to the Cache River in southern Illinois before and after flooding to calculate the amount of flood water storage. The 90-acre swamp, which is separated from the river by a natural levee, stored 80,131 cubic meters (m^3) of water. If this amount of storage were extrapolated to the entire area of swampland in the watershed, total wetland storage would equal 8.4 percent of the total flood runoff as measured at a downstream gage (52).

Bernet found that flow was about 5,000 cubic feet per second (ft^3/s) into the Thief Run Wildlife Management Area and the Agassiz National Wildlife Refuge, while outflow was approximately 1,400 ft^3/s. He calculated that the flood storage capacity and losses due to the other factors of these two wetland areas reduced the floodpeak at Grand Forks, by about 0.5 foot and at Crookston by about 1.5 feet (8).

Comparison of Floodpeaks From Wetland and Nonwetland Watersheds

By studying floodpeaks in 15 watersheds, Novitzki found that floodpeaks may be as much as 80 percent lower in watersheds with large lake and wetland areas than in similar basins with little or none. Watersheds with 40-percent lake and wetland area have floodpeaks only 20 percent as large as those with little or no wetland area. While floodpeaks were found to be lower in watersheds with a large percentage of wetlands, total streamflow in the spring was higher in basins with large lake and wetland areas (63).

Analysis of Flood Hydrographs

Flood hydrographs—graphs of the time distribution of runoff from a drainage basin—of perched peat bogs and peatlands indicate that these wetlands temporarily store and slowly release storm waters (5,9). Long-term hydrography from the Passaic River, N.J., and the Ipswich River, Mass., showed that the wetlands adjacent to the rivers play an important role in delaying runoff (31). Synthetic hydrographs (not calculated on historical data) for eight wetland areas also showed reductions in peak flows (94).

Actual flood-storage capacity often will depend on environmental conditions prior to flooding or on the relationship of a particular wetland to the regional hydrology. For example, when evapotranspiration rates are low and water is ponded in wetlands, runoff during periods of heavy precipitation may be greater from wetlands than from upland areas (because the soil is saturated and the surface storage capacity quickly is exceeded) (51 ,77, 92). On the other hand, high rates of evapotranspiration and low water tables favor storage of floodwaters. In some cases, wetlands provide no storage capacity for floodwaters. For example, a hydrographic analysis of two Massachusetts swamps indicated that both wetlands contributed significantly to floodpeaks because of their rapid discharge of ground water (64).

The Role of Vegetation in Flooding

There have been a few attempts to isolate the effect of vegetation on flooding. The frictional drag on runoff flowing through wetland vegetation is represented by a roughness coefficient called "Manning's 'n. " The higher the value of "n," the greater the drag and the slower the flow velocity of floodwaters. Values of n' vary widely and are highly dependent on the type and amount of vegetative cover. In general, the value of 'n" for a river wetlands in or adjacent to it can be approximately twice the value of channels without associated wetlands (15).

Impact of Wetland Filling and Development on Flooding

The Corps has used model-generated hydrographs to estimate the volume of storm water that could be stored in the basin wetlands of the Charles River, Mass., and to determine the reduction in storage, assuming future encroachment (89). Following a storm in 1955, approximately 50,000 acre-ft of storm water flushed past the Charles River Village gaging station with a peak flow of 3,220 ft^3/s. This amount is equivalent to 5 inches of runoff from the 184-square-mile drainage basin. On the adjacent Blackstone River, which has few, if any, wetlands, the storm discharge peaked at 16,900 ft^3/s and the bulk of the storm water was discharged in a much shorter time period than on the Charles. Based on this analysis, it was predicted that a 40-percent reduction in wetland area along the river would result in a 2- to 4-foot increase in floodpeaks and would increase flood damages by at least $3 million annually.

Hydrographs of the Neponset River Basin, Mass., were used to determine the impact of encroaching on the basin's flood plains and wetlands (l). The study predicted that the basinwide flood level for the 100-year flood would increase 0.5 feet if 10 percent of the flood plain/wetland storage capacity were lost, and 3 feet if 50 percent of the flood plain/wetland storage capacity were lost. Filling a wetland will reduce its storage capacity; if the fill material rises above the level of the flood plain, flood conveyance value also may be reduced.

The effects of drainage on floodflows are slightly more complicated. One point of view is that drainage increases floodpeaks by synchronizing and speeding the runoff of water and by eliminating the potential storage of runoff in wetlands. A contrasting viewpoint is that drainage channels may reduce floodpeaks by draining away heavy rains that otherwise would have left the soil saturated through the winter, reducing the storage available during critical spring rain and snowmelt. Research to date has not yet resolved this controversy.[5]

Shoreline Erosion Control

Shoreline erosion is a natural process caused by river currents during flooding, tidal currents in the coastal areas, and wind-generated waves along the shores of large lakes, broad estuaries, and ocean-facing barrier islands. Boat wakes also can cause considerable shoreline damage.

Four characteristics of vegetated wetlands are responsible for reducing erosion: 1) the low-gradient shore that absorbs and dissipates wave energy (70); 2) the dampening and absorption of wave energy by the plants themselves (44,95); 3) the root structure and peat development in wetlands that bind and stabilize the shore (71, 76); and 4) the deposition of suspended sediment that is encouraged by dense growth of wetland plants. [s]

Vegetated freshwater or saltwater wetlands located adjacent to open but usually sheltered bodies of water significantly reduce shoreline erosion caused by large waves generated by occasional storms and boat traffic.[7] Wetlands adjacent to rivers also may reduce riverbank erosion from strong currents during major flooding. Although it generally is agreed that wetland vegetation does not naturally establish itself in high-energy environments where the potential for erosion is greatest, wetland plants, once established, do help to control erosion, stabilize the soil, encourage deposition of sediments, and dampen wave energy. Isolated wetlands not associated with larger bodies of water will not have significant value for erosion control.

Potential Economic Importance

Shoreline erosion is a major problem in many coastal areas. In Virginia, for instance, it has been estimated that 1,476 hectares of tidal shoreline eroded away between 1850 and 1950. This amount represents approximately 20 percent of the 5 million metric tons of silt and clay that wash into Virginia's estuaries annually (39). The impacts of shoreline erosion include: loss of public and private property and the subsequent loss of taxable income for localities, filling of navigable waters with eroded sediment, increased turbidity of waters, siltation of fish and wildlife habitat, and loss of recreationally valuable sand beaches. Millions of dollars are spent each year to reduce shoreline erosion and maintain the navigability of channels.

Ability of Wetlands to Control Shoreline Erosion

Wetlands not only resist erosion themselves, but also protect the more easily eroded upland areas shoreward of the wetland. Three studies have com-

[5]See the following references for reviews of information pertaining to the impacts of wetlands draining on flooding: 1) L. J. Brunn, J. L. Richardson, J. W. Enz, and J. K. Larsen, "Streamflow Changes in the Southern Red River Valley of North Dakota, *North Dakota* Farm Research Bimonthly Bulletin, vol. 38, No. 5, 1981, pp. 11-14; 2) John M. Malcolm, "The Relationship of Wetland Drainage to Flooding and Water Quality Problems and Its Impact on the J. Clark Salyer National Wildlife Refuge, " FWS, Upham, N. Dak., 1979; and 3) J. E. Miller and D. L. Frink, "Changes in Flood Response of the Red River of the North Basin, North Dakota-Minnesota, " U.S. Geological Survey, Open File Report 82-774, 1982.

[6]Recent reviews of the scientific literature have been completed by P. R. Adamus and L. T. Stockwell, "A Method for Wetland Functional Assessment, ' U.S. Department of Transportation, Federal Highway Administration, Office of Research, Environmental Division, Washington, D. C., 1983, p. 176.

'Most of the existing literature on this function has been reviewed in the following: 1) H. H. Allen, "Role of Wetland Plants in Erosion Control of Riparian Shorelines, " *Wetlands Functions* and Values: *The State of Our Understanding,* P. E. Greeson, J. R. Clark, and J. E. Clark (eds.) (Minneapolis, Minn.: American Water Resources Association, 1979), pp. 403-414; 2) Carter, et al. (15); 3) R. G. Dean, "Effects of Vegetation on Shoreline Erosional Processes, *Wetland Functions and Values: The State of Our Understanding,* P. E. Greeson, J. R. Clark, and J. E. Clark (eds.) (Minneapolis, Minn.: American Water Resources Association, 1979), pp. 415-426; and 4) Institute for Water Resources (88).

pared the rate of erosion of uplands buffered by wetlands to that of unbuffered uplands.

In a study of two similar sites on the Hackensack River in New Jersey, the marsh vegetation at one site was cut; at the other site, the marsh was left in its natural condition (26). Both sites were subjected to waves generated by heavy boat traffic. While the uncut site exhibited only a negligible retreat of the bank over the year of monitoring, the bank at the second site retreated nearly 2 meters, with most of the change occurring immediately after the marsh was cut.

In a second study, the rate of erosion of upland areas at three sites on the Chesapeake Bay over a 20-year period was measured with aerial photographs. Wetlands eroded as fast as adjacent uplands; however, erosion of uplands buffered by the wetlands was negligible (70).

In a third study the retreat/advance of the shorelines of an artificially planted marsh ***(Juncus roemerianus, Phragmites australis, Typha latifolia, and Spartina alterniflora)*** and of an adjacent unplanted area were measured over a period of 8 years (7). Initial erosion of the planted area was followed by a period when the shoreline actively expanded before it appeared to reach equilibrium. In general, the volume of sediment eroded from the unplanted shore averaged 2.3 m^3 per lineal meter-year (m^3/lineal m-yr.), nearly four times the average rate observed in the planted marsh. In addition, the unplanted shore retreated at a rate that was more than twice that observed for the marsh-fringed shore, in a 1981 survey of 86 marshes planted to control shoreline erosion in 12 coastal States, 33 plantings were found successful, 25 were partially successful, and 28 failed (43). Even planted marshes, however, were more frequently successful under less severe wave environments.

Limitations of Wetlands to Control Erosion

Natural wetlands are typically found in low-energy environments, sheltered from extensive wave action (4, 17). Artificial wetlands, however, often are constructed in higher wave-energy environments where natural wetlands would not typically occur. Young rooted plants are used rather than allowing the shoreline to seed itself naturally. In addition, with many artificial plantings, a "toe' or low ridge is constructed below the marsh to contain the marsh soil and to reduce the impact of incoming waves until the plants are established firmly. Most of the literature citing the erosion-control functions of wetlands is based on observations of marshes specifically planted to control erosion. For example,

Ground Water Recharge

Ground water recharge is the ability of a wetland to supplement ground water through infiltration/percolation of surface water to the saturated zone (88). Some wetlands that are connected hydrologically to a ground water system do recharge ground water supplies and assume an important local or regional role in maintaining ground water levels. However, owing to the low permeability of organic soils or the relatively impermeable layers of clay typically found in wetlands, adjacent upland areas often have a greater potential to recharge ground water (16). In addition, wetlands may often serve as discharge rather than recharge areas. [8]

Ground water recharge can occur in isolated (basin) wetlands, such as cypress swamps, prairie potholes, Midwestern and Northeastern glaciated wetlands, and flood plain wetlands. Cedarburg Bog, adjacent to Milwaukee, Wis., is an example of a high-value recharge area (58). Much of the precipitation falling on this basin percolates downward through the soil and enters openings in a dolomite aquifer. Since the bog occupies the basin of a former postglacial lake on a high point in the surrounding topography, the water percolates radially away from the bog, influencing ground water supply over an area of 165 mi^2.

While some wetlands may recharge ground water, their recharge value relative to upland areas may be low. In three watersheds in Minnesota, for instance, the greatest amount of ground water recharge was found to occur on upland sands, and the least in wetland peats (93). In addition, the quantity of water recharged may vary widely. For example, in one wetland studied only 39 gallons per day (gal/d), or 0.05 percent of the annual water budget, infiltrated the wetland (12). On the other hand, the average yearly natural recharge calculated for Lawrence Swamp in Massachusetts was

[8] Adamus and Stockwell, op. cit.

8 million gal/d (assuming 44 inches of precipitation/yr) (56).

The quality of the ground water resource also determines the value of a particular recharge area. While Lawrence Swamp recharges large quantities of water to the shallow aquifer directly underneath it, this aquifer has a high content of fine sands, iron, and manganese and cannot be used as a water supply (56).

Water Quality Improvement

By temporarily retaining pollutants, such as suspended material, excess nutrients, toxic chemicals, and disease-causing micro-organisms, it is generally believed that wetlands improve, to varying degrees, the quality of the water* that flows over and through them. Dissolved nutrients (i. e., nitrogen and phosphorous) may be taken up directly by plants during the growing season and by chemical absorption and precipitation at the wetland soil surface. Organic and inorganic suspended material also tends to settle out and is trapped in the wetland. Some pollutants associated with this trapped material may be converted by biochemical processes to less harmful forms; some may remain buried. Others may be taken up by the plants growing in the wetland and either recycled or transported from it.

The accumulation of toxic chemicals, such as heavy metals and petroleum and chlorinated hydrocarbons by wetlands may be only temporary (from days to years). On the other hand, some toxic chemicals have accumulated in many wetlands over a much longer time. With some toxic chemicals, like degradable pesticides, the fact that these pollutants are secured in the wetland long enough to degrade is important. Other toxics either remain buried or are taken up by the wetland plants.

While wetlands may, under natural circumstances, retain nutrients on a net annual basis, the value of a particular wetland for water quality improvement depends on the effect of the nutrient storage on an adjacent or connected body of water. However, even if a wetland does not retain large amounts of nutrients on a net annual basis, it may influence the timing of nutrient inputs into adjacent waters. By retaining nutrients during the growing season, for instance, and exporting them after the growing season, wetlands may have a positive influence on water quality. Freshwater wetlands have been used successfully for secondary treatment of sewage effluents.

*The term "water quality" is defined here as the chemical, physical, and biological condition of the water itself and not more broadly as the condition of the wetland and its associated habitat.

Trapping Suspended Sediment

Excessively high levels of suspended material in the water column can be detrimental. By increasing turbidity, suspended sediment can interfere with fishing, swimming, and the esthetic appeal of water. Reduction in light penetration due to increased turbidity can kill aquatic plants, and settling of the suspended sediment can smother bottom-dwelling invertebrates and impair fish spawning. If suspended sediment has a high organic content, the dissolved oxygen level in the water column may decrease to levels that may adversely affect many organisms.

One of the major water quality functions of wetlands is the removal of suspended sediment. By reducing wave energy and the velocity of water flowing through the wetland, wetland plants encourage the deposition of suspended sediment. In fact, sedimentation rates are related directly to the density of marsh vegetation (7). Measurements of sediment accretion, most of which are for marine or estuarine environments, range from 0.04 centimeters (cm) to 1,100 cm/yr.[9]

The ability of vegetated wetlands to trap suspended sediment more effectively than similar unvegetated areas was shown clearly in an 8-year study on Currituck Sound in North Carolina. During the first 5 years, planted marsh lost an average of 1.4 m^3/linear m of beach/yr, while an adjacent unplanted area lost 3.3 m^3/yr. Between 1978 and 1979 the planted areas, however, captured an average of 1.5 m^3 of sediment/yr; the unplanted area lost an additional 1.3 m^3. From 1979 to 1980, the planted area gained 0.6 m^3 and the unplanted area lost 0.4 m^3. During the last year of the study, the planted area appeared relatively stable, while the unplanted area lost 1.0 m^3 (7).

[9]Adamus and Stockwell, op. cit.

As the elevation of wetlands increases, accretion of sediment will slow. In one study, for instance, a Spartina marsh near the mean high-water level annually accreted from 2.0 to 4.25 millimeters (mm) of sediment. An area of colonizing Spartina at a lower elevation, however, accreted sediment at the rate of 9.5 to 37.0 mm/yr (10). Marshes tend to trap sediment as long as they are inundated by sediment-laden waters.

Suspended organic and nonorganic material has a strong tendency to adsorb other pollutants, including nutrients, pathogens, and toxics, such as heavy metals and chlorinated and petroleum hydrocarbons, that then are deposited with the sediment in wetlands (10). The ability of wetlands to "trap' suspended material greatly influences the fate of pollutants associated with the suspended material and the potential ability of a particular wetland to improve water quality.

Removing Toxic Substances

Heavy metals, chlorinated and petroleum hydrocarbons, radionuclides, and other potentially harmful toxic substances may persist for many years. Because they tend to adsorb onto suspended material, toxics can be trapped in wetlands, either temporarily or permanently. At the sediment surface, these metals remain immobilized. Once buried and exposed to the anaerobic conditions that typically prevail in sediment, metals again can become mobile; however, they will be trapped within the sediment by the oxygenated zone at the sediment surface (54,55). Heavy-metal-removal efficiencies of wetlands vary from 20 to 100 percent, depending on the metals involved and the physical and biological variations that exist in wetland habitats (85).

For compounds such as heptachlor, lindane, or enderin, which degrade readily in soils, the trapping of the sediment results in a very efficient and permanent process for removing these contaminants from the water. (Natural or manmade alterations of the wetland caused by lowering the water table, dredging, and the like, however, could mobilize large quantities of toxic materials.) However, in general, it is not known yet to what extent wetlands processes are capable of removing toxic materials over the long term.

Some toxics may be taken up from the sediment by wetland plants and transferred through the food chain to higher trophic levels when the plant material is consumed, either directly by herbivores or as detritus. Food chain transfer will depend on the toxic chemical and its form as well as the characteristics of the plant species and the chemical's location in the plant. For example, food chain transfer is known to occur with some metals, such as mercury or cadmium, but may not occur with others, such as lead. Synthetic materials, including chlorinated hydrocarbons, are taken up by wetland plants, but food chain effects are not known. There probably is some selectivity of uptake of toxics by particular wetland plant species, but the available data are insufficient to indicate any universal trends. In summary, though wetlands may remove toxics from water, it is possible that such removal of heavy metals eventually may lead to contamination of higher trophic levels by passage up the food chain (42).

Influencing Nitrogen and Phosphorus

Nitrogen and phosphorus are two nutrients that are necessary for the growth of algae. In excess, however, they can cause "blooms" of algal growth that can impart an unpleasant taste to drinking water and can interfere with recreational uses of water. In addition, the decomposition of algae can reduce levels of dissolved oxygen in the water column to levels that may be harmful to other organisms that need oxygen for survival.

Nutrients are retained in wetland by similar mechanisms as other pollutants (85). Both nitrogen and phosphorus readily adsorb to sediment and thereby tend to become trapped in the anaerobic sediment of wetlands. As with other toxics, however, nutrients are not necessarily permanently trapped; they may, for instance, be rapidly assimilated by rooted wetland plants. In fact, the bulk of the nitrogen and phosphorus for plant growth apparently comes from the sediment. At the end of the growing season, much of the assimilated nutrients may be leached from the plants. Boyd, for instance found that about 50 percent of the phosphorus in dead cattail tissue was leached over a

20-day period. * Another fraction of the nutrients in the plant is exported from the wetland as detritus; this fraction is probably highly variable, depending largely on the hydrology of the wetland. The dead plant tissue remaining in the wetland is rapidly colonized by bacteria and the byproducts of the decomposition process, including inorganic nutrients, are released into the water column. Nitrogen stored in the plant, for example, is converted by these decomposes to ammonia. Plant material remaining in the wetland is eventually reincorporated into the sediment. It has been hypothesized that a significant amount of the nitrogen and phosphorus available from the sediment for plant uptake is recycled from the plant growth of the previous year (42).

Water Quality Considerations

Aggregate Effect.—Present understanding of the processes described above is not sophisticated enough to predict their aggregate effect on water quality. Nitrogen fixation, for instance, the opposite process of denitrification (atmospheric nitrogen is fixed by certain bacteria and algae), can contribute significant amounts of nitrogen to the wetland nitrogen budget and therefore cancel the effects of denitrification, Some wetland studies have measured the quantity of all pollutants entering the wetland from all sources—ground water, surface water, precipitation, and so forth-and the amount leaving the wetland. The aggregate effect of all wetland processes on water quality is reflected by the difference between the amount of pollutant entering and leaving the wetland. In this manner, it can be determined whether wetlands act as a sink or a source of pollutants.

Thirty-nine input-output studies, focusing for the most part on nitrogen and phosphorus, were reviewed. These studies were screened carefully to meet a number of stringent criteria. First, since the behavior of the wetland varies greatly during different seasons, only those studies sampling monthly for at least a year were selected. Second, all chemical forms of nitrogen and phosphorus had to be measured: measurement of both organic and inorganic forms is necessary since the various forms are interconvertible. For nitrogen, total nitrogen (Kjeldahl) must have been measured in unfiltered samples and in nitrate and nitrite. For phosphorus, measurement of total phosphorus from unfiltered samples was required. Third, for studies of undisturbed wetlands, all reasonable input and output sources had to be measured, including intermittent or temporary sources of surface runoff, ground water, and precipitation. In the case of an artificial pollution source, such as a sewage outfall, the failure to measure natural sources of nutrients was overlooked on the assumption that such sources were comparatively trivial. Measurement of all significant sources and sinks of water, however, was required, even if the quantity of naturally occurring nutrients was overlooked.

Freshwater Systems.—Of 30 freshwater input-output studies reviewed, only seven (12,23,27,52, 62,98,99), met all the criteria listed above. A major drawback of these studies is that large quantities of pollutants doubtlessly flow into and out of wetlands during storms or floods. The chance of getting a good sample of nutrients flowing into a wetland during a major flood is small if outflow is sampled only monthly. One study (52), for instance, found that 99 percent of the nutrient flow into a flood plain swamp occurred during a single flood. The swamp floods approximately once every 1.13 years.

Although Crisp (23) found a net export of nitrogen and phosphorus in an eroding British peatland, all other authors found net reductions of nutrients in freshwater wetlands. Large percentage reductions generally were observed where sewage was applied (12,27,98) and small percentage reductions were observed where nutrient sources were natural (52,62). One study (99) was unusual in that sewage and natural water were applied to artificially enclosed marsh plants so that surface outflow was prevented. Water that had filtered through the marsh sediments was sampled in outside wells. Since the natural hydrology of the marshes had been altered, the large percentage reductions in both the natural and sewage-treated marshes may not be representative of activity of natural marshes.

● The fate of nitrogen is more complicated than that of other pollutants thus far discussed. Nitrogen occurs in several forms in natural water: nitrite, nitrate ammonia, and organic nitrogen (proteins and other large molecules). In addition, the air contains over 78 percent nitrogen gas, which is exchanged continuously through the surface waters. Relatively large populations of micro-organisms in wetlands, under the right circumstances, can convert nitrogen from one form to another. Thus, nitrogen can be removed ultimately from water by microbial conversion to gas through the process of denitrification, or conversely, fixed from the atmosphere and converted to inorganic nitrogen.

Estuarine Systems. —Input-output studies are more difficult to conduct in estuarine or marine environments owing to tidal fluctuations. Nine estuarine studies were screened using the same criteria used for the freshwater studies. Findings from a single acceptable study (91) are reported in table 4. These results suggest that nitrogen was exported from a Massachusetts salt marsh.

Evaluating Wetlands for Water Quality.— To evaluate the value of a wetland for improving water quality, a number of factors must be considered. First is the condition of water in the water body adjacent to the wetlands. In many lakes, estuaries, and rivers, excessive nutrient concentrations cause undesirable algal blooms. In other bodies of water, however, desirable levels of primary productivity may be limited by a lack of these nutrients. If these waters have phytoplankton-based food chains, low nutrient concentrations can result in low productivity at all levels of the food chain. In this case, nutrients would be considered beneficial and not pollutants.

The reduction of excess nutrients necessary to bring about an improvement in water quality is another consideration. For instance, an evaluation of a proposal to reconstruct wetlands along the Kissimmee River in Florida and thereby reduce nutrient loadings to Lake Okeechobee, concluded that a 50-percent reduction in phosphorous loadings would improve water quality, but a 10-percent reduction would have little effect (41). In another study, lake-edge wetlands in Wisconsin did retain nitrogen and phosphorus; however, the levels of nutrients flowing out of the wetland still were high enough to cause excessive algal growth (47).

The timing of nutrient inputs and outputs also is important. A study of phosphorus inputs and outputs from a forested riverine wetland in Illinois found that while the swamp took in 11 times more phosphorus than was discharged, nearly all of it was retained during flood periods (52).

Disease-Causing Micro-Organisms

Viruses and bacteria from sewage effluent or runoff from pastureland may contaminate drinking water, recreational water, and commercial fisheries. Because these micro-organisms are adsorbed onto particles suspended in the water column, they may be trapped along with the suspended material by wetlands. Pathogens can remain for many months in the soil matrix where they may be exposed to ultraviolet radiation or attacked by chemicals and other organisms, or they may naturally die off.

Table 4.—Summary of Input-Output Studies

Reference	Wetland type	Location	Artificial/ natural	Sampling frequency/duration	Pollutant	Input (kg/ha/yr)	output (kg/ha/yr)	Percent change
Crisp (1966)	Peat bog	Britain	N	Weekly/l year	N P	745 38-57	4,864 71	+ 552 + 25 - -87
Mitsch, et al. (1977)	Flood plain swam D	Illinois	N	Monthly and bimonthly	P	8,127	7,694	- 5
Boyt, et al. (1977)	Riverine swamp	Florida	A	Monthly/l year	P	90.0	11.5	-87
Dierberg and Brezonik (1978)	Cypress swamp	Florida	A	Monthly/2 years	N P	144 113	12 4	-91 -96
Novitzki (1978)	Fresh marsh	Wisconsin	N	Monthly (stream, wells); periodically (runoff)/3 years	N P Sediment	233 5.0 3,909	183 4.6 735	-21 -8 -81
Yonika and Lowry (1979)	Fresh marsh shrub swamp	Massachusetts	A	Monthly and bimonthly/ 1 year	N P	4,782 859	1,817 205	-62 -76
Zoltek and Bayley (1979)	Fresh marsh	Florida	A/N	Monthly/2 years	N P(art.) N(art.) P(nat.)	3,565 4,575 645 46	2,284[a] 343[a] 315[a] 16[a]	-36 -93 -51 -65
Valiela, et al. (1975)	Salt marsh	Massachusetts	N	Monthly/l year	N(nat.)	26,252	31,604	+ 20

[a]Including groundwater dilution calculated by chloride budget.

SOURCE: References cited in column 1.

There is little published information on the fate of pathogens in wetland systems (3).

Fish and Wildlife Values

Wetlands are important to many species of fish and wildlife for food, habitat, and support of the food chain. The importance of plant productivity is reflected in the relatively high carrying capacity of wetlands for certain species. Bottom land hardwood forests, for instance, have been found to support nearly twice as many whitetail deer per unit area as do upland forests, owing, it is thought, to the abundance of food. Wetland vegetation also provides nesting material and sites for numerous birds and mammals; some freshwater fish rely on clumps of vegetation for depositing their eggs. Finally, emergent wetland plants provide the cover necessary for protection from predators or for stalking prey for species of birds as well as fish and shellfish. Some species spend their entire life within a particular wetland; others are residents only during a particular lifecycle or time of year.

Because of their value for food and habitat, wetlands often become a focal point for varied wildlife populations within a particular region. The importance of wetlands is reflected by the relatively large proportion of wetland in the National Wildlife Refuge System. While only 5 percent of the Nation's area (excluding Alaska) is wetland, nearly 40 percent of the area protected under the refuge system is wetland. In turn, these areas attract hunters, birdwatchers, and many other wildlife enthusiasts. Of the top 25 wildlife refuges most visited, 19 have a significant wetland component. Refuges containing wetlands attracted nearly 14 million visitors in 1981, approximately 50 percent of the number visiting all of the national wildlife refuges (90).

Because of their numbers, it is impossible to describe adequately all the different species that use wetlands. This section focuses on recreational and commercial species of prime importance to man and on endangered species that depend to varying degrees on the food and habitat found uniquely in wetlands. Some species, termed "wetland specialists, are heavily dependent on wetlands. They include migratory waterfowl, mammals, the alligator, freshwater game fish, crayfish, and 35 endangered species. Because of the direct link between wetlands and these species, wetland losses will cause significant and adverse impacts on these indigenous populations.

This section also identifies other wildlife that heavily use wetlands as well as other nonwetland areas. Deer, for instance, browse in bottom land hardwoods, but they are not limited to these areas. Wetland resources may, however, be a critical or limiting factor in their survival. Because these animals are not linked as strongly to wetlands as are wetland specialists, wetland losses would adversely affect populations of nonspecialists to a lesser extent.

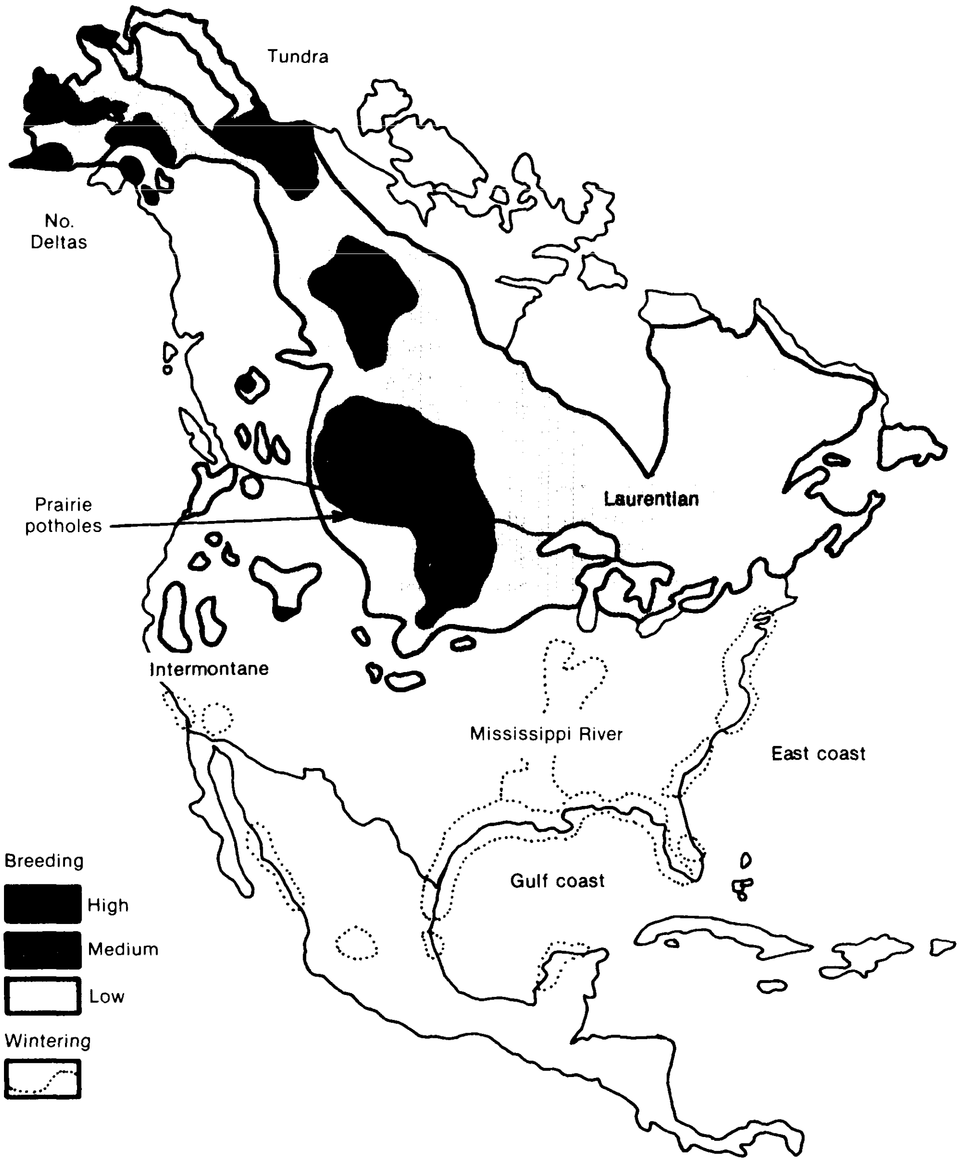
Finally, this section discusses the food chain values of wetlands. Many commercially and recreationally important species that do not directly use wetlands for feeding, nesting, or protection may feed on animals lower in the food chain that do rely directly either on wetlands or on detritus that floats from the wetland into adjacent bodies of water. The most important example of this food chain effect in terms of commercial and recreational value is the link between coastal wetlands and estuarine-dependent fish.

Food and Habitat

Migratory Waterfowl.—Wetlands are vital to many species of the duck, geese, and swan family of North America for nesting, food, and cover. These birds primarily nest in Northern freshwater wetlands in the spring and summer, but use wetlands for feeding and cover in all parts of the country during migration and overwintering. The survival, return, and successful breeding of many species, therefore, depend on a wide variety of wetland types distributed over a large geographic area of the country (fig. 5). The major migratory routes, breeding and nesting areas, and overwintering areas roughly correspond with regions of greatest wetland concentration (see fig. 1).

The most important areas for ducks and geese are the breeding areas of the North, like the prairie-pothole region, Canada, and Alaska. For overwintering, the Chesapeake Bay, the gulf coast, the central valley of California, and the Mississippi River stand out (fig. 5). Also essential, but not in-

Figure 5.—General Pattern of Duck Distribution in North America



SOURCE: M. Weller, *Freshwater Marshes: Ecology and Wildlife Management* (Minneapolis, Minn.: University of Minnesota Press, 1981).

dicated on figure 5, are coastal saltwater and freshwater tidal marshes, inland freshwater marshes, and bottom land hardwoods that are used as overwintering and stopover areas by migratory waterfowl during their biannual migrations (33). Shrub swamps are used only to a limited extent by waterfowl, and bogs and mangroves are used only sparsely (81).

While diets vary with any species and locality, depending on food preferences, availability, and the time of year, wetland vegetation generally comprises a significant component of the diet of ducks, geese, and swans. A major distinction between feeding habits can be drawn between "dabbling," or surface, ducks and "diving" ducks, or pochards.

The mallard, for instance, the most commonly hunted waterfowl in the United States, is a dabbling duck and feeds on plants and food just under the surface of the water. Bulrush, smartweed, and wildrice are the emergent wetland plants, and pondweed and wild celery are submerged plants favored by the mallard. In contrast, the canvasbacks, a diving duck, typically feeds in deeper water. They prefer submerged plants, such as pondweed, wild celery, and widgeon grass to emergent vegetation but still may feed on emergents when preferred foods are not available. Geese and swans, on the other hand, favor emergent wetland vegetation to submerged plants. Canadian and snow geese, in particular, feed on the rootstock of salt marsh cordgrass as well as on cultivated crops (81).

Waterfowl also depend on wetlands for nesting sites. Inland freshwater and saltwater marshes and coastal tundra are the most important wetland types for waterfowl breeding (96). In general, waterfowl prefer wetlands where open water and vegetation are interspersed. Temporarily flooded wetlands have been known to have high breeding-pair densities, probably because of plentiful invertebrates, which breeding waterfowl require for egg production (96). Northern freshwater tidal marshes are used to a more limited extent for breeding, and wooded swamps and bottom land hardwoods are used by wood ducks for nesting (66,78).

Of the 44 species of waterfowl that use North American wetlands, 4 species of geese and 10 to 15 species of ducks are hunted in sizable numbers (6,59). In the 1980-81 season, for instance, 1.9 million people killed 12.9 million ducks and 1.7 million geese (13). FWS estimated that 50 percent of all hunters 16 years and older, or 5.3 million hunters, hunted migratory birds (includes nonwaterfowl) in 1980, spending $638 million, or 11 percent of all hunting expenditures (32). In addition, FWS estimated that of 100 million Americans 16 years and older who participated in outdoor activities related to fish and wildlife, 83.2 million participants spent $14.8 billion on observing and photographing fish and wildlife. Sixty-six percent of these participants were involved directly with observing or photographing waterfowl.

Other Birds.—There are several other types of birds that are found commonly in wetlands (48). The American coot is physically and ecologically similar to the duck and is shot in considerable numbers. Coots have diets similar to those of ducks but build floating nests in emergent vegetation. Snipe also inhabit freshwater marshes and wet meadows and are strictly carnivores, feeding on aquatic invertebrates they pull from mud with their long bills. The four rail species and the gallinules, which have special adaptations to wetlands, are commonly found there and are hunted to some extent. Herons, egrets, cranes, storks, and ibises nest colonially in wetlands. Herons and egrets feed on fish, frog, and invertebrates in shallow marsh waters. Ibises and storks nest over water in protected sites of deep marshes but feed in wet meadows and uplands.

Mammals.—A number of mammals live in wetlands. For example, muskrats may live in bank burrows or "houses" constructed of wetland vegetation along the banks of freshwater and saltwater marshes, rivers, and streams. [10] In freshwater their diets may consist of cattail, bulrushes, waterlilies,

[10] The following discussion is based on four sources of information: 1) Schamberger, et al. (80); 2) W. H. Burt and R. P. Grossenheider, *A Field Guide to the Mammals*, 3d ed. (Boston: Houghton-Mif?lin, 1976); 3) F. C. Daibner, *Animals of the Tidal Marsh* (New York: Van Nostrand Reinhold, 1982); 4) Odum, et al. *(68).*

Photo credit: U.S. Fish and Wildlife Service, Jim Leupold

A white-faced bis ends its young in a marsh at Bear River National Wildlife Refuge. Many water birds depend on marsh vegetation for nesting sites wildrice, and pondweed. In salt marshes, they feed heavily on cordgrasses. They occasionally eat insects, clams, and crayfish. In coastal areas, muskrats reach their highest densities in brackish marshes dominated by bulrushes and cordgrasses.

Another mammal, the nutria, is a related rodent that first was introduced from South America into Louisiana in 1938 for its fur. It is twice the size of the muskrat but is ecologically similar. Nutria prefer freshwater marshes, though they also may be found in low- to high-salinity marshes.

Mink that inhabit wetlands usually rely on crayfish and frogs in the North-Central States and prey heavily on muskrats during droughts and periods of muskrat overpopulation. However, fish are the most important food for a North Carolina population of mink, and crayfish are most important for mink in Louisiana. Mink appear to use the different coastal wetlands with equal success. In general, however, densities of these mammals are higher in freshwater rather than saltwater marshes,

Nutria are harvested for their fur in Louisiana, Maryland, the Carolinas, Texas, Oregon, and Washington. Mink and muskrat are taken in almost all States, though the majority are trapped in the wetland-rich States of the upper Midwest, the Dakotas, and Louisiana (68). In 1979-80, for instance, these species represented 32 percent of the total mammal-harvest value of approximately $295 million (for unfinished pelts). [11] This is a significant contribution to the fur industry, which recorded sales of almost $1 billion in 1980.

	Number harvested*	Average pelt price	Total value (rounded)
Muskrat	8,634,753	$8.63	$74,526,548
Nutria . .	1,344,652	7.25	9,748,727
Mink . . .	394,214	22.42	8,838,277

" 1979-1980 season

While mammals are harvested primarily for their pelts, they also are valuable for meat and various byproducts. During the 1979-80 season in Louisiana alone, 582,000 lbs of nutria and 18,000 lbs of muskrat, both valued at $0.04/lb, were harvested for meat; their combined value was $24,000.

Alligators.—Alligators are found in the wetlands of the Southeast, from North Carolina to Texas, preying on a variety of vertebrates, including mammals, birds, fish, and other reptiles. Alligators need shallow waters and banks for rest and warming in the sun. They use wetland vegetation for cover, protection, and nest construction. Controlled harvest of wild alligators for their hides and meat is permitted in some areas of Louisiana. In 1979, *over* 16,000 alligators worth about $1.7 million were harvested in the Louisiana coastal region (40).

[11] Information on the economic value of wetland furbearers comes from two sources: 1) Fur Resources Committee, International Association of Fish and Wildlife Agencies, fur harvest chart for the United States and Canada (27 species), 1979-80. Figures in text for the United States alone; and 2) Eugene F. Deems, Jr., and Duane Pursely, "North American Furbearers, A Contemporary Reference, International Association of Fish and Wildlife Agencies, 1982,

Photo credit: U.S. Fish and Wildlife Service

A nutria wading in a marsh at Belle Isle, La. These furbearers reach their greatest density in freshwater marshes, though they may also be found in low-to-high salinity marshes

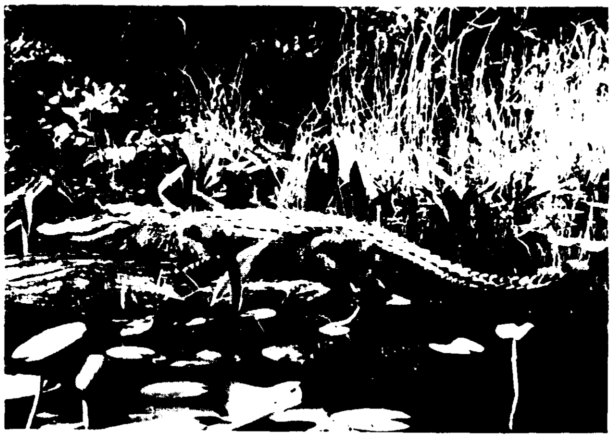


Photo credit: U.S. Fish and Wildlife Service

Alligators need shallow water and banks for rest and warming in the Sun. They use wetland vegetation for cover and nest construction

Crayfish.— Crayfish require the fluctuating water levels found in wetlands for mating and egg laying. Crayfish also feed primarily on wetland vegetation (46). Although there are commercial crayfish fisheries in Wisconsin and the Pacific Northwest, the most valuable crop comes from the Lower Mississippi River Basin, particularly Louisiana. Approximately 25 million lbs, representing revenues of $11 million, are harvested annually. *

Fish and Shellfish.—Many freshwater and saltwater fish require wetlands at some stage of their lifecycle.[12] Pike, pickerel, and muskellunge seem to prefer vegetated shallow water for broadcasting their eggs and may even spawn on land that is only temporarily flooded in the spring.[13] Large mouth bass spawn in the temporarily flooded zones of bottom land hardwoods. An abundant supply of invertebrates in these areas supply necessary food during a critical period after the fish eggs hatch (38). The alewife and the blueback herring spawn in freshwater tidal marshes and flood plain forests along the east coast (18).

Members of the perch family (including walleyes), the sunfish family (including bluegill, bass, and crappie), and the pike family (including pickerel and muskellunge) commonly are found in vegetated wetlands, owing to the protection from predators afforded by the vegetation, strong currents, sunlight, and the fact that the prey of all these fish often take refuge in the wetland. Grey snapper, sheepshead, spotted sea trout, and red drum move into mangroves after spending their first few weeks in submerged seagrass beds. These fish feed heavily on either small fishes or amphipods (86).

Juvenile marine fish and shellfish also use coastal marshes, particularly marshes of intermediate salinity, because this salinity excludes both marine and freshwater predators (2). (See table 5 for a list of species.) Pacific coast wetlands probably do not serve the same nursery function as do the Atlantic coast and gulf coast wetlands (68).

Table 5.—Selected Commercial or Sport Fish and Shellfish Utilizing Coastal Marshes as Nurseries

Sand seatrout
Weakfish
Croaker
spot
Menhaden
Striped mullet
Bay anchovy
Striped bass
White perch
Silver perch
Summer flounder
Brown and white shrimp

SOURCE: Odum, at. al., 1979, op. cit., note 68.

Endangered Species.—Approximately 20 percent of all plant and animal species found on the Federal Government's list of endangered or threatened species heavily depend on wetlands for food and/or habitat (table 6). Many other plant and animal species not included on the Federal list are found on State lists. A number of endangered species not listed in table 6 also may use wetland resources to a greater or lesser extent. [14]

Other Wildlife.—While relatively few animals depend entirely on resources found only in wetlands, many animals heavily exploit wetland resources. Foxes and raccoons, for instance, may prefer den sites in wetlands, owing to their close proximity to the water (72). In fact, the availability of wetland resources may determine the health and survival of many animals during critical times. Wetlands, for instance, are preferred by deer, pheasants, and other animals as winter cover because of the presence and availability of food. Cedar swamps, for example, are the only feeding grounds that can sustain white-tailed deer through northern Michigan winters. In Minnesota, white-tailed deer spend 80 percent of their time in wetlands between December and April (79).

During droughts and dry years, wetlands serve as reservoirs that are extremely important to regional wildlife stability. Southeastern swamps provide food resources when upland resources are unavailable (57). In a survey conducted by FWS, State

● Calculation of the crayfish catch ($11 million, 25 million lbs), based on data supplied by Larry Delabreteonne.

[12] Adamus and Stockwell, op. cit.

‘Information comes from two sources: 1) C. L. Hubbs and K. F. Lagler, ' 'Fishes of the Great Lakes Region, Cranbrook Institute of Science, Bulletin No. 26, Bloomfield Hills, Mich., 1958; 2) M. B. Trautman, ' 'The Fishes of Ohio, " Ohio State University Press, Columbus, 1957,

[14] For a more complete review of the species that use wetlands, see John Kusler, "Our National Wetland Heritage: A Protection Guidebook, " Environmental Institute, Washington, D. C., 1978. The table was prepared by the Office of Endangered Species and subjected to approximately 30 reviews.

Table 6.—Endangered Wetland Species on the Federal Endangered and Threatened Species List

Range	Species (including subspecies, groups of similar species, and genera)
Alaska, Northwest California	Aleutian Canada goose
California	Saltmarsh harvest mouse California clapper rail Light-footed clapper rail San Francisco garter snake Desert slender salamander Santa Cruz long-toed salamander Delta green ground beetle Truckee barberry San Diego mesa mint Crampton's Orcutt grass Saltmarsh bird's beak (a snapdragon)
California, Arizona	Yuma clapper rail
Carolinas to Texas, California	Brown pelican
Rocky Mountains east to Carolinas	Whooping crane
Iowa	Iowa Pleistocene snail
Southeast	American alligator Houston toad Pine barrens tree frog
Carolinas	Bunched arrowhead
Florida	Everglades kite Cape Sable seaside sparrow Dusky seaside sparrow American crocodile Atlantic saltmarsh snake
Appalachians	Chittenango ovate amber snail
Massachusetts	Plymouth red-bellied turtle
Maine	Furbish lousewort
Hawaii	Hawaiian coot Hawaiian duck Laysan duck Hawaiian gallinule Hawaiian stilt
Guam, Marianas Islands	Marianas mallard

SOURCE Office of Technology Assessment

game managers identified the game and fur animals that use wetlands in their States (table 7). A large number of nongame species were found to use wetlands.

Food Chain Support

The infusion of nutrients that comes with spring flooding, combined with the nutrients already stored in wetland soils, results in wetland plant productivity that often is significantly higher than the productivity of adjacent open-water or upland areas. For instance, the fertility of flood plains, resulting from the annual deposits of enriched sediment carried by spring floods, is widely recognized. Similarly, coastal salt marshes and certain types of inland freshwater wetlands that receive a regular supply of nutrients achieve some of the highest rates of plant productivity of any natural ecosystem,

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Table 7.—Game and Fur Animals Identified by State Game Managers as Found in Wetlands

Small game:
Grouse, ruffed
Grouse, sage
Grouse, sharp-tailed
Hungarian partridge
Mourning dove
Pheasant
Quail, bobwhite
Quail, Gambel's
Quail, valley
Rabbit, cottontail
Rabbit, swamp
Snowshoe hare
Snipe
Squirrels (gray and fox)
Woodcock

Big *game:*
Antelope
Black bear
Black-tailed deer
Elk
Mouse
Mule deer
White-tailed deer

Fur animals:
Beaver
Bobcat
Fox (red and gray)
Opossum
Otter
Raccoons
Skunk
Weasel

SOURCE: S. T. Shaw and G. C. Fredine, *Wetlands of the United States*, U.S. Department of the Interior, Fish and Wildlife Service, 1971

Plant material produced by wetlands may be an important link in the food chain. In bottom land hardwood areas, decomposing leaves serve as the base for springtime explosions in populations of invertebrates, which are an important source of protein for egg-laying waterfowl. Many researchers also have examined the importance of detritus from estuarine marshes as food for commercially and recreationally valuable estuarine fish. Wetlands generally produce a great deal of plant material, some of which is flushed into the estuary in the form of detritus. In some estuaries, such as those found along the Georgia and Louisiana coasts, where the ratio of marsh to open water is high, detritus is a major component of the diet of estuarine fish.

Potential Importance of Estuarine Fish and Shellfish From Wetlands.—Table 8 shows the 10 most recreationally important species of marine fish, judging by estimated number of fish landed.

Table 8.—The 10 Most Recreationally Important Marine Fish in the United States in 1979 Ranked by Number of Fish Landed

	Thousands of fish	
	Estuarine	Nonestuarine
Flounders (summer and winter)	38,649	
Bluefish[a]		27,332
Seatrout (3 species)	22,440	
Sea catfishes		20,727
spot	18,480	
Atlantic croaker	16,505	
Pinfish		12,811
Perch (4 species)	9,556	
Snappers (Several).		9,363
Grunts (several)		8,606
Total	105,630 (57%)	78,839 (43%)

[a]Disagreement over estuarine dependence

SOURCE: National Marine Fisheries Service, "Fisheries of the United States, 1980," Current Fishery Statistics No. 8100, 1981.

Out of an estimated 2.98 million marine fish caught by recreational fishermen in the United States in 1979, 5 out of the top 10 species, or 57 percent by number, were estuarine-dependent. By weight, they comprised about 62 percent of the total catch of 438.6 million lbs.

The percentage of estuarine-related fish and shellfish out of the total U.S. fisheries harvest is high. * Table 9 shows the 15 most important species or groups of species commercially harvested by U.S. fishermen in 1980, ranked by their dockside value.[15] Eight of these fifteen species commonly are found in estuaries at least sometime during their lifecycles. They represent 61 percent of the dockside value and 77 percent of the total weight of the catch of the 15 groups listed. Commercial landings by U.S. fishermen for fish and shellfish in U.S. ports totaled 6.48 billion lb in 1980, with a dockside value of $2.23 billion. Approximately 4.08 bil-

*It should be noted that there is disagreement on which fish should be considered "estuarine. " This rises partially from different definitions of the term and partially from lack of knowledge regarding many of the details of marine fish life histories. For this discussion, we have used Stroud's (1971) survey of 15 fisheries biologists on the estuarine dependence of nearly 100 fishes.

[15]Estimated total catch, all regions, from National Marine Fisheries Service, 1981. Estuarine dependence based on McHugh (1966) and Stroud (1971). 1) National Marine Fisheries Service, "Fisheries of the United States, 1980, " Current Fishery Statistics No. 8100, 1981; 2) J. L. McHugh, ' 'Management of Estuarine Fisheries, *A Symposium on Estuarine Fisheries*, American Fisheries, Soc. Spec. Pub]. No. 3, 1966, pp. 133-154; 3) R. H. Stroud, "Introduction to Symposium, *A Symposium on the Biological Significance of Estuaries*, P. A. Douglas and R. H. Stroud (eds.) (Washington, D. C.: Sport Fishing Institute, 1971).

Table 9.—The 15 Most Important Fish and Shellfish Harvested by U.S. Fisheries in 1980

	Thousands of dollars		Thousands of pounds	
	Nonestuarine	Estuarine	Nonestuarine	Estuarine
Shrimp (several species, all coasts)	—	$ 402,697	—	339,707
Salmon (5 species)		532,277	—	613,811
Tuna (6 species)	$233,125	—	399,432	—
King crab	168,694	—	185,624	—
Menhaden (Atlantic and Gulf)	—	112,012	—	2,496,649
Sea scallops	110,429		28,752	—
Flounders (several species, all coasts)	—	82,4&	—	216,920
American lobster	75,233	—	36,952	—
Oyster	—	70,075	—	49,081
Snow, or tanner crab	55,161	—	121,674	—
Sea herring (Atlantic and Pacific)	44,955	—	291,069	—
Hard clam	—	44,068	—	13,370
Blue crab		55,167	—	163,206
Atlantic cod	31,883	—	118,245	—
Dungeness crab	—	21,613	—	38,025
Total	$719,480	$1,120,397	1,181,748	3,930,769
Percent	390/0	61 0/0	230/o	77 "/0

SOURCE: National Marine Fisheries Service, "Fisheries of the United States, 1980," Current Fishery Statistics No, 8100, 1981,

lion lbs of estuarine fish and shellfish species were landed by U.S. commercial fishermen in 1980. This represented 63 percent of total U.S. commercial landings at U.S. ports, with a dockside value of $1.15 billion, 51.5 percent of the value of the total catch. The retail value of the estuarine-related catch is more speculative.

Factors Affecting Production of Plant Material. —The production of plant material in wetlands generally is high relative to other upland ecosystems, such as grasslands (table 10), largely because of the flux of nutrients and water through wetlands (75), In general, production of plant material will be greatest in wetlands of flowing or regularly fluctuating water and lowest in stillwater wetlands (unless enriched by nutrients) (14), Approximately 15 percent or less of the annual plant growth of coastal marshes* is harvested by direct feeding by macroinvertebrates such as fiddler crabs, snails, amphipods, and polychaete worms (49). After the growing season, most standing plant material on marshes dies.

Up to 70 percent of the net primary productivity of coastal wetlands may be exported from the wetland to open-water areas (49). The amount exported will vary—in the "high marsh, only 10 percent may be exported, while areas adjacent to the water's edge may export much more. In some cases, there may be no net export. Any detrital particles exported from the marsh rapidly are colonized by bacteria, fungi, and other micro-organisms which increase the concentration of protein and fatty acid content, enhancing caloric value. These microbes also adsorb dissolved organic compounds from the surrounding water. As a result, the original plant material is transformed into a nutritious food source for filter feeders. [16]

*This discussion pertains to coastal marshes, Limited research indicates that dissolved organic compounds and decaying plant material are exported from inland wetlands at a greater rate than from uplands of equivalent area.

[16] Sather and Smith, OP. cit.

Table 10.—Wetland Plant Productivity
(metric tons per hectare per year)

	Range
Coastal:	
Salt marshes (aboveground only):	
Louisiana and Georgia	22
North Atlantic	4-7
Pacific coast	3-19
Freshwater tidal wetlands (above and below ground)	13-16
Inland:	
Freshwater marshes (above and below ground):	
Sedge-dominated marshes	9-12
Cattail marshes	20-34
Reed	15-27
Bogs (above and below ground)	4-14
Wooded swamps	7-14

SOURCE: *Wet/and Functions and Values: The State of Our Understanding,* P, E. Greeson, J. R. Clark and J. E. Clark (eds.) (Minneapolis, Minn.: American Water Resources Association, 1979), pp 146-161

Analysis of the stomach contents of estuarine fish and shellfish shows a wide variety of foods. For instance, the stomach contents of menhaden include primarily algae, but also detritus, small crustaceans, and even small fish and fish eggs (50). Commercial shrimp seem to have an even broader diet, consisting of single-celled algae, algal filaments, detritus, bacteria, protozoa, and easily captured animals, including very small worms and crustaceans (25). Analysis of the stomach contents of oysters and hard clams often shows both detritus from vascular plants and phytoplankton, probably from the open estuary. However, there is evidence that most of the food value comes from the phytoplankton (37,69,84).

While commercially and recreationally important fish may not directly consume detritus as their major food source, they may feed on invertebrates that use detritus as a major food source. Newly hatched Atlantic croaker, for instance, eat the small crustaceans found in the water column, particularly various copepods commonly found in the tidal creeks dissecting grassy salt marshes (2). As they grow, they add larger items to their diets, such as amphipod crustaceans, mysid shrimp, small crabs, worms of all sorts, mollusks, and smaller fish (69, 84). Also, opposum shrimp, a common marsh invertebrate, is a major component of the diet of striped bass on both the east and west coasts. Chironomid midge larvae were found to account for over 80 percent of the diet of juvenile chum and chinook salmon (24).

Most coastal marshes export detritus to adjacent coastal waters. While estuarine fish and shellfish may directly and indirectly use detritus when available, the quantitative significance of wetlands-derived detritus to the food supply of the estuary relative to contributions of detritus from other terrestrial or open-water food sources generally is not known, but probably varies widely with both species and estuary, If the estuary has very few marshes and much open water, such as in the North and Middle Atlantic States and most areas in the Pacific, the likelihood is increased that the ultimate source of organic matter for fish is not the marsh grass, but the phytoplankton. For example, Chesapeake Bay is the source of a great deal of commercially valuable seafood, but its ratio of marsh to open water is only 0.04; the ratio at Sapelo Island, Ga., is nearly 2.0. Given what is known about the phytoplankton production in the Chesapeake Bay, the annual contribution of salt marshes to total available energy is only around 2 to 5 percent (61). In fact, the scientific literature lacks convincing evidence, at least for Atlantic and Pacific coasts, supporting the belief that coastal marshes play a significant role in supporting fish and shellfish productivity through the export of detritus (68).

Climatic and Atmospheric Functions

Although there has been little research related to these functions, some wetland scientists have hypothesized that large wetlands help to maintain lower air temperatures in the summer and prevent extremely low temperatures in the winter. They also are a source of water to the atmosphere, leading to the formation of cumulus clouds, thunderstorms, and precipitation. Finally, wetlands, through processes of microbial decomposition, either may store or emit gaseous byproducts important to global atmospheric stability.

Moderation of Local Temperatures

Water warms and cools slowly in comparison with land areas; thus, wetlands will have a moderating influence on daily atmospheric temperatures. Drained agricultural areas in Florida, for instance, were found to be 50 F colder in the winter than were surrounding, undrained areas (35). It has been suggested that wetland drainage of the Everglades may have increased frost act ion (87). Because deeper water bodies contain more water than wetlands with the same area, lakes will have a more moderating influence on atmospheric temperature than will wetlands (35).

Maintaining Regional Precipitation

Wetlands contribute to rainfall through processes of evaporation and the release of water vapor from plants (evapotranspiration). In a study of Florida cumulus clouds, for instance, lakes larger than 1 mile in diameter exerted a noticeable effect on clouds in the area (35), It has been hypothesized that wetland drainage could reduce summer thunderstorm activity in Florida by reducing evapotransporation, leading in turn to regional rainfall deficits (22).

Maintain Global Atmospheric Stability

There is increasing concern now that increases in atmospheric nitrous oxide from man's activities may adversely affect the stratosphere and may influence the radiative budget of the troposphere. Studies on tidal salt marshes have shown that microbial decomposition in wetland soils under anaerobic conditions can convert nitrous oxide to other chemical forms. The importance of this process on a global scale remains unclear (36).

Terrestrial detritus may form one of the largest but least accurately known pools of carbon in the biosphere. It generally is agreed that the world pool of detrital carbon is several times larger than the total carbon content of the atmosphere or of the world biota. A significant fraction of detritus is found as peat or in the highly organic soils of wetlands (34). If left undisturbed, the carbon in these organic soils remains as reduced organic carbon. Since the mid-19th century, the conversion of wetlands has resulted in the oxidation of organic matter in the soil and the release of carbon dioxide to the atmosphere (65). Many scientists feel that increasing levels of carbon dioxide in the atmosphere will lead to global warming.

Methane, a byproduct of microbial decomposition of organic material in wetlands, also is thought to function as a sort of homeostatic regulator for the ozone layer that protects modern aerobic life from the deleterious effects of ultraviolet radiation (65).

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