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BIOLOGICAL ASPECTS OF RESTORED AND CREATED WETLANDS

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ABSTRACT: Wetland biology typically is hydrologically driven. The hydrology of created and restored wetlands frequently differs from that of natural systems, and the resulting floral and faunal composition of the wetland may also differ. In general, restored wetlands are more similar to natural wetlands than are created wetlands, and the biota of restored wetlands will more closely resemble that of natural wetlands. Created wetlands vary greatly from natural wetlands in both the hydroperiod and the quality of the water moving through them. Consequently, created wetlands are often biologically quite distinct from natural wetlands.

Substantial efforts to restore wetlands throughout the United States have been taking place since the mid-1980s. The goals of wetland restoration are to 1) improve water quality, to 2) control stormwater, and to 3) provide habitat for a variety of plants and animals. Numerous species of plants and animals, including many endangered or threatened species, are dependent upon wetland habitats. Following restoration of the hydrologic regime, native aquatic plants return to restored wetlands within one year. As the water regime and plant cover become established, the wetlands are colonized by a variety of animals, including aquatic invertebrates. Use of the wetland system by wildlife is directly related to the size of the wetland, but distance between wetlands may affect the occurrence of taxa that have restricted dispersal ability.

Unlike most natural wetlands, artificially created wetlands may have constant water regimes that can influence the floral composition of the system. Wetland plants that need periods of drawdown are often eliminated with time. The biology of wetlands created for wastewater treatment is also greatly influenced by influent water quality. Wastewater often contains high levels of organics and ions that stress both the plants and the animals. If the system is used for the primary or secondary treatment of wastewater, the invertebrate assemblage will shift to pollution-tolerant species. Even created wetlands utilized for tertiary wastewater treatment may be subjected to water of lower quality than natural wetlands, and they may experience a lesser shift toward pollution-tolerant species. However, increased nutrient inputs can lead to greater productivity in wastewater treatment wetlands than is found in comparable natural wetlands.

Wildlife and avian use of constructed wetlands are directly related to the size of the facility. Large systems attract a greater diversity of birds. These treatment systems may provide major bird-watching areas for the people they serve. Large waste treatment wetlands also harbor significant numbers of amphibians, reptiles, and wetland-utilizing mammals. Small wetlands that serve only a single family farm will be utilized less by wildlife but can still provide usable habitat.

KEYWORDS: Created wetlands, restored wetlands.

INTRODUCTION

Many types of wetlands exist, but all wetlands share one common characteristic — they flood with sufficient regularity that emergent vegetation must survive an anaerobic root environment for a substantial portion of the year (Gosselink and Turner, 1978). Beyond that, agreement on a single definition for the term "wetland" has been difficult to reach. Wetland ecological functions include the provision of aquatic and semiaquatic wildlife habitat, sediment and toxicant retention, nutrient metabolism, groundwater recharge or discharge, flood attenuation, and production export. Different natural wetlands provide different combinations of these functions. The degree to which they are provided also varies among wetlands (Kent, 1994a).

Generally, wetlands are identified using three criteria (Mitsch and Gosselink, 1993):

1. The presence of water at the surface or in the root zone for a portion of the growing season;
2. The presence of plants adapted to wet conditions (hydrophytic vegetation); and
3. The presence of hydric soils that differ from those of the surrounding uplands.

Wetlands may be viewed as transitional between upland and aquatic habitats, providing the terrestrial limit for aquatic organisms and the aquatic limit for terrestrial organisms (Mitsch and Gosselink, 1993). However, wetlands are distinct ecosystems with unique characteristics. The specific hydrologic regime in a natural wetland is the major determinant of biotic development (Glaser, *et al.,* 1978; Gosselink and Turner, 1978; van der Valk, 1981; Wetzel, 1993). Material and energy flow are greatly influenced by the timing and length of periods of drawdown and inundation. Palustrine and ocean-shore wetlands typically display vegetational zonation in response to changes in water depth within a wetland (Penfound, 1956; Mitsch and Gosselink, 1993).

Kantrud, *et al.* (1989) describe three vegetation zones associated with emergent wetlands in the Prairie Pothole Region of the Dakotas. These zones are applicable to Indiana's emergent wetlands as well:

1. The *wet meadow zone* is generally composed of grasses, reeds, sedges, forbs, and woody plants; it lacks submergent vegetation;
2. The *shallow marsh zone* is generally composed of grasses, sedges, non-persistent forbs, submerged and floating-leafed plants, mosses, and liverworts; and
3. The *deep marsh zone* is typically composed of cattails, bulrushes, and submerged and floating-leafed plants.

The location of plants in each zone is directly associated with water levels within the wetland. The wet meadow zone typically is associated with shallow water levels, whereas the deep marsh zone is associated with deep water levels. Water level fluctuations occur naturally as a response to climatic conditions and are influenced by the topography of the bottom of the wetland basin. The seeds of many wetland plants float and often accumulate near shorelines. Other seeds collect in the bottom sediments (seed bank) and are dependent upon proper environmental conditions for germination.

Periods of complete drawdown occur and affect plant zonation patterns within the wetland. For example, invasive species (e.g., grasses and forbs) rapidly colonize new areas that were previously flooded. Following inundation, the typical vegetation zones will again become established. In natural wetlands, these changes are dynamic rather than stable (McDonald, 1955; van der Valk, 1981). Vegetation establishment may be regulated by the timing and duration of soil exposure, because many wetland plants require exposure to the air for seed germination (van der Valk and Davis, 1978; van der Valk, 1981).

Gosselink and Turner (1978) define the hydrologic regime as a four-function aspect of a wetland:

1. The chemical composition of the water entering the wetland (a function of the water source);
2. The velocity at which the water moves through the wetland;
3. The frequency and duration of inundation; and
4. The rate at which the water is replaced within the wetland.

The interplay of these four factors will greatly influence the biology of a wetland. In turn, the wetland biota can influence wetland hydrology (Gosselink and Turner, 1978; Mitsch and Gosselink, 1993). Biogeochemical cycles are typical of wetlands, where they are mediated by the biological components of the wetland in conjunction with wetland physico-chemical factors. Primary producers, consumers, microbes, and detrital components contribute greatly to these processes. The activities of animals and the accumulation of organic matter can change the wetland's hydrologic regime (Mitsch and Gosselink, 1993).

Although animals utilize wetlands for a variety of habitat needs, most uses are related to the presence, duration, and amount of water in a given wetland. Not all wetland plants are dependent upon the presence of water. Submerged and floating plants need water for normal growth, because they lack support when out of the water. Emergent wetland plants are not limited in this way. However, all wetland plants that grow in wetland soils are adapted to handle the stresses associated with a strongly reducing root environment (Gosselink and Turner, 1978; Tammi, 1994) created by the presence of water. The physiological and morphological adaptations that allow aquatic plants to withstand a strongly reducing root environment should provide the same adaptive advantage in a similar environment that lacked water. Typically, animals are adapted to the physical properties of water, while plants are adapted to the chemical effects of the presence of water.

Indiana contains a variety of wetland types. Peat bogs are found in northern Indiana. Emergent palustrine marshes are scattered throughout the State, either standing alone or as a shoreline component of lakes. Riparian forested wetlands may be found along portions of many of Indiana's rivers. Each of these wetlands is biologically unique.

Wetlands shape both environmental functions and cultural values (Kentula, *et al.,* 1992; Mitsch and Gosselink, 1993; Reimold, 1994). Historically, the wetlands of the United States have been viewed as waste places with minimal or negative cultural value, and they have been actively converted to other uses (Mitsch and Gosselink, 1993; Reimold, 1994). In the conterminous United States, more than half of the wetlands existing prior to European settlement have been lost (Mitsch and Gosselink, 1993), and many of the remaining natural wetlands have been degraded as a result of human activity (Kent, 1994b). In Indiana, as in most of the upper Midwest, the loss of wetlands has exceeded the national average. Current estimates indicate that 87% of the wetlands present in Indiana prior to European settlement have been drained and converted to other uses (Mitsch and Gosselink, 1993). Nationally, wetland losses continue and are estimated to occur at the rate of 0.5 million acres per year (Kent, 1994b).

Recently, attention has turned either to re-establishing wetlands in areas that were previously drained and converted to other uses or to creating new wetlands in areas where they did not exist previously. Hammer (1994) offered a set of definitions that may aid in the proper description of these different types of wetlands:

1. *Natural wetlands.* These areas support, at least periodically, a vegetation composed primarily of hydrophytes. The substrate may be either undrained hydric soil or a non-soil, which is saturated with water or covered by shallow water each year at some time during the growing season. Natural wetlands have and continue to support a typical wetland flora and fauna.

2. *Restored wetlands.* These areas (which previously supported a natural wetlands ecosystem) were modified or changed to eliminate the typical flora and fauna and then used for other purposes. Subsequently, these areas were altered once more to restore the poorly drained soils and the wetlands flora and fauna.

3. *Created wetlands.* These wetlands formerly had well-drained soils and supported a terrestrial flora and fauna. The land was deliberately modified to establish the requisite hydrological conditions to produce poorly drained soils, which support a wetlands flora and fauna. *Constructed wetlands* are a subcategory of created wetlands. These areas also consist of former terrestrial environments that have been modified to create poorly drained soils, which support a wetlands flora and fauna. The primary purpose of their creation is contaminant or pollutant removal from wastewater. Constructed wetlands are designed to transform many pollutants into their gaseous forms for release to the long-term biogeochemical reservoir in the atmosphere and to trap others (e.g., metals) in the substrate. Although constructed wetlands are designed and operated as wastewater treatment systems, many sites do support other uses.

In many instances, the biology of restored or created wetlands can be similar to the biology of natural wetlands. In this paper, these similarities will be explored and the deviations from the biology of natural wetlands that occur in restored and created wetlands will be discussed.

BIOLOGY OF RESTORED WETLANDS IN INDIANA

Historically, most of the wetlands in Indiana have been converted to cropland due to intense agricultural practices within the State. Although wetland loss since the late 1700s has been substantial, current estimates from agencies involved in wetland restoration are that approximately 200,000 wetland acres have been restored in Indiana since 1988 (T. Burnside, S. Fetters, and J. Ruwaldt, pers. comm.). This total may include some acreage that would more appropriately be considered created wetlands rather than restored wetlands. Wetland restoration and creation need not develop new wetlands in the same proportions in which they were lost (Barbour and Miles, 1988; Kentula, *et al.,* 1992). In Indiana, wetlands have been restored following mining operations (Mulyani, 1992), road construction (Barbour and Miles, 1988), and the abandonment of farms (Hartman, 1994).

The process of converting a wetland into an area that can be farmed involves the placement of underground field tiles to drain the basin and denuding the area of its wetland vegetation. Restoration reverses this process through the following steps:

1. Locate the field tiles draining the wetland;
2. Remove a section of the original tile and replace it with a solid section of pipe, plugging the tile; and
3. Install a standpipe at the junction of the plug and the open drain tile to establish basin water depth.

Following restoration of the hydrologic regime, plants and animals are allowed to naturally recolonize the area. Newly created wetlands are not fully functional wetlands (Kentula, *et al.,* 1992; Ferlow, 1993). However, given enough time, the process can return an area that was a wetland to its predeveloped condition.

Some animals utilize wetland habitats only for feeding or resting, while others are dependent upon wetlands to complete their life cycles. Amphibians serve as excellent examples of the latter group. In Indiana, four amphibian species are listed as threatened or endangered, and five are listed as being of special concern (Table 1). Of these nine species, the hellbender (*Cryptobranchus alleganiensis alleganiensis*) is under review for Federal listing under the Endangered Species Act (Indiana Department of Natural Resources, 1990). Many frogs utilize wetlands for courtship activities, and they lay their eggs in water. Many other amphibian species also utilize wetlands. The smallmouth salamander (*Ambystoma texanum*) and the eastern tiger salamander (*Ambystoma tigrinum tigrinum*) are common species in Indiana that utilize the periphery of swamps for breeding activities and that lay eggs in or at the water surface (Connant and Collins, 1991). Like all salamanders, the larvae of these two species are aquatic. The biology of these species is highly dependent upon wetland habitats, and restored wetlands offer additional habitat for animals requiring water to complete their life cycles.

Mammals utilize wetland habitats for cover and feeding. Fritzell (1989) found 17 mammalian species associated with wetland habitats in the Prairie Pothole Region of Iowa. Similar mammalian usage can be expected on restored emergent marshes in Indiana. Two species that influence wetland ecosystems in the

Table 1. The amphibian species listed as threatened, endangered, or of special concern in Indiana.

Scientific Name	Common Name	Indiana Status
Cryptobranchus alleganiensis alleganiensis	Hellbender	Endangered
Pseudotriton ruber ruber	Northern red salamander	Endangered
Hemidactylum scutatum	Four-toed salamander	Threatened
Rana aerolata circulosa	Northern crawfish frog	Threatened
Ambystoma laterale	Blue-spotted salamander	Special concern
Necturus maculosus	Mudpuppy	Special concern
Rana blairi	Plains leopard frog	Special concern
Rana pipiens	Northern leopard frog	Special concern
Scaphiopus holbrookii holbrookii	Eastern spadefoot	Special concern

north-central region of Indiana and thus the other species utilizing these habitats are the muskrat (*Ondotra zibethica*) and beaver (*Castor canadensis*). At high population densities, these two species may be pests. Beaver may adversely affect the hydrology of restored wetlands. Muskrats can create open water areas by removing extensive amounts of vegetation, thus eliminating vegetative cover for other species; their burrowing activities may damage dikes in restored wetlands and compromise system hydrology (McDonald, 1955; van der Valk and Davis, 1978). Generally, mammalian species enhance wetland management practices.

Wetlands with a mosaic of open water and vegetation at a ratio of 1:1 are important for the management of breeding waterfowl (Weller and Spatcher, 1965; Kaminski and Prince, 1981; Ball and Nudds, 1989). Muskrat houses are used as nesting sites by Canada geese (*Branta canadensis*), and their homes may be used as brooding and resting areas by other waterfowl species (Payne, 1992).

Aquatic invertebrates are an important link in the food chain in wetland ecosystems (Murkin and Wrubleski, 1988). These invertebrates serve as shredders, facilitating detrital decomposition, and are an important food source for many organisms, including waterfowl and numerous other marsh birds (Riley and Bookout, 1990). The make-up of aquatic invertebrate communities is closely related to wetland hydrology and water quality. Some taxa are more tolerant than others of adverse water quality. Aquatic invertebrates in seasonally flooded wetlands must be adapted to handle the extreme changes in habitat conditions. Special adaptations include the ability to complete their life cycle before the basin dries out, eggs that can survive desiccation, and the ability to disperse readily to new sites (Kantrud, *et al.,* 1989), either by flying or by clinging to the bodies of other animals (Borror, *et al.,* 1989). Recent studies in restored Iowa wetlands show that diverse aquatic invertebrate communities are present in the wetlands within one to two years after restoration (Delphey, 1991; VanRees-Siewert, 1993). However, in comparison to natural wetlands, these newly restored wetlands contain smaller proportions of non-insect taxa (Delphey, 1991), which is not surprising given the more limited dispersal ability of these taxa. Distance between wetlands influences the successful dispersal of many aquatic invertebrate taxa.

In addition to the presence or availability of water, other factors such as inter-wetland distance and wetland size have important implications for the management and survival of some species. The intensive agricultural practices found throughout the Midwest and the concurrent destruction of wetlands, especially in Indiana, has increased the isolation of wetland habitats. Some species are more vulnerable to habitat isolation than others. The probability of successful dispersal to neighboring habitats decreases as inter-patch distance increases (Wolfenbarger, 1949), especially for those animals that are highly adapted to aquatic environments (Gibbs, 1993) and that cannot survive long-term exposure to terrestrial habitats. Studies of wetland-associated species have shown that newts can migrate a maximum of 1 km (Gill, 1978) and that salamanders can migrate a maximum of 400 m (Gordon, 1968). Frogs can migrate distances of between 237 m (Jameson, 1956) and 2.5 km (Berven and Grudzien, 1990). Small mammals (Class Insectivora) have migrated distances of approximately 1 km (French, *et al.,* 1975).

Inter-island distance has been shown to affect the richness and diversity of avian communities on oceanic islands (MacArthur and Wilson, 1963). Classical island biogeography theory has been extended to cover a variety of isolated habitats (Ricklefs, 1993), including wetlands. However, distance between wetlands (islands) in a fragmented agricultural landscape (ocean) does not significantly influence bird species richness or diversity at restored wetlands in Indiana (Hartman, 1994). Inter-wetland distance typically is orders of magnitude smaller in Indiana than the distance between oceanic islands. Birds are capable of traversing the intervening terrain between wetlands in Indiana without difficulty. However, some waterfowl species (e.g., blue-winged teal (*Anas discors*)) exhibit small home ranges during the breeding season. Numerous individuals may be found in wetlands located close together at this time (Gibbs, 1993). A complex or group of wetlands may be important in attracting and supplying the needs of similar waterfowl species (Fredrickson and Reid, 1988; Swanson, 1988; Krapu and Duebbert, 1989).

Size is also an important design consideration for wetland restoration. Area is an influential factor on bird species richness (MacArthur and Wilson, 1963; Weller and Fredrickson, 1973; Brown and Dinsmore, 1991), especially in wetland habitats (Tyser, 1983; Delphey and Dinsmore, 1993, Hartman, 1994). As size increases, the amount of potentially usable habitat increases. Larger wetlands are more likely to contain diverse habitat types, ranging from deep open water through shallow marshes and perhaps including riparian forests. Increased habitat diversity may contribute to greater avian utilization of larger wetlands, both restored and natural. Some avian species are associated only with large wetlands and may be considered to be area-dependent (e.g., in Indiana, such species include the swamp sparrow (*Melospiza georgiana*), mallard (*Anas platyrhynchos*), pied-billed grebe (*Podilymbus podiceps*), and Canada goose (*Branta canadensis*) (Brown and Dinsmore, 1986)). The greater diversity found at large wetlands does not imply that small wetlands, especially those that are highly isolated, are unimportant. Small wetlands, including those within a larger wetland complex, may be especially important for the persistence of populations with limited growth rates and low population densities (Gibbs, 1993).

The distribution of plants in newly restored wetlands, if they are not artificially planted, is dependent upon both the abiotic and biotic factors. Seed banks generally provide a source of plant stock, and typically are dominated by annuals and flood-intolerant species (Mitsch and Gosselink, 1993). Seed banks in restored Iowa wetlands have shown resilience to long periods of drainage and intensive farming practices (LaGrange and Dinsmore, 1989). Plants are dispersed passively by wind and actively by animals. Propagules may either attach to animals externally or remain viable after passing through their digestive systems (van der Pijl, 1972). Inter-wetland distance influences the probability of successful dispersal for aquatic plant taxa.

BIOLOGY OF CREATED WETLANDS IN INDIANA

Wetlands may be created for a variety of reasons: 1) flood control and stormwater retention; 2) replacement (mitigation) of wetlands lost to development; 3) treatment of wastewater from domestic, municipal, industrial, mining, or agricultural sources; and 4) as part of land reclamation following extensive disturbance (Bastian and Hammer, 1993; Mitsch and Gosselink, 1993; Hammer, 1994). Wetlands created for mitigation or land reclamation are designed to replace, in some way, natural wetlands that have been lost due to human activities. These created wetlands should function similarly to natural wetlands. However, wetlands created for stormwater control or wastewater treatment are neither designed nor intended to replace natural wetlands. These constructed wetlands may display some wetland functions, but usually they will not be full replacements for natural wetlands. Large constructed wetlands receiving relatively clean water may approximate natural wetlands, but their purpose is to provide a specific service, either flood abatement or water treatment. Therefore, these systems are not substitutes for existing wetlands.

Wetlands created for mitigation are intended to replace the wetland functions lost through the development of natural wetlands for human use (Mitsch and Gosselink, 1993). Typically, acceptable mitigation requires the creation of more acres of wetland than will be lost through the development project. Ideally, at least as many acres of the type of wetland lost will be created to replace the ecological functions lost. Mitigation wetlands and wetlands created during land reclamation typically function as natural wetlands with the hydrologic regime dominating development. The biology of these wetlands will be similar to natural wetlands following an initial establishment period, if they are properly designed and installed (Mitsch and Gosselink, 1993). Hydrologic inputs are from rainfall, surface flow, and groundwater, the same sources as in natural wetlands. These wetlands are not developed to provide waste treatment or flood control, and they are not impacted by water quality any differently than natural wetlands. In practice, difficulties have been encountered in establishing and maintaining proper hydrology in mitigation projects (Mitsch and Gosselink, 1993). Improper hydrology can result in the failure of the wetland creation project (D'Avanzo, 1989).

Wetlands used for stormwater retention (called *biofilters*) usually develop as natural wetlands (Ferlow, 1993). Dense vegetation coupled with basin area decrease the rate of stormwater flow allowing the suspended particulates to settle. Pollutants adhering to suspended particles are removed by physical action and sequestered in bottom sediments just as in a natural wetland that receives input from runoff. Wetlands created for stormwater retention can provide functional wildlife habitat and improve downstream water quality while reducing flood peaks (Ferlow, 1993; Davis, 1995b). However, the potential for pollutant accumulation and contamination must be addressed (Davis, 1995b). Created wetlands fed with runoff from developed areas may be influenced by the presence of petrochemicals and other anthropogenic pollutants. Stormwater retention wetlands around an agricultural watershed may be influenced by large additions of fertilizers and pesticides. Plants and animals sensitive to these types of pollution may be adversely affected in the created wetlands so impacted. The degree of impact will vary among taxa and will be a function of accumulation rates, degradation rates, and the specific location of potential toxicants within the wetland.

Constructed wetlands used for wastewater treatment operate on the same principles as conventional wastewater treatment plants; only the scale of operation is changed (Hammer, 1994). In either case, an optimal environment is maintained for microbial populations to transform water pollutants into nontoxic byproducts through their metabolism. Constructed wetland systems support more diverse microbial assemblages than conventional wastewater treatment plants, but the metabolic processes involved are still basically the same (Hammer, 1994). Two types of constructed wetlands are in widespread use for wastewater treatment: subsurface flow wetlands and free water surface wetlands (Brix, 1993; Hammer, 1994). Variations on these two designs are typically used regardless of the type of wastewater being treated. Both types of systems are found in Indiana.

Subsurface flow systems have no exposed water surface. Water moves through an underground matrix of crushed rock. Wetland plants are scattered across the surface of the system and grow hydroponically, their roots extending downward into the crushed rock matrix to reach water. The plants transport oxygen to the root zone and create aerobic microenvironments that facilitate nitrogen cycling. Subsurface flow systems function as trickling filter wastewater treatment plants and have little visual resemblance to natural wetlands (Hammer, 1990). Frequently, subsurface flow systems appear as a crushed rock garden with occasional wetland plants. Microorganisms grow on the surfaces of the rock and utilize contaminants in the wastewater as food. Their metabolic transformations clean the water as it passes through the system. In Indiana, subsurface flow wetlands are currently used for the treatment of domestic waste, either for single family residences or small groups of residences. In fact, wetlands used for on-site residential waste treatment should always be subsurface flow systems (Steiner, *et al.,* 1993). With standing water, olfactory and public health problems are always possible. When working properly, the subsurface flow design eliminates the potential for these problems. From a biological perspective, subsurface flow wetlands provide only those wetland functions associated with water quality and nutrient cycling.

Created wetlands that are constructed for uses other than domestic wastewater treatment or final polishing of treated wastewaters with low nutrient loads are always free water surface systems rather than subsurface flow systems (Hammer, 1994). Free water surface wetlands remain functional at higher suspended solids loadings than subsurface flow systems. It is impractical to provide sufficient pretreatment to lower the effluent-suspended solids concentrations to a level that would allow the operation of subsurface flow wetlands loaded with agricultural wastes (Hammer, 1994). The pore spaces within the crushed rock matrix would quickly clog, leading to system failure.

Free water surface wetlands are designed to resemble natural emergent marshes, both in appearance and function. Water moves above the ground between the stems of the emergent vegetation. The plant surfaces provide a colonizable substrate for microbial attachment and growth. Free water surface wetlands act as fixed-film bioreactors with the microbial films that cover the immersed vegetation providing the mechanism of most wastewater treatment (Hammer, 1990). Wetland plants sequester nutrients in their underground tissue, effectively eliminating a portion of the soluble nutrients moving through the system (Wetzel, 1993). In Indiana, free water surface systems are found as components in animal waste management systems and stormwater detention basins.

Wetlands built for wastewater treatment differ from other created wetlands. In large systems, such as those used to treat municipal wastes, the constant water inflow is different from the hydrologic regime found in natural wetlands. Periods of inundation and drawdown do not alternate. However, a substantial shift from the characteristics of natural wetlands may not occur, if the vegetation planted in the wetland is capable of tolerating perpetual inundation. Plants that require cyclic drawdown and exposure to complete their life cycles will fare poorly in such systems unless the management strategy is designed specifically to accommodate these species. Treatment wetlands with multiple, parallel cells can be manipulated to have one cell dry while the remainder of the system continues to operate. This usage pattern facilitates routine maintenance and can simulate drawdown cycles. Small wastewater treatment wetlands may have only periodic inputs of water, and the associated hydrologic regime may closely resemble that found in natural wetlands. Wetland plants not specifically planted in the created wetland might eventually colonize the system, and the vegetation will then tend to mirror that of natural wetlands. Volunteer plants should not be discouraged, unless they pose weed problems.

The chemical make-up of influent wastewater influences wetland biology. Constructed wetlands receiving wastewater from a municipal treatment system may function as natural wetlands. Normally, the load of solids, nutrients, and organics flowing into these wetlands will be small, if the wastewater has undergone both primary and secondary treatment at the municipal treatment plant. In certain instances, these systems may be more productive than similar natural wetlands in the region. Following secondary treatment, the nutrient levels in the wastewater can remain higher than in natural runoff. The increased nutrient load in created wetlands can result in increased primary productivity for the man-made systems relative to nearby natural systems. The increased productivity results from a higher number of trophic levels and an increase in productivity at many of these levels. At Arcata, California, a large constructed wetland used for tertiary polishing of municipal wastewater receives greater use by birds and other wildlife than nearby natural wetlands (Gearhart and Higley, 1993). This system has become a focal point for local wildlife viewing, including organized bird-watching trips by local Audubon Society Chapters.

Industrial wastewater impacts wetland biology more strongly than municipal wastewater. Industrial effluents are often heated. However, water temperatures are not high enough to inhibit microbial growth following secondary treatment. The elevated temperature do result in higher microbial growth rates and prolonged growing seasons. Cold tolerant wetland plants can grow year round without senescence, if the root zone is maintained at a sufficiently high temperature even though air temperatures may drop below -10° C (pers. obs.). Microbial activity continues throughout the year, resulting in a higher level of winter treatment than in similar municipal wetlands.

Typically, the chemical make-up of industrial wastewater will not have a strong influence on wetland biology. Industrial wastes will have undergone secondary treatment prior to entry into the created wetlands. In industries such as those involved in pulp production, the treated wastewater remains dark due to the presence of tannins and other secondary plant compounds. These compounds affect light penetration and inhibit algal production and the growth of submerged plants. This condition is not without parallels in nature. Southern blackwater swamps and northern tamarack swamps have similarly colored water as a result of the presence of compounds leached from the trees growing in the slow moving water.

Certain industrial wastes contain trace levels of compounds that can influence the composition of the lower trophic levels in a wetland. Halogenated compounds, complex organic compounds, metals, and solvents may be either acutely or chronically detrimental to organisms at any trophic level (Metcalf and Eddy, Inc., 1991). Also, the lower level of dissolved oxygen in industrial wastewater may limit populations of aerobic organisms in constructed wetlands. In most instances, these impacts will be slight enough to cause little deviation from the biology of natural wetlands.

Constructed wetlands used for treating the runoff from mining operations will differ most strongly from natural wetlands. These wetlands are continuously loaded with water having a low pH and containing high concentrations of heavy metals. However, wetland vegetation can be maintained under these conditions, and effective treatment can be obtained for many years (Brodie, *et al.*, 1993; Davis, 1995a). At present, no wetlands are being used to treat acid mine drainage in Indiana.

The Environmental Protection Agency has compiled a database on the constructed wetlands being used for municipal and industrial wastewater treatment in North America (U.S. Environmental Protection Agency, 1994). All of these projects have wastewater treatment as their primary goal, and virtually all of them list research as a secondary goal. However, the database shows that 23 of the listed projects have uses other than research. These uses include wildlife habitat (waterfowl and mammals), hunting, fishing, recreation, bird-watching, and nature study. The Des Plains River Wetland System in northeastern Illinois provides wildlife habitat as well as biking, jogging, and horseback trails for use by the general public while at the same time cleaning the wastewater passing through it (U.S. Environmental Protection Agency, 1993). Human functional utility (wastewater treatment) need not preclude the development of natural wetland functions as well as aesthetic benefits.

Constructed wetlands used for the treatment of agricultural wastewater are less likely to be similar to natural wetlands than the constructed wetlands used to treat industrial wastewater. These systems are not designed to treat water to discharge standards, but rather to reduce nutrient loads and decrease the amount of land needed for the on-farm disposal of animal wastes. Farm wastewater will not have undergone secondary treatment prior to entry into the wetland. Primary settling of solids will be accomplished in lagoons or other manure management systems, but the concentration of nutrients, ions, and organics will be extremely high relative to their concentrations in the water typically entering natural wetlands. Agricultural wastewater from livestock and dairy operations will tend to have very high concentrations of ammonia-nitrogen and high conductivity levels. These factors greatly stress the invertebrates and plants. Many native Indiana wetland plants will not tolerate these stresses, particularly if the operational depth of the wetland is greater than 15 cm (Reaves, *et al.,* 1995b). Increased operational depth places additional oxidation-reduction stress on roots that can exacerbate the impacts from other stresses. Growth will be impaired in some species, particularly in young plants during spring establishment. Therefore, a supply of freshwater is desirable to maintain soil saturation until the young plants are well established. Cattails (*Typha* spp.) and softstem bulrush (*Scirpus validus*) are particularly tolerant of the contaminant levels found in animal waste and are likely to be the dominant plants in these wetlands (Reaves, *et al.,* 1995b).

Invertebrate communities using agricultural wetlands will typically be composed of species capable of tolerating high organic levels, particularly in wetlands used for the treatment of livestock wastewater. High organic loads and low dissolved oxygen concentrations prevent the establishment of many clean water species. In systems that are not properly maintained by their operators, breakdowns occur. If high levels of fecal material enter the wetland system, flies of the family Syrphidae may become major components of the invertebrate assemblage. These flies utilize water polluted with high levels of fecal matter for reproduction. Larval Syrphid flies, called rattailed maggots, are found near the surface of these waters and are readily apparent when present in a wetland. The appearance of large numbers of these larvae is indicative of system failure.

In Indiana, free water surface treatment wetlands will typically be used in livestock operations and will tend to be less than an acre in size. Following treatment in the wetland system, the farm's wastewater will still contain relatively high levels of nutrients and ions. Invertebrate assemblages in these systems will be pollution tolerant species rather than the typical clean-water invertebrates found in natural wetlands. However, even though small and degraded when compared to natural systems, farm wastewater treatment wetlands offer some benefits to traditional wildlife. An operational constructed wetland on a dairy farm in north-central Indiana supports breeding mallards (Reaves, *et al.,* 1995b) and attracts deer. Human utility is combined with a degree of natural wetland function.

The implementation of a management strategy will have a great influence on the biology of created wetlands. During vegetation establishment, water levels must be carefully regulated (Hammer, 1994). Wetland plants have a lower tolerance to flooding when young, and careful management is necessary to insure that these young plants are not drowned. System managers should determine a hydrologic regime for routine operation, because the establishment and maintenance of water depth and hydraulic loading will have the greatest influence on wetland biology. Should water depth be too great, a pond rather than an emergent marsh will be created. Plants may develop as floating mats rather than root in the wetland bottom (Reaves, *et al.,* 1991). Extended drawdown periods may encourage invasion by facultative and upland plants, resulting in reduced vegetative cover and decreased aesthetic value when these plants die following flooding to operational depth. Operational strategies can include planned drawdowns, vegetation harvesting, or fire management to maintain the system at the desired successional stage.

Wastewater treatment wetlands must be kept wet, or they will lose the microbial community that performs the bulk of the wastewater treatment. Flooding after a substantial dry period will be followed by a substantial lag in system performance as the populations of microbes recover. The result is short-term system failure and poor water treatment until the microbial populations recover.

Agricultural wastewater treatment wetlands must be maintained as marshes, and the livestock must be kept away from them. Farm animals can denude a wetland of its vegetation and greatly reduce its treatment efficiency. Soil compaction from trampling can result in long-term damage to wetland's vegetation and to a loss of berm integrity through the formation of erosion channels. Farmers must maintain a solids removal system as a pretreatment for wastewater entering these systems.

The functional life of most wastewater treatment wetlands is determined by the length of time it will take the wetland basin to fill with sediment. Elimination of solids from the wastewater stream prior to entry into a constructed wetland will extend the operational life of the system. Additionally, large masses of solids high in organic content may move through wetland systems relatively intact. Dissolved oxygen levels around the mass quickly drop to near zero, and both the aerobic decomposition of organic matter and nitrification are greatly reduced, leading to system failure (Reaves, *et al.,* 1995a) if not promptly corrected.

CONCLUSIONS

Wetlands lost through time are gone and can never be replaced. For example, many major airports and much of the land area of both the District of Columbia and Chicago once were wetlands (Mitsch and Gosselink, 1993). Society will not allow these areas to be returned to their natural state. Since the wetlands that have been lost can neither be regained nor replaced, other alternatives must be explored to develop and maintain vital wetland resources. Slowing the rate of natural wetland loss and improving degraded natural wetlands are worthwhile endeavors, but they will not eliminate the losses. Created and restored wetlands are an option for regaining some of the ecological functions lost with the elimination of such a large percentage of the nation's natural wetlands.

Created wetlands possess unique aspects related to the purpose of their creation. Certain functional aspects of created wetlands may exceed those found in natural wetlands, particularly for flood control, recreation, and water quality. However, optimum performance in one functional area usually leads to reduced performance in others. Habitat functions typically will be less in created wetlands. Alterations in hydroperiod, water depth, and nutrient and contaminant loadings to these wetlands exert influences on biotic development. The differences between created and natural wetlands become greater as the quality of the water processed by the created wetlands declines. Therefore, floral and faunal characteristics may differ from morphologically similar natural wetlands in the region. Though different from natural wetlands, created wetlands may offer ecosystem services similar to those found in natural wetlands as well as functional utility for humans.

In most instances, restored wetlands exhibit biological characteristics similar to natural wetlands of comparable size. Within 10 years, restored wetlands functionally resemble comparably sized natural wetlands from the same region. Unfortunately, many of the restored wetlands found on agricultural land may be returned to agricultural production at the end of the government programs that allowed their restoration. Farmers are not obligated to maintain the wetlands past the end of the initial period. The potential for reconversion is less for reclaimed mine lands and highway projects, but this potential still exists. For restoration of wetlands to be a viable, long-term approach to increasing wetland acreage, some type of permanent conservation easement must be developed for these lands.

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