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IMPROVING THE SUCCESS OF WETLAND CREATION AND RESTORATION WITH KNOW-HOW, TIME, AND SELF-DESIGN^{1,2}

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Abstract. The creation and restoration of new wetlands for mitigation of lost wetland habitat is a newly developing science/technology that is still seeking to define and achieve success of these wetlands. Fundamental requirements for achieving success of wetland creation and restoration projects are: understanding wetland function; giving the system time; and allowing for the self-designing capacity of nature. Mitigation projects involving freshwater marshes should require enough time, closer to 15–20 yr than 5 yr, to judge the success or lack thereof. Restoration and creation of forested wetlands, coastal wetlands, or peatlands may require even more time. Ecosystem-level research and ecosystem modelling development may provide guidance on when created and restored wetlands can be expected to comply with criteria that measure their success. Full-scale experimentation is now beginning to increase our understanding of wetland function at the larger spatial scales and longer time scales than those of most ecological experiments. Predictive ecological modelling may enable ecologists to estimate how long it will take the mitigation wetland to achieve steady state.

Key words: *achieving successful wetland mitigation; creating wetlands; ecological engineering; ecological modelling; freshwater marshes; functional analysis of wetlands; mitigation of wetland loss; Olentangy River Wetland Research Park, Ohio; wetland succession.*

INTRODUCTION

The way in which we measure “success” of created or restored wetlands and our ability to achieve success are two issues that have come under increased discussion in recent years by wetland scientists and managers. Success in the general sense here means the establishment of a biologically viable and sustainable wetland ecosystem. Some call a wetland a success when it replaces the functions lost in a wetland that is being replaced; others would gauge success of a created or restored wetland against natural reference wetlands in the region. Unfortunately, there has been little formal published follow-up of the poorly named (see Renner 1994) “mitigation wetlands” that are constructed to replace wetlands that are unavoidably lost and there are few satisfactory methods for assessing replacement of the functions lost with the original wetland (Mitsch and Gosselink 1993). Regulators and consultants have chosen to use simple indicators of “success” to expedite the process and to keep monitoring costs low. Normally 3–5 yr of simple once- or twice-per-year monitoring is required, with easily measured parameters such as plant lists, animals witnessed, and percentage vegetation cover as the overall indicators. Assessing success is then based on comparing these easily measured parameters with a relatively simple set of criteria that were stipulated in the original permit for

the project; these criteria may or may not accurately reflect wetland function.

After reviewing pertinent literature, we discuss three fundamental requirements for achieving success of wetland creation and restoration projects: understanding wetland function, giving the system time, and appreciating the idea of self-design. Our hypothesis is that most attempts to measure and achieve success of created and restored wetlands—caused by a lack of application of good wetland science to the problem and compounded by the existing construction-schedule-driven process—are flawed because of misunderstanding or misapplication of these factors. We then argue that ecosystem-level research and ecosystem modelling may provide better guidance on when created and restored wetlands can be expected to comply with criteria that measure their success.

STUDIES ON WETLAND MITIGATION SUCCESS

Most studies suggest that there is much room for improvement in the building of wetlands. Maguire (1985) used area, vegetative cover, and implementation of permit conditions to estimate mitigation success in Virginia and found that only 50% of 23 mitigation wetlands were “successful.” In most unsuccessful cases, the mitigation project had not been implemented. An additional study by Reimold and Cobler (1985) conducted for the U.S. Environmental Protection Agency (EPA) gave similar results. Glubiak et al. (1986) and Quammen (1986) both suggested the need for better management of mitigation wetlands. Additionally Glubiak et al. (1986) predicted that while the protection

¹ Manuscript received 10 June 1994; revised 3 April 1995; accepted 12 April 1995.

² For reprints of this group of papers on wetland mitigation, see footnote 2, page 33.

of wetlands through a permit process—Section 404 of the Clean Water Act enacted by the U.S. Congress in 1972—was somewhat effective, it would not prevent wetland area losses as effectively as it should.

In the mid-1980s some scientists involved in wetland restoration and mitigation believed that mitigation was working (Harvey and Josselyn 1986), while others suggested that more research needed to be done and that, if not properly conducted, a wetlands mitigation project could easily fail (Race 1986). Kusler and Groman (1986) raised concerns about the granting of Section 404 permits to contractors when alternative sites are available. Many questions and issues were raised by Kusler and Groman (1986) and Golet (1986) regarding permitting processes and the actual success of wetland mitigation projects. Their major issues were: When should destruction/damage and subsequent creation/restoration be permitted? How is the damage to the original system measured and how is the creation/restoration deemed sufficient? Golet (1986) suggested that under no circumstances should damage to a wetland be allowed unless there is absolutely no alternative.

While there are many factors that could be used to monitor progress of mitigation wetlands, observing vegetation has often been the easiest and probably the most common method (see, e.g., Wentworth et al. 1988, Jarman et al. 1991, Atkinson et al. 1993). This concept has already been codified in several parts of the country. For example, in Massachusetts, vegetation cover of $\geq 75\%$ is the major success criterion, even if vegetation composition is very different from that of the original wetland (Jarman et al. 1991). Reinartz and Warne (1993) argue that while vegetation cover may be an easy measure of success, it is a poor indicator of function.

Recent investigations of wetland mitigation projects, as a greater number of mitigation sites have become available for scrutiny, generally reinforce the early concerns. For example, Erwin (1991) found that, of 40 mitigation projects in south Florida involving wetland creation and restoration, only about half of the required 430 ha of wetlands had been constructed and that 24 of the 40 projects (60%) were judged to be incomplete or failures. The most significant problems identified with created wetlands were improper water levels and hydroperiod. Sifneos et al. (1992) collected information from permits on Louisiana, Alabama, and Mississippi wetland mitigation projects and found that in Louisiana (their primary area of interest) only 8% of areas impacted by dredge-and-fill activity was compensated for, and $>50\%$ of the areas receiving permits covered <0.4 ha. Additionally, only 10% of the mitigation wetlands were monitored by at least one site visit. The lack of standardized record-keeping from state to state made the study difficult. The study suggests that follow-up monitoring and information on wetland functions be required in future permit decisions. Kentula et al. (1992) investigated several mitigation wetlands in Or-

egon and Washington and found a net loss in wetland area of 43% for Oregon and 26% for Washington. Data were either incomplete or of poor quality and up-to-date standardized databases were recommended. In a similar study, but without field checks, Holland and Kentula (1992) examined >300 Section 404 permits issued in California from 1971 to 1987 and found that while 1260 ha of compensatory mitigation (wetland creation, restoration, or preservation) had been required for impacts to 1180 ha of wetlands over that period, there was little follow-up of the permits and fewer than one-third (31.5%) required any field monitoring. Confer and Niering (1992) found that when comparing five created freshwater marshes with five nearby natural ones, the created marshes generally had greater water depth and thus more open water. They state that most of their created wetlands were highly dependent on highway runoff as a water source. Roberts (1993), quoting several ecologists, summarizes the skepticism by calling wetland trading "a loser's game."

IMPROVING THE ODDS OF WETLAND SUCCESS

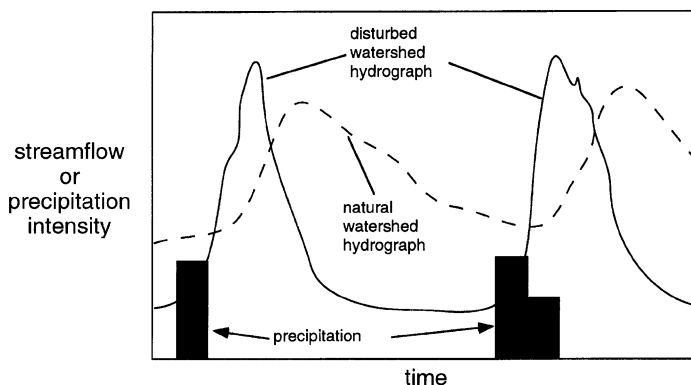
We propose three general concepts that will need attention of those involved in wetland mitigation if we are truly going to address the issue of creating and restoring viable wetland ecosystems: (1) Understand wetland function; (2) Give the system time; and (3) Allow for the self-designing capacity of nature. These points are discussed in detail below.

Understand wetland function

Mitsch and Cronk (1992) proposed that the "know-how" of building and restoring wetlands is based on an empiricism with little scientific backing, and is learned and relearned every time a new wetland is built. Wetland restoration and creation are relatively new fields and few engineers are trained in ecology and few ecologists have any experience in engineering methods. Engineers, consultants, scientists, and landscape architects can, and frequently do, claim to be experts with little experience or little knowledge of wetland ecology; without any certification standards for individuals involved in wetland creation and restoration, projects are often carried out by organizations and individuals not well versed in wetland ecology. A relatively high number of "failures" of mitigation wetlands can be attributed to a general lack of understanding of first principles of wetland science.

For example, an understanding of wetland hydrology as the fundamental forcing function of wetlands is well understood conceptually (Mitsch and Gosselink 1993) yet not always put into practice by many of those involved in wetland mitigation. The importance of hydrology is discussed in detail in a companion paper by Bedford (1996). Erwin (1991) pointed out that a number of Florida wetlands were considered failures in his Florida study because they lacked suitable hydrology. In so-called "on-site mitigation," wetlands are devel-

FIG. 1. Comparison of a hypothetical stream hydrograph in a natural watershed vs. one from a highly disturbed urban or suburban watershed. Placing the wetland in either of these two watersheds would probably lead to significantly different wetland structure and function.



oped in watersheds near the wetlands being drained or lost; their success is often problematic because of the usual proximity of the mitigation project to a human-altered landscape and the accompanying changes in hydrologic conditions. In these settings, created and restored wetlands can be subjected to "flashy" streams and human-regulated hydrologic conditions. In urban and suburban settings, floods are often greater and occur more quickly after precipitation; low-flow conditions are drier than in a "natural" hydrology (Dunne and Leopold 1978). Both of these conditions lead to generally greater water level fluctuations compared to those in more natural settings (Fig. 1). Unpredictable and rapidly fluctuating hydrology can lead to wash-outs, scouring, planting failure, and animal and macroinvertebrate emigration, leading to decreased biodiversity and even loss of water quality function.

Give the system time

A flaw in the measurement of mitigation wetland success is the limited amount of time that regulators and the land development process allow for newly created wetlands to develop before passing judgment. The legal and economic necessities seem to dictate the ecological patterns of nature, encouraging "quick-fix" wetlands while not allowing for the stochasticity of nature. Engineers have long recognized the probabilistic nature of hydrologic events (e.g., precipitation and streamflow) yet relatively deterministic indicators such as wetland plant viability, open water area, endangered species, and waterfowl are expected to develop in a relatively short time span, usually 5 yr. The very best that we can have after 5 yr of monitoring a mitigation wetland is a general idea of the wetland's ecological trajectory and even less understanding of its function.

In one of the longest-running documentations of a constructed wetland in this country, an 8-ha freshwater tidal marsh (Windmill Point), was constructed in 1974–1975 within dikes in the James River in eastern Virginia, USA. Early indications, from 1978 to 1982, considered the wetland a success as it supported a diversity of herbaceous vegetation typical of tidal freshwater

marshes (Newling and Landin 1985). At that time the monitoring was referred to as "long-term." But the dikes were breached in 1986 due to flooding on the James River, eliminating the vegetation and submersing the wetland in the river (Landin 1994, *personal communication*). Sixteen years after construction the project could be termed by some as a hydrologic and ecological failure if long-term survival of the wetland was one of its goals.

Because of the stochastic nature of hydrologic events and the slow development of ecosystems, sometimes in spurts, sometimes in the slow process of recruitment and growth, the 5-yr time horizon can be viewed as arbitrary and probably much too short. As ecological models show (see e.g., Jørgensen 1994), the further initial conditions are from steady-state, the longer it will take for that system to reach or approach steady state (Fig. 2). Short monitoring times favor measuring success with transplanted vegetation and pioneer organisms; long-term success is less dependent on these initial conditions.

Allow self-design

There are two general approaches for introducing vegetation (and other organisms) in wetland creation and restoration projects. One is the "designer" approach of introducing species and expecting their survival in Gleasonian zones, akin to gardening or landscape architecture. The other emphasizes the "self-design" or "self organization" capacity of Nature to both recruit species on its own and to make choices from those species introduced by humans (Odum 1989, Mitsch 1993). In self-design the emphasis is on the introduction of as many species as possible, knowing that natural forces will help in the ultimate design by choosing the most appropriate species. Self-design also recognizes the importance of natural colonization of species in wetlands.

In one of the few studies to make a preliminary comparison of these two general approaches, Reinartz and Warne (1993) compared 11 created wetlands in southeastern Wisconsin that were naturally colonized with 5 wetlands in the same region where 22 species were

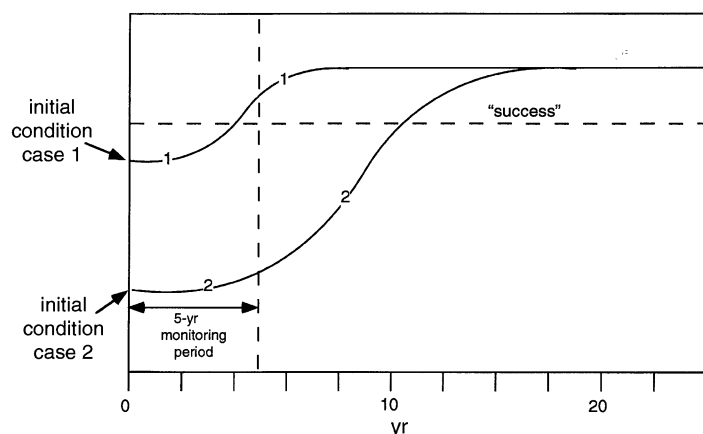


FIG. 2. Hypothetical comparison of the pattern of one wetland criterion for "success," e.g., percentage vegetation cover, for two different initial conditions at the same hypothetical wetland site. In Case 1 the wetland would be considered a "success" after 5 yr, while in Case 2 the wetland would be considered a "failure." Each wetland case could end up eventually at the same level, but well after 5 yr. In reality, a multiplicity of criteria would be used in this comparison.

introduced by seeding. The diversity and richness of plants in the colonized wetlands increased with age, size, and proximity to the nearest wetland source even though *Typha* spp. comprised 15% of the vegetation for 1-yr-old wetlands, and 55% for 3-yr-old wetlands. Seeded wetlands had a high species diversity and richness after 2 yr and *Typha* cover in the seeded sites was lower than in the naturally colonized sites after a 2-yr period.

Many studies to date (e.g., Confer and Niering 1992, McKnight 1992), especially those on restoration of non-coastal wetlands, have probably over-predicted—because of short time horizons and small spatial scales—the survivability of transplanted species in "designer" wetlands. (An exception to this short time horizon is the long-term observation of Frenkel and Boss [1988], through aerial photography, of the spread of *Spartina patens* in areas along Oregon's coastal wetlands.) With enough time and space, introduced species may be less successful than we initially believed. A better idea is to give the wetland system many possibilities through multiple-seeding, multiple-transplanting, and establishment of hydrologically open systems; this allows nature to participate in the wetland design.

PROVIDING THE NEEDED RESEARCH TOOLS

In addition to the above suggestions for wetland managers and ecological engineers who are attempting to design and monitor wetlands, there are some important approaches that wetland scientists can use to reduce the uncertainty of wetland mitigation.

Select the proper experimental scale

The limited ability of science as we generally practice it to both understand and solve our dilemmas in natural resource conservation was argued by Ludwig et al. (1993) and debated in the pages of *Ecological Applications* (Levin 1993). Taking the cue from Holling (1993) and Costanza (1993) in that discussion, we question whether reductionistic experimental science, with its short time scales (often the time required for

a Ph.D. dissertation) and its small spatial scales (often in laboratories or small field plots) can correctly prescribe how to build large wetlands. A holistic systems approach, with the appropriate time and space scales, should at least have equal emphasis.

As one example, a number of studies of wetland function were carried out with four full-scale constructed wetlands at the Des Plaines River Wetland Demonstration Project in northeastern Illinois (Sanville and Mitsch 1994). Hydrologic conditions were varied for high- and low-flow conditions for entire wetlands (average size: 2.4 ha), not just experimental plots; the studies were carried out over 3 yr. Researchers had important findings in estimating detention and mixing (Kadlec 1994), water quality function (Hey et al. 1994, Phipps and Crumpton 1994), sedimentation (Brueske and Barrett 1994, Fennessy et al. 1994a), vegetation development (Fennessy et al. 1994b), aquatic metabolism (Cronk and Mitsch 1994a, b), and avian success (Hickman 1994) in created wetlands, most as a function of hydrology.

In a comparison of two natural tidal marshes with a 0.65-ha constructed marsh in coastal Virginia 5 yr after construction, Havens et al. (1995) found seasonal differences in fish and shellfish abundances between natural and constructed marshes, with lower numbers in the latter. They attribute the differences to relative lack of organic carbon and less morphometric heterogeneity (e.g., stream rivulets, microtopography) in the created marsh.

We recently initiated a full-scale comparison of "self-design" and "designer" approaches to wetlands at the Olentangy River Wetland Research Park at The Ohio State University (Fig. 3; Mitsch and Wu 1995, Mitsch 1995). In one newly constructed wetland basin (1 ha), we planted, in approximately the stratification that we would find in nature, ≈ 2500 individuals representing 14 species of wetland plants. In an identical constructed wetland basin nearby, we planted nothing. Hydrologic conditions are being maintained as similar as possible in the two basins and there is no predeter-



FIG. 3. The Olentangy River Wetland Research Park at The Ohio State University in Columbus, Ohio, USA, is a whole-ecosystem long-term experiment begun on 14 May 1994 with the planting of one of the deep-water marshes shown in foreground (right basin) with ≈ 2500 plants representing 15 wetland species. The second deep-water marsh (left basin) remains unplanted. Each basin is 1 ha in size and water is supplied by pumps in the lower right-hand corner of the site to create a similar hydrology for each basin. The Olentangy River, shown flowing from bottom right to the top of the picture (with the university ≈ 0.5 km downstream of the site on the horizon of the picture), is the source of the water, which is pumped in proportion to the river flow in the same patterns for each wetland basin. The photo was taken in November 1993 prior to the introduction of water to the wetlands (photo by Mark Myers, Apex, Columbus, Ohio).

mined completion date to our experiment. We believe that our "experiment" is closer to the scale necessary for documenting the forces, e.g., plant recruitment, geese and muskrat invasions, etc., that influence eco-

system development. Working at this full scale precludes extensive replication because of land and construction costs, yet our understanding of ecosystem development and other wetland functions will come only

from studying spatial scales and longer time scales to supplement traditional ecological experiments.

Develop predictive modelling

Little attention has been paid to ecological modelling—the one tool that can expand the time horizon—in predicting success of created and restored wetlands. While this approach must be used with caution and proper qualifications, it enables ecologists to project into the future and estimate how long it will take the mitigation wetland to achieve some type of steady state. A few publications (Costanza and Sklar 1985, Mitsch et al. 1988, Mitsch 1994) have reported on the state of the art of simulation modelling in wetland ecology, but this powerful “systems” tool has rarely been used to predict mitigation success. Stochastic inputs, adaptive model structure (Jørgensen 1994), higher-order modelling languages (e.g., STELLA) and spatially dynamic models are useful advances in ecological modelling, but simple-structure models that aggregate components into overall variables such as “vegetation” or “nutrients” can be just as effective (Mitsch et al. 1995). In an application of modelling for a mitigation project in central Ohio, Niswander and Mitsch (1995) used simulation models both to “fill in” information to make calculations about ecosystem function (phosphorus retention) of a created freshwater marsh and to “enhance the time horizon” by predicting one structural aspect of this project well into the future—the survival of planted wetland trees over the next 50 yr. Modelling, of course, will not provide an exact prediction of conditions well into the future but, when used with good wetland ecology and sufficient field monitoring, it can provide another tool for those interested in predicting the future of created and restored wetlands.

CONCLUSIONS

There is optimism that wetlands can be created and restored and that wetland function can be replaced, despite a recent spotty record in the United States with the mitigation of wetland loss. The spotty record is due, in our opinion, to little understanding of wetland function by those constructing the wetlands, insufficient time for the wetlands to develop, and a lack of recognition or underestimation of the self-design capacity of nature. Understanding wetlands enough to be able to create and restore them requires a substantial training in plants, soils, wildlife, hydrology, water quality, and engineering. We should give mitigation projects involving freshwater marshes enough time, closer to 15–20 yr rather than 5 yr, before judging their success. Restoration and creation of forested wetlands, coastal wetlands, or peatlands may require even more time. For example, the restoration of certain coastal salt marshes has been suggested to require at least 50 yr (Frenkel and Morlan 1991). Finally, we should recognize that Nature remains the chief agent of both self-

design and ecosystem development; humans are not the only participants in the design process.

Science will need to make significant contributions to the process of reducing our uncertainty about predicting wetland success. Wetland mitigation needs to become part of an applied ecological science, not a technique that is relearned each time without theoretical underpinnings. Scientists need to make the connections between structural measures (e.g., vegetation density, diversity, productivity) and functions such as wildlife use, organic sediment accretion, or nutrient retention in quantitative and carefully designed experiments. Simply having a list of plant species is inadequate for regulators or managers to estimate ecosystem function. Simulation models and experimentation at the proper spatial and temporal scales should be able to help us predict the behavior of these wetlands and estimate proper designs.

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