MEASURING MITIGATION

A Review of the Science for Compensatory Mitigation Performance Standards

April 2004

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April 2004

Measuring Mitigation: A Review of the Science for Compensatory Mitigation Performance Standards

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EXECUTIVE SUMMARY

Attention to the federal compensatory mitigation program has been growing over the years and became heightened after the release of a National Academy of Sciences 2001 report evaluating the success of compensatory mitigation to achieve no net loss of function of the nation's wetland resources. The report concluded that "the goal of no net loss of wetlands is not being met for wetland functions by the mitigation program, despite progress in the last 20 years," and was accompanied by findings and recommended measures to improve compensatory mitigation. One such measure recommended that clearly specified performance standards be adopted to enhance mitigation effectiveness.

The NAS report and subsequent documents catalyzed reflection and analysis among the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and other federal agencies entrusted with the protection of freshwater and coastal wetlands. Among these subsequent activities, an interagency task force developed the "National Wetlands Mitigation Action Plan," which incorporated many of the recommendations of the NAS study and laid out a series of actions and time lines to improve the ecological performance and results of wetland compensatory mitigation, including a commitment to analyzing the existing body of literature on biological indicators and functional assessments for their potential use as the basis for compensatory mitigation performance standards. From such analysis, the federal agencies, working with states and tribes, will develop guidance for creating performance standards for monitoring and adaptive management of wetland compensatory mitigation projects—an action that is set to be completed by the agencies by 2005.

This report on mitigation performance standards attempts to capture the status of the peer-reviewed literature on selected biological indicators, abiotic factors, functional assessments, and developmental trajectories to help evaluate the success of compensatory mitigation within a constrained regulatory time frame. A better understanding of potential wetland pathways could help in developing indicators along a regulatory monitoring time line that will illuminate whether a wetland site is on the path to functionality. Some of these indicators have the potential to be tailored to evaluate mitigation performance at early stages. This report also identifies holes in the literature base where further research would be beneficial. Ultimately, this report may provide the background research to help the federal agencies in their development of performance standards and monitoring guidance by 2005.

This report examines the peer-reviewed literature on a number of selected parameters (or indicators) that might be adapted for performance standards. These parameters comprise biotic factors, including amphibians, fish, macroinvertebrates, birds, algae, mammals, and vegetation; abiotic factors, including hydrology, soils and sediments, and nutrients; and a selection of landscape perspectives and methodologies, including the hydrogeomorphic (HGM) approach, developmental trajectories, and lessons from general restoration reviews.

Many of the indicators reviewed hold promise for use in a performance standard assessment. As a body, the literature reflects the relative youth of the science of wetland restoration and creation—research is dominated by studies of wetland mitigation sites younger than 10 years old. Few long-term monitoring studies exist—research typically takes place over just a few growing seasons or two years. Most long-term studies suggest that an appropriate monitoring time frame far exceeds the typical five-year regulatory time frame expected in mitigation projects.

This report finds a number of recurring themes that address the challenges and recommendations for potential performance standards:

- **Baseline information.** Perhaps the most widely asserted theme is the profound importance and critical deficiency of baseline information. Indices of biological integrity require the collection of baseline data, as do functional assessments. Collecting baseline information can be costly and time-consuming, and therefore is less represented in literature than researchers assert it should be.
- **Landscape-level perspective.** An emphasis on a landscape-level perspective for monitoring and assessment is widely endorsed by the scientific community. Many taxa are intimately intertwined with the landscape beyond a particular wetland mitigation site.
- **Standardization.** Many studies advocate for a standardized system of data collection and access, uniformity of language and definitions, and better standardization of sampling protocols

- **Transferability.** A challenge in the development of national performance standards is the limited transferability of findings from region to region or from wetland type to wetland type.

The findings in the literature suggest that performance standards can be developed and implemented. As the articles reviewed for this report indicate, each biological and abiotic metric offers its own set of strengths and weaknesses for use as indicators of wetland condition and functional performance. However, the strategic use of a combination of metrics could accentuate the strengths in some while minimizing the weaknesses in others. Through a well-chosen collection of performance standard metrics, regulators may ultimately be able to measure the ecological viability of functions in created, restored, and enhanced wetlands to understand better whether the site is on its way to becoming a self-sustaining wetland to replace the one lost.

INTRODUCTION

A CALL FOR PERFORMANCE STANDARDS

A heightened attention to the success of compensatory mitigation has been growing over the years, marked notably by a National Academy of Sciences 2001 report evaluating the success of compensatory mitigation to achieve no net loss of function of the nation's wetland resources. The principal findings of the academy's National Research Council Committee on Mitigating Wetland Losses concluded that "the goal of no net loss of wetlands is not being met for wetland functions by the mitigation program, despite progress in the last 20 years." The council presented a number of findings and recommended measures to be taken by the federal agencies and others to improve compensatory mitigation. Among its findings, the NRC committee found that "performance expectations in Section 404 permits have often been unclear, and compliance has often not been assured nor attained." The committee recommended that clearly specified performance standards be adopted to enhance mitigation effectiveness. These performance standards, suggested the committee, should measure the ecological viability of the replaced functions and should indicate whether a wetland is already or will become a self-sustaining wetland. The committee cautioned, however, against too heavy a reliance on vegetation measures of performance, because vegetation metrics potentially would fail to reflect wetland conditions from the perspective of ecological function. The same year, the General Accounting Office released a study of "in-lieu-fee" mitigation (a form of compensatory mitigation in which the permittee pays a fee to a third party to conduct mitigation offsite, in lieu of onsite mitigation), which found that success of in-lieu-fee mitigation was impossible to assess because data were not collected and no standards were set. The GAO recommended that the federal agencies, led by EPA, establish ecological success criteria for in-lieu-fee mitigation.

The NAS's pivotal report, and the GAO's supporting conclusions catalyzed reflection and analysis among the U.S. Environmental Protection Agency, the U.S. Army Corps of Engineers, and other federal agencies entrusted with the protection of freshwater and coastal wetlands. Among these subsequent activities, an interagency task force developed the "National Wetlands Mitigation Action Plan" (December 24, 2002), which incorporated many of the recommendations of the NAS study and laid out a series of actions and time lines to improve the ecological performance and results of wetland compensatory mitigation.

The action plan specifically addresses the NAS call for performance standards. In the action plan, the agencies commit to analyzing the existing body of literature on biological indicators and functional assessments for their potential use as the basis for compensatory mitigation performance standards. From such analysis the federal agencies, working with states and tribes, will develop guidance for creating performance standards for monitoring and adaptive management of wetland compensatory mitigation projects—an action that is set to be completed by the agencies by 2005.

This report on mitigation performance standards follows in the shadow of these documents. The report attempts to capture the status of the peer-reviewed literature on selected biological indicators, abiotic factors, functional assessments, and developmental trajectories to help evaluate the success of compensatory mitigation within a constrained regulatory time frame. A better understanding of potential wetland pathways could help in developing indicators along a regulatory monitoring time line that will illuminate whether a wetland site is progressing toward functionality. Some of these indicators have the potential to be tailored to evaluate mitigation performance at early stages. This report also identifies holes in the literature base where further research would be beneficial. Ultimately, this report may provide the background research to help the federal agencies in their development of performance standards and monitoring guidance by 2005.

PERFORMANCE STANDARDS AND THEIR POTENTIAL ROLE IN WETLAND MITIGATION

Performance standards (often known as success criteria, success standards, release criteria, performance indicators, measures of success) are observable or measurable attributes or outcomes of a compensatory mitigation project that help determine whether the project meets its goals and objectives (this is the definition used by the NAS study). A number of biological metrics have been suggested for their use as wetland performance standards including, for example, measures of herbaceous plant density, cover by exotic species or native species, aquatic invertebrate diversity, and composition of fish assemblages. Abiotic metrics, such as soil conditions, hydrologic criteria, and nutrient thresholds have also been suggested.

Performance standards are criteria used to evaluate how a compensatory mitigation site is performing after it has been established. They are therefore different from design criteria or design specifications, which guide how a site will be constructed. Although one might envision a design specification as a "year-zero performance standard," design specifications are outside the scope of this review.

The NRC Committee on Mitigating Wetland Losses envisioned performance standards to be an integral part of the compensatory mitigation process. Performance standards would be developed from mitigation goals and objectives. Mitigation carried out according to specifications identified by a wetland permit would be subject to a clear set of performance standards by which the regulatory agency(ies) could identify the extent to which the mitigation wetland is functioning as a replacement for the wetland lost. They would also provide information on the wetland's progress toward full function or "functional equivalency" of the lost wetland. Moreover, performance standards could be useful for assessment of enforcement actions when mitigation fails to live up to the standards outlined in the permit.

The challenge is to develop and implement scientifically based performance standards that will work within a regulatory structure. Where performance standards have been required in the past, they typically have been too vague to be enforceable or too focused on vegetation. Conversely, the NRC committee and other scientists in the field emphasize that performance standards should be clear, measurable, and pertain to the ecological functioning of the replacement wetland.

SCOPE AND ORGANIZATION OF THIS REPORT

This report examines the peer-reviewed literature on a number of selected parameters (or indicators) that might be adapted for performance standards. These parameters comprise biotic factors, including amphibians, fish, macroinvertebrates, birds, algae, mammals, and vegetation; abiotic factors, including hydrology, soils and sediments, and nutrients; and a selection of landscape perspectives and methodologies, including the hydrogeomorphic (HGM) approach, developmental trajectories, and lessons from general restoration reviews. The report is organized around these groupings, although categorization is never clean when addressing biological systems. Many other groupings could have been used, and many articles fall into more than one category. For example, a large number of articles address equally both plants and soils, and likewise, the literature on fish and vegetation are intertwined. In cases where an article could fall into many different categories, this report, reviews them only once. The reader is encouraged, however, to peruse the tables in Appendix D to find additional articles reviewed in other sections.

Similarly, a great number of different assessment methodologies are used within various studies of the biotic or abiotic parameters, such as indices of biotic integrity (IBIs), the U.S. Fish and Wildlife Service's HEP methodology, and the hydrogeomorphic (HGM) approach to wetland evaluation, but we found that very few articles in the peer-reviewed literature review the methodologies themselves. One possible exception to this is HGM, which does have a peer-reviewed literature base, and is therefore pulled out and addressed independently. Even with HGM, however, the bulk of review of this methodology falls into the category of grey literature, including agency reports and manuals. These documents are extremely valuable, however, they lie outside the scope of this report.

The body of the report presents a concise overview of each parameter in relation to its potential for performance standards. This overview includes, where applicable, points of consensus or contention in the literature base, as well as trends identified by the reviewers. It then steps back and offers some larger conclusions about performance standards in general, based on the findings of the peer-reviewed literature. These conclusions do not make recommendations, but rather they highlight cross-cutting findings or challenges that may enable or deter implementation of comprehensive performance standards within a regulatory framework. Appendices A, B, and C provide detailed summaries of the articles reviewed (following the categorization used in the body of the report), and Appendix D presents tables of the literature reviewed. These tables are grouped first by parameter, and then by geographic region.

While this report contains many self-designed limitations, its overall intent is to bring together a large portion of the current day peer-reviewed literature on potential indicators that could be used for performance standards.

BIOTIC PARAMETERS

AMPHIBIANS

Some scientists advocate the use of amphibians as biological indicators because of their sensitivity to habitat conditions. The vulnerability of amphibians to wetland conditions is related to their unique biological characteristics, including permeable skin exposed to water and the atmosphere, dependence on wetlands for breeding, structure of embryos in unprotected egg masses, the requirement of a sufficiently stable hydroperiod to promote larval survival but not the invasion of fish, and limited dispersal abilities (U.S. EPA 2002). Also, because many amphibians have an extended terrestrial portion of their life cycle, they can be used to assess the condition of the combined wetland-upland complex, including landscape fragmentation (U.S. EPA 2002, Semlitsch 2000).

The studies reviewed for this report indicate that although some amphibian metrics may be good indicators of wetland health on a regional scale the use of amphibians as indicators of individual wetland health may be limited (U.S. EPA 2002; Adamus et al. 2001; Gibbs 1993, 2000; Semlitsch 2000). A chief consideration is that amphibian populations fluctuate greatly among years, at times for no identifiable reasons (Pechmann et al. 1991, Cohn 1994). Therefore, short-term studies may be misleading if presence or absence of amphibian species at individual wetlands is used as a metric (Pechmann et al. 1991, Cohn 1994, Semlitsch 2000, U.S. EPA 2002, Babbitt and Tanner 2000). Factors contributing to population fluctuations include annual variation in meteorological conditions—including drought that dries up ponds before amphibian eggs can mature, or before larvae can metamorphose, or before juveniles can mature and exit ponds—or flood years in which high water levels temporarily link formerly fish-free wetlands to water bodies containing fish. In addition, not all amphibians breed every year (e.g., drought or low-temperature years), thus an unknown portion of the population might not visit the wetland for breeding in a given year (Semlitsch 2000, Adamus et al. 2001). Simply because amphibians are not sampled in a given year does not mean that they are absent from the wetland (Cohn 1994, Gibbs 1993). Some amphibians are very cryptic and exist in low numbers, such as the eastern spadefoot toad *(Scaphiopus holbrookii),* that breeds irregularly under specific weather conditions. Certain descriptors, however, may be useful criteria for wetland performance standards; they include relative proportion within taxa, animal condition (length/weight ratios), and physical health (abnormalities), among others (U.S. EPA 2002).

Efforts to separate natural from human-induced causes impacting populations are confounded by many known and unknown factors. Amphibians may exist in metapopulations, such that a currently unused wetland might appear suitable but awaits future recolonization from another nearby wetland (Gibbs 1993, 2000). The cumulative loss of small wetlands in clusters may result in the eventual extinction of many wetland species (Richter and Azous 1995, Paton and Crouch 2002), especially turtles (Gibbs 1993). Sensitivity to fragmentation varies among studies showing landscape effects (Hecnar and M'Closkey 1996, Kolozsvary and Swihart 1999, Gibbs 2000), and lack of landscape effects (Gibbs 1993). Variation among studies may be due to variation by region, taxa, or study duration.

Many types of amphibian monitoring require substantial resources in terms of labor and equipment. Because wide population fluctuations are typical of amphibians, long-term sampling is required, well beyond the 3–5 years typically required by regulatory agencies in the United States (Petranka et al. 2003). Few long-term amphibian studies have been published, however, thus few data exist to evaluate long-term studies in natural and altered settings (Hecnar and M'Closkey 1996, Adamus et al. 2001, Cohn 1994). A variety of capture techniques may be required to assess all species and life stages in a given wetland (Kolozsvary and Swihart 1999, Olson et al. 1997, Semlitsch 2000, U.S. EPA 2002). Particularly in southern regions, sampling throughout the year may be required to get a representative picture of species richness and distribution (Babbitt and Tanner 2000, Paton and Crouch 2002). Finally, because the amphibian fauna differs among regions, results cannot necessarily be extrapolated to other regions, and a standard may have to be developed and validated for application in each new area (U.S. EPA 2002)—a finding not relegated only to amphibian taxa, however, but common in other potential wetland indicators as well.

The studies reviewed for this report indicate that in many cases it is possible to relate the distribution and abundance of amphibians to wetland characteristics such as hydroperiod, vegetation, and water quality. Several of the reviewed studies indicate that amphibian communities differ between natural and mitigated wetlands, suggesting that mitigation efforts do not accurately replicate the habitat conditions in natural pools. For example, in southcentral Florida, where an extensive marsh system was drained to create a cattle ranch, the existing marsh system was replaced by upland habitat and a series of isolated pools. The authors of the study speculated that as a result, anuran species composition shifted to those more strongly associated with wetlands lacking fish predators (Babbitt and Tanner 2000). Four created ponds constructed in North Carolina to mitigate for those lost to development could not hold water. Consequently, they were lined with plastic and became permanent ponds, while the original ponds had been temporary. Toward the end of the study, the community structure of adult and juvenile amphibians differed among and between the created pools and between the created pools and the reference site (Petranka et al. 2003). Amphibian species richness in South Carolina exhibited a unimodal pattern along a hydroperiod gradient with wetlands that contained water for 8–10 months of the year having the greatest species richness (Snodgrass et al. 2000). The driving force behind species composition between natural and created wetlands appears to be hydrology and related substrate and vegetation.

Amphibians have a place in wetland monitoring. Amphibians are widely considered charismatic relative to most invertebrates, and thus it may be easier to gain public support or participation for monitoring programs. Furthermore, amphibian adults are relatively easy to identify, which makes them attractive for monitoring programs. Amphibian eggs and larvae are more difficult to identify, but each of these individually, or in combination offers potential for developing criteria of value (Olson et al. 1997, U.S. EPA 2002).

FISH

The reviewed literature indicates that fish community characteristics, including composition, composition variability, species richness, fish density, abundance, size, and length, can be effective indicators of differences among wetlands with respect to hydrologic conditions (including salinity, temperature, and velocity), hydrogeomorphic attributes, tidal flooding, macroorganic matter accumulation, substrate composition, macrobenthic invertebrate species dynamics, and other wetland properties. However, some authors argue that the metrics, as they typically have been employed, do not effectively assess wetland performance or development.

Fish-based indicators for wetlands often are constructed from data gathered in a few sampling events over a limited time period (e.g., LaSalle et al. 1991, Moy and Levin 1991). These indicators usually are taxonomic, providing a snapshot of the status of a variable at one or multiple (temporally similar) points. Classic examples include measures of density, fish size, and species composition. Experts such as Beck et al. (2003) contend that these types of taxonomic measures as insufficient because they cannot describe habitat function and the ways in which fish use a wetland.

Dionne et al. (1999), commenting on the flaws of their own study with respect to taxonomic-type assessments, note that "visitation is necessary but not sufficient evidence for the value of restored and created marshes as fish habitat. From the results of this study, we cannot determine how fish growth and survival in manipulated marshes compares to that in natural marshes.…Measures of fish feeding or growth should be added to the criteria." Fonseca et al. (1990) caution that "abundance data need to be interpreted through functional mechanisms such as predation which act to produce the observed abundances in order to separate habitat function from dysfunction." Yet doubt exists regarding whether there is sufficient research (on either typical wetland conditions or fish behavior in specific types of wetlands) or technical capacity to allow researchers to create generalized habitat metrics capable of describing fish growth, development, recruitment, feeding, and other functional attributes. Beck et al. (2003) argue that research is insufficient, and Minello et al. (2003) concur, noting that "relatively few studies have examined growth rates (of transient nekton species in salt marshes)…no single technique appears to adequately address experimental difficulties…encountered in the measurement of habitat specific growth rates for nekton.…While habitat-specific growth should be an important measure of nursery value, there are insufficient data available to use growth rates for effectively comparing marshes with other habitat types." Problems associated with developing functional assessment metrics for fish in wetlands may limit the use of fish metrics in assessing wetland performance.

Nonetheless, an amalgam of fish-based metrics, some admittedly taxonomic and others more closely approximating functional assessments (such as percentage of top carnivore species or percentage of intolerant versus tolerant species), might provide viable indicators of performance. Karr (1991) notes that careful and well thought out indicator construction is relatively more important than the inclusion of any one species in the indicator, observing that "I believe that just about any taxon could be selected and produce a reasonable level of insight about the water resource if appropriate wisdom is brought to bear on development of robust and general metrics." This theory underlies the concept of a fish-based IBI.

IBIs have been used to assess lake and stream health since the early 1980s, when Karr (1981) first proposed a fish-based IBI containing 12 parameters grouped in two categories—species composition and richness and ecological factors. Karr noted that IBIs could be used to assess different water body types if their component metrics were adjusted to account for local conditions. In subsequent years, scientists followed this recommendation and created IBIs for multiple types of streams, rivers, and lakes; Drake and Pereira (2002), Harig and Bain (1998), and Lyons et al. (1995), among others, describe the process of constructing and implementing modified IBIs.

Scientists only recently have begun developing fish IBIs for wetlands, although research in this area shows promise. Simon (1998) and Simon et al. (2000) successfully developed IBIs for fish alone, and for fish, amphibians, and macroinvertebrates for small palustrine wetlands and vernal ponds in northern Michigan. However, the extensive descriptions of the IBI construction process found in both Simon articles (detailing why and how the authors replaced Karr's sucker species count metric with a minnow count metric, for example, or why and how they replaced Karr's metrics of percentages of carnivores and hybrids with percentages of pioneer and lake obligate species) reveal a comprehensive understanding of the natural conditions and functions of dunal and palustrine wetlands in the region. An IBI requires a baseline—a set of ideal wetland conditions and functions, developed from focused study of a significant number of natural wetlands, to which created or restored wetlands are compared. Baselines necessarily vary with wetland type. However, multiple articles reviewed here (e.g., Drake and Pereira 2002) argue that current wetland classification systems are not sufficiently advanced to provide type-specific baselines. Fish-based IBIs for wetlands could be useful assessment tools, and recommendations for their construction and use are detailed in the specific studies summarized in this report—but more extensive research on wetland conditions seems necessary before wetland IBIs can be easily constructed and widely applied. (An important caveat: Simon [1998] and Simon and co-authors [2000] note that very small wetlands often possess two or fewer fish species, so IBIs based solely on fish are not appropriate for these wetlands; also, these and other authors note that when sample sizes—of fish or any other indicator species—are small, IBI scores tend to be less robust).

The literature cumulatively provides a picture of an "ideal" fish-based wetland performance standard. First, and perhaps most telling regarding the usefulness of fish metrics, the indicator would include multiple metrics, and not all metrics would involve fish. Following the recommendations of many studies (Karr 1991, Harig and Bain 1998, Lyons et al. 1995, Simon 1998, and Simon et al. 2000), crayfish, amphibians, macroinvertebrates, and other species could be included as indicators to make the standard robust and applicable to different environmental conditions and geographic areas. At least one metric would assess species composition, an effective first-warning indicator of community change in response to environmental disturbance (Harig and Bain 1998). Measures of fish growth and function, including assessments of biomass, feeding patterns, residence time, and recruitment (as applicable), would be developed and included.

Critical to the question of whether fish-based performance standards should be used to assess wetland performance is the issue of efficiency—that is, whether fish metrics are the most direct or accurate route toward performance assessment. Commentary in the literature suggests that performance might best be assessed at other levels. Hampet et al. (2003) link a wetland's fish community dynamics to characteristics of its benthic invertebrates, macroorganic matter, and soils—suggesting that assessment of these properties might be most useful. Minello and Webb (1997) point to the importance of tidal flooding in shaping fish community function, an argument Moy and Levin (1991) support as they discuss the importance of vegetation and *Spartina foliosa* stem densities to fish community density. Williams and Zedler (1999) argue that fish communities are significantly influenced by hydrogeomorphic factors. Fish-based assessments can reveal information about these other wetland components, but as noted above, they may not yet be capable of providing information that is performance-indicative, given the current state of research.

INVERTEBRATES

Invertebrates are widely used as biological indicators for the health of lakes and streams, and indices are currently being developed in several states and regions (U.S. EPA 2002 [IBI], table 2). They are considered useful as indicators by many wetland scientists. For example, they are widely distributed, they are sensitive to variation in water quality (especially nutrient enrichment and metals); different species exhibit a range of tolerances to environmental stress; and they are relatively sedentary, which allows the aerial extent of perturbations to be determined. Their sedentary nature, however, can also be a disadvantage if sampling does not occur near a localized disturbance. Another reason some macroinvertebrates are considered useful biological indicators is their long life cycles relative to other organisms, which ensures that they will be in their habitat long enough to be affected by a perturbation, and it also allows the use of age structure as an additional indicator (Merritt and Cummins 1996, U.S. EPA

2002 [IBI]). Invertebrates are also important components of wetland food webs (U.S. EPA 2002 [IBI]).

Potential shortcomings with the use of invertebrates as biological indicators include their insensitivity to responding to all impacts, (for example, they are relatively insensitive to impacts to wetlands from herbicides). In addition, their distribution and abundance can be affected by other factors besides water quality (e.g., current velocity, conditions of substrate). Their abundance varies seasonally, which must be considered in a sampling design. Dispersal abilities may result in their presence in wetlands where they do not regularly occur (Merritt and Cummins 1996). Furthermore, identification may be difficult, requiring staff trained in invertebrate taxonomy and incurring high laboratory costs (U.S. EPA 2002 [IBI]). Efforts to reduce costs through rapid assessment techniques may underestimate impacts due to under-sampling of rare species (Cao et al. 1998, EPA Rapid Bioassessment Protocol; however see Chessman et al. 2002). Indices in Puget Sound lowlands, for example, proved sensitive to small sample sizes (Doberstein et al. 2000). Trained staff familiar with the biology of the organisms and their habitats also need to further interpret IBI scores to avoid erroneous conclusions based solely on numerical values (Wilcox et al. 2002). Wilcox et al. (2002) found that macroinvertebrate IBI scores in the Great Lakes region varied widely within and among years as the result of natural variation in lake levels, and this high variation precluded their use as indicators of human impacts.

An additional problem with the use of invertebrate IBIs in performance standards is that they may not be effective for all types of wetlands. Wilcox et al. (2002) give examples of other wetlands that because of their high variability might be less suited for the use of macroinvertebrate IBIs. Examples of these variable wetlands include prairie potholes, large regulated rivers, and tidal freshwater marshes. In confirmation of this prediction, Tangen et al. (2003) found that biotic and abiotic factors outweighed the influence of land-use practices on the invertebrate community. More information is also needed on intermittent streams (Wilcox et al. 2002). Habitats that are likely well suited for the use if invertebrate IBIs included "deep water swamps not prone to flooding, inland marshes not supplied by ground water,…tidal marshes in regions not threatened by periodic hurricanes (Wilcox et al. 2002). Furthermore, studies indicate that indices of biotic integrity based on macroinvertebrates are applicable to estuarine systems in Massachusetts (U.S. EPA 2003), the Mid-Atlantic United States (Lockwood 1997, Llanso et al. 2002, Ranasinghe et al. 2002), a freshwater marsh in Ohio (Spieles and Mitsch 2000), and a large riparian wetland in Minnesota (Galatowitsch et al. 1998).

BIRDS

Although our understanding of the usefulness of birds as wetland indicators is in its infancy, birds appear to exhibit several characteristics that make them potentially useful as indicators of environmental change. Birds are indicators of gross habitat conditions, such as vegetation structure (Buffington et al. 1997, 2000; Dobkin et al. 1998), but also more subtle wetland characteristics, such as organic matter (Cole 1997) or invertebrate abundance (Cooper and Anderson 1996). Some species of birds are habitat specific, and breeding birds of bottomlands (Buffington et al. 1997, 2000) and western riparian habitats (Farley et al. 1994) are intolerant to variation in habitat conditions. Birds are also sensitive to environmental change, such as that caused by urbanization (Blair 1996, Rottonborn 1999). They are relatively easy to survey, and no specialized keys or extensive lab work are required to identify species.

The applicability of birds as indicators has been demonstrated by studies comparing bird communities between natural and restored wetlands. Birds responded to mitigation efforts in Armenia (Balian et al. 2002); however, restored bogs in Sweden did not provide habitat for bird species characteristic of natural bogs (Bolsher 1995). Delphey and Dinsmore (1993) found that birds were more abundant in natural than constructed prairie potholes. Melvin and Webb (1998) found bird species richness and evenness was greater on natural than on restored salt marshes, probably as the result of greater habitat diversity of native wetlands. In contrast, Brown (1999) in New York and Ratti et al. (2001) in North and South Dakota found that mitigation efforts were effective, judging from similarity between bird communities in native and restored wetlands.

The usefulness of birds as indicators is further suggested by studies reporting a connection between bird assemblages and wetland age (e.g., Buffington et al. 1997, VanRees-Siewert and Dinsmore 1996), indicating their potential for use as a performance standard. Most articles that address the correlation between birds and wetland age demonstrate that the relationship probably stems from changes in the vegetation community—especially increasing community complexity—with increased wetland maturity. For example, Buffington (1997) noted that the vegetative structure in a bottomland forest changed as the forest matured—the canopy height, canopy closure, and basal area all increased with the age of the forest. The increased structural complexity of these mature bottomlands attracted a more diverse complement of birds.

One feature of birds as subjects of IBIs is that they can represent conditions beyond the scale of a single wetland (Fairborn and Dinsmore 2001, EPA 2002). For example, urban wetlands are lower quality for some bird species because of characteristics outside of the wetland in the urban matrix (Blair 1996, Rottonborn 1999). Also, the quality of wetlands as habitat for many species varies as a function of the amount of similar habitat nearby and the connectivity among wetlands (Gibbs 1993). Such wetland complexes are not necessarily reflected in IBIs based on more localized species, however in the case of a study of waterfowl, the abundance of waterfowl does reflect the existence of these wetland complexes (Austin et al. 2000). Naugle et al. (2001) found that local-scale habitat variables explained the distribution of many bird species breeding in South Dakota prairie potholes, but wildlife was most abundant in wetland complexes surrounded by native prairie. An important message in many of these studies is that the position of the site relative to other wetlands and development in the landscape must be considered when siting a wetland (Blair 1996, Rottonborn 1999).

Disadvantages of using birds as indicators include the following (EPA 2002): Many bird species are migratory, which introduces the uncertainty of whether the status of a population is influenced by local habitat conditions or events occurring away from the study area. Furthermore, the scale of the area being represented by a bird IBI depends on the home range size of the birds occupying the site, which complicates the interpretation of IBIs based on birds. Little is known about the use of birds as indicators of wetland health, relative to the use of fish or invertebrates, so clearly this would be a productive area for further study.

ALGAE

There are clear advantages associated with using algal indicators in wetland performance standards. Studies suggest that patterns in algal growth and development can be reliable indicators of specific environmental conditions. Algae-based performance standards potentially can measure wetland performance at a fine grain because algae species tend to be highly sensitive to disturbances such as changes in water temperature, pH, nutrient loading, and pollution level and type, and often respond to these disturbances before the disturbances measurably affect other potential indicators. Finally, some experts contend that the sampling and laboratory testing required to gather and convert algal data into workable metrics is less time consuming and requires less skill than similar processes associated with other indicators (U.S. EPA. 2002 [Algae]).

However, the literature also indicates that creating and operationalizing algae-based standards can be difficult; authors primarily are concerned with the complexity of algal responses and community characteristics, problems associated with measurement, and lack of necessary research. The sensitivity that makes algal metrics appear advantageous in the theoretical realm generates difficulties in real-world application: "The exact nutrients that contribute to algal community shift is [sic] often difficult to identify due to correlations among many nutrients…[and] other chemical constituents of water, particularly pH altering bicarbonates, can regulate the response of algae" (Adamus et al. 2001). Moreover, intra-wetland spatial heterogeneity of algal communities can be high, with specific algal formations strongly affected by site-specific nutrient or disturbance gradients that may not reflect general wetland conditions. Extensive and possibly time-consuming multi-site sampling may be necessary to mitigate the effects of this heterogeneity.

Authors note that while some algal indicators may be relatively easy to construct and implement, others, such as metrics assessing biomass, volume, and density, can be time-consuming or costly in both phases. In a series of articles, Galatowitsch and Mayer describe their inability to find any significant correlation between characteristics of substrate-grown algae communities and natural versus restored wetlands, suggesting that no multivariate assessment instrument should rely wholly or primarily on algal indicators.

The literature on wetland performance standards typically discusses two categories of assessment techniques: multivariate approaches and approaches based on IBIs. However, IBIs require that reference conditions—that is, the typical conditions of the considered indicator in the natural wetland to which the restored or created wetland will be compared—be described explicitly. And, as the authors of EPA's "Methods for Evaluating Wetland Condition #11" (U.S. EPA. 2002 [Algae]) point out, current research (on both algal community behavior and wetland classification) is not sufficient to correlate algae species and algae community types with wetland characteristics in a manner necessary to establish an IBI baseline.

Some of these problems can be mitigated, and some are unimportant if appropriate sampling techniques or metrics are selected. The literature suggests that soil coring is one of the most effective means of gathering algal data, allowing researchers to integrate algae species from many wetland sites (reducing heterogeneity and site-specific variability) and sample in any season. Problems associated with heterogeneity and sensitivity can be minimized further if researchers primarily use taxonomic metrics, such as measures of species composition, rather than more volatile metabolic metrics, or if they create indicators based on multiple (wetland-representative) species grouped according to typical sensitivities. Finally, some authors point out that precise (and time-consuming) characterization of algae communities may not be necessary for the construction of valid indicators, arguing that metrics based on algae identified at the genus level or coarser can effectively distinguish important environmental differences between restored or created and natural wetlands.

On balance, algae-based performance metrics—while theoretically very useful—seem difficult to actually construct and implement. The arguments against basing multivariate assessments on algal community characteristics are compelling, as is the evidence that insufficient research exists to construct the baseline necessary for an algal IBI.

MAMMALS

Research focusing on mammals as indicators of wetland health are rare in the literature base. Although this review may have missed critical material, it suggests that only a limited number of mammals (e.g., water shrews) would be appropriate as a biological indicator of wetland performance. Mammals, however, may be useful as one component of a set of indicators used in performance monitoring.

VEGETATION

The use of vegetation in monitoring wetland performance is perhaps the most widely recognized and ubiquitous metric currently in use. However, many researchers caution against the use of vegetation alone, and other studies suggest that vegetation metrics such as percent cover may be misleading for gauging wetland functional performance. Several studies indicate a lack of data correlating percent cover with other measures, such as biomass and species diversity. Some studies caution that vegetation can survive for many years in poor conditions before dying off (e.g., Dawe et al. 2000), and some do not show declines until well beyond five years. Percent cover may be related, however, to a wetland's functioning for retention/removal of dissolved elements (Cole 2002). The percent cover of invasive exotic species may also describe the performance of a wetland. Cover by plants may be a part of basic criteria necessary to ensure that wetland area has been replaced, but it is not enough alone to show that function has been replaced. Additional targeted performance standards are needed to show that the functional objectives have been achieved. Because vegetation is fundamental to the wetland food web, it affects almost every other taxonomic group as well as other wetland processes (U.S. EPA 2002).

In general, vegetation may work as indicators of wetland status because they are present in all wetlands, are immobile, can reflect chronic stress on the system, are well studied, and information to identify wetland plants is readily available (U.S. EPA 2002). General limitations to their use include the lag time between the introduction of a stress and a plant's response, and the seasonal restrictions and laboriousness of identification and sampling; furthermore, individual species' response to specific stressors (as opposed to general response to anthropogenic changes) is not well understood (U.S. EPA 2002).

Some researchers suggest that the use of above- and/or belowground plant biomass may be a useful indicator of wetland performance, although biomass alone can be misleading because its use cannot distinguish between a wetland containing a diverse species composition and one containing a monoculture (Cole et al 2001). However, Cole et al. (2001) found no relationship between biomass and age of the wetland, nor between biomass and organic matter. Collection of biomass data can also raise problems because of the difficulty in obtaining the belowground measurement and in separating live from dead roots (Stroud 1976).

Measures of native species diversity and richness have shown to increase with wetland age, size, and proximity to the nearest established wetland (Reinartz and Warne 1993), suggesting that these measures could be incorporated into a performance standard. The density of tree and/or herbaceous cover could also be useful (Kadlec and Knight 1996). However, Zedler's series of studies of cordgrass marshes created for an endangered species of clapper rail tell a cautionary tale about using density as a single measure of performance. In the marshes created for the rail, shoot height was vital to use by the rail, along with other parameters. Zedler (1993) points out that cordgrass height distributions and density parameters monitored together were better measures than previously used canopy structure measures. Other studies suggest that measures of flowering stems would be more useful than simple density alone. Still others suggest that there is a relationship between vertical structure and age of wetland, as well as structural complexity of wetlands (e.g., Havens et al. 2002).

As with many other performance indicators, the length of the monitoring period also affects the reliability of results. Dawe et al. (2000) found that cover and species composition reached reference marsh values within 6 years after planting, and that the aboveground biomass took 13 years after planting to attain reference site values. The authors warn that success still could not be concluded even after 13 years. Other studies suggest that monitoring time frames for created wetlands to develop similar vegetation biomass may be 3–9 years (Craft et al. 2002), 20 years (Zedler 1993), 13 years (Dawe et al. 2000), and longer for wetlands containing woody species. However, Kellogg and Bridgham (2002) found that study sites attained similar parameters of species richness, diversity, and aboveground biomass as reference sites after only 5–6 years.

ABIOTIC PARAMETERS

HYDROLOGY

Hydrology is widely regarded as the most important factor determining wetland structure, function, and persistence (Mitsch and Gosselink 1993, NRC 2001, Bedford 1996, 1999). Although it is also recognized that climate drives the entire hydrologic system (Brinson 1993, Bedford 1996, Wilcox et al. 2002), hydrologic conditions affect abiotic factors such as nutrient availability, sedimentation, and soil anaerobiosis (Mitsch and Gosselink 1993). Hydrology influences vegetation structure through seed dispersal, species establishment and composition, sediment trapping, nutrient retention, root zone saturation, and water shading. Consequently, wetland restoration or creation depends on establishing appropriate hydrology (Brinson 1993, NRC 2001).

Many agree that our understanding of wetland hydrology is not advanced enough to predict or create wetland hydrology (Zedler 1996, Bedford 1996, Hunt et al. 1999). The importance of understanding past and present profiles of wetlands within the landscape have been recognized (Bedford 1999, Brinson 1993). One method of assessing the hydrology function in a wetland is the hydrogeomorphic (HGM) classification and functional assessment system that categorizes wetland type by general hydrologic characteristics (Brinson 1993; see section on HGM later in this report). Wetlands within a class are assumed to have similar functions that differ from those in other classes and subclasses within a given region (Brinson 1993). Hydrology will be the determining factor of whether a mitigated or created wetland is successful.

Soil and hydrology are interconnected. In a study comparing HGM classifications between regions, it was determined that there were major differences among subclasses between regions (Cole and Brooks 2000). Permeability of soil was one factor that accounted for differences in mean water depth and duration of saturation between regions. Dense, low-permeability soils hold water, while more permeable soils have greater interaction with groundwater sources (NRC 2001).

Vegetation and hydrology are also closely linked. Hydrologic variability influences plant community structure. For example, variability in water levels in the Great Lakes lead to extreme changes in plant communities and the faunal habitat they provide. (Wilcox et al. 2002). Kolka et al. (2002) found that vegetation was an appropriate and important indicator of hydrologic character. Rising and falling water basins influenced sedge growth in restored sedge meadows (Budelsky and Galatowitsch 2000). Hydroperiod influences vegetation community structure and species richness. In a study conducted by David (1999) restoration of hydroperiods in a wetland increased the native vegetative species and nearly eliminated the non-native species.

When researching hydrology, many authors recommend that field studies should last longer than five years to better assess the hydrologic functions in a particular wetland. Also, some authors studying mitigated wetlands recommend the incorporation of a wetting and drying cycle so that they can resemble and function more like that of natural wetlands. They heavily stress the importance of attaining the correct hydrology, because it controls so many other functions of the wetland.

Although hydrology is the most basic and perhaps the most essential part of wetland function, further research is needed to improve the ability of mitigation sites to mimic the hydrology of the natural wetlands they replace. In addition, many authors point out the importance of increasing monitoring time frames in order to better assess wetland hydrologic developments.

SOIL, SEDIMENT, SUBSTRATE, NUTRIENTS

Wetland performance standards based on soil, sediment, substrate, or nutrient (hereafter, grouped together as “soil”) indicators may be among the most valid metrics discussed in this report, especially when used in conjunction with biotic metrics. The data necessary for monitoring these indicators are relatively easy to gather, and metrics based on these indicators are relatively easy to construct. These metrics describe attributes associated with accumulated organic matter; soil acidity, density, porosity, composition, pH; soil carbon, phosphorus, and nitrogen; soil column structure, above- and below-ground biomass, and porewater nutrient concentration, among other soil indicators.

Soil reference conditions necessary for IBI-type soil baselines are well documented, allowing easy comparison of soil attributes between natural and restored or created wetlands. Many studies particularly focus on the importance of organic matter content in wetlands, and studies typically find differences between the amount of organic matter development between natural wetlands and mitigation sites. Soil metrics can be descriptively powerful—as Craft (2000) notes, invertebrate communities are influenced significantly by soil organic matter and other soil attributes, as is wetland vegetation; mammals, fish, and other wetland animals that depend on invertebrate prey are indirectly influenced by soil attributes. Performance standards based on soil attributes assess one of the driving forces in wetland development.

The disadvantages associated with soil-based performance standards primarily are related to characteristics inherent to restored or created wetlands. Soil metrics cannot indicate wetland performance success in the typical 5 to 10 year mitigation site monitoring period because wetland soil attributes do not converge with reference expectations except in the long run, if at all. Craft (2000) suggests that soil organic matter accumulation indicators in natural and created saline wetlands might match after 10 or 15 years; Craft, Seneca, and Broome (1991) make similar observations concerning porewater composition and other soil properties, although they do not specify a time frame; and Nair et al. (2001) propose that soil carbon and nitrogen percentages in a created wetland might reach reference levels 15 to 20 years after wetland development. State or federal monitoring of wetland performance typically does not span more than 5 years. Yet the time factor alone might not be problematic; these observations seem to imply that the trend in soil attributes is toward convergence with natural conditions, suggesting that short-term monitoring could identify these trends (or lack thereof) and rate performance accordingly.

However, some experts express doubt that measurable trajectories exist for soil attribute development toward reference conditions. Those that conclude that trajectories might exist observe that their research—and research in the field generally—is insufficient to describe the trajectories, and that policymakers should not conclude that they are linear. Gibson et al. (1994) note: "It is not clear when or if nutrient pools and plant canopies of constructed marshes would match those of natural marshes," and Bishel-Machung et al. (1996) argue that the time elapsed since construction of a wetland is not a significant determinant of soil organic matter accumulation in the wetland—that is, the development of soil organic matter cannot be tracked temporally. Craft et al. (2002) find that development trajectories may exist for above-ground biomass and macroorganic matter, but caution that "…the trajectories are not linear." Other authors debate or comment on the existence of developmental trajectories for other wetland components. LaSalle et al. (1991) implicitly lend support to the idea of developmental trajectories, but Simenstad and Thom (1996), Streever (2000), and Zedler and Callaway (1999) are highly critical of the linear trajectory models proposed in current literature and assumed in some restoration projects.

In principle, soil-based metrics are a viable means of measuring wetland performance: soil attributes are measurable, information-laden, and descriptively powerful. The main problem is that these metrics are not necessarily indicative; at best, they can determine success of wetland development only in the long term, and at worst, experts doubt whether the data they provide actually can or should inform wetland performance standards specified at any time scale. They also do not measure health or community structure and integrity.

Note: Because of the close association between soils and vegetation, many studies of soils and vegetation are also found in the vegetation section of this report.

LANDSCAPE PERSPECTIVES AND METHODOLOGIES

HYDROGEOMORPHIC (HGM) APPROACH

The hydrogeomorphic (HGM) approach is a tool for assessing the ability of a wetland to perform functions. Unlike other methods, HGM focuses on the assessment of hydrologic source, hydrological regime, and geomorphic setting of wetlands (Brinson 1993). Hydrology is viewed as the most important influence affecting the character of wetlands, and thus replacement wetlands cannot be equivalent to natural wetlands unless their hydrological features are equivalent (Cole et al. 1997, Mitsch and Gosselink 1993, NRC 2001, Bedford 1996). Functional assessment under other systems is typically based on the measurement of structural features within mitigated wetlands or comparison of structural features between mitigated and natural wetlands (Kentula 2000). The inherent problems in using structural similarity to infer functional equivalence is illustrated by studies indicating that although the structure of mitigated wetlands was similar to natural wetlands at the outset, mitigated wetlands were unable to maintain native plants (Gwin et al. 1999, David 1999) and animals (Petranka et al. 2003, Zedler 1996, Brown and Smith 1998) over time, presumably because of differences in hydrology between mitigated and natural wetlands. Gwin et al. (1999) concluded that the concept of hydrological equivalence as exemplified in the HGM procedures contributed greatly to the evaluation and mitigation of wetlands.

The HGM method is also more objective than other approaches that rely heavily on professional judgment. HGM has a rigorous process for quantifying the judgment of a group of scientists with step-by-step peer review and documentation (Hruby 1999). First, wetlands are classified based on their hydrogeomorphic characteristics (landscape setting, water source, hydrodynamics); second, a set of reference wetlands is established that range from lowest to highest levels of function; and finally, a relative index of functions is used to assess wetland functions as compared with the highest quality wetlands in the reference set (Brinson 1993, 1995).

A strength of HGM is that it uses reference wetlands of similar classification typical of the region for assessment of functional performance that presumably represents an optimum natural function (Brinson 1993, NRC 2001). Gauging the impact of development or management on wetlands requires an understanding of the unmanipulated condition (Keough et al. 1999). The use of reference wetlands facilitates the precise identification of specific wetland attributes for the mitigation site, and are useful in setting restoration targets and success criteria (Rheinhart et al. 1993, NRC 2001). For example, Findlay et al. (2002) found that use of reference sites for tidal wetlands allowed more objective targets for restoration. Similarly, by using the HGM method, Gwin et al. (1999) were able to distinguish between natural and mitigated wetlands that were similar in structural characteristics by their hydrogeomorphology.

A potential disadvantage of the HGM method is that it is very time consuming to develop the models that form the structure of the methodology. This method requires the collection of detailed information and development of functional models of hydrology (Cole and Brooks 2000; Cole et al. 1997, 2002) at mitigated and reference wetlands, and reference wetlands must be assessed for each classification (NRC 2001). For example, it took Cole et al. (2002) 4 years to collect and analyze sufficient hydrologic data to support functional models of hydrology for four regional subclasses in Pennsylvania. Also, HGM models are not transferable outside the region in which they were developed, even if they are classified similarly (Cole et al. 2002). Finally, the selection of reference wetlands can be subjective and can be constrained by logistics and finances, which might bias the selection of sites, and thus might not represent the "highest functioning" wetlands, as specified by the technique (Findley et al. 2002).

A number of regional guidebooks have been published recently by the U.S. Army Corps of Engineers' Waterways Experiment Station. Although these guidebooks are not a part of the peer-reviewed literature base, they have the potential to be valuable for evaluating mitigation performance in the regions where they have been developed.

DEVELOPMENTAL TRAJECTORIES

A developmental trajectory for compensatory mitigation wetlands—that is, the pathway that a created or restored wetland takes as it ages—is an attractive concept for performance standards, because it holds the possibility of monitoring a site in the early stages and, from those early measurements, being able to predict the likelihood of the site attaining functional equivalency with the wetland it replaced.

The literature base on developmental trajectories for wetlands is growing, and many studies on the topic are ongoing, but ranks of published studies are sparse because of the relative newness of the subject. However, this is likely to change quickly as more research attention is turned to investigating possible trajectories.

A 1991 study by LaSalle and co-authors indirectly supports the argument that trajectories for wetland development exist and can be measured and/or tracked. The authors studied two created wetlands four and eight years after their creation, and found the sites were generally similar to nearby natural wetlands with respect to vegetation, macrofaunal assemblage attributes, soil and substrate type and composition, and fish and shellfish assemblages. The implication of their findings is that developmental targets for created wetlands can be met in a relatively short time span because key created wetland components progress rapidly toward these targets. The authors do not address, however, whether this progress is linear or otherwise. Similarly, Craft and co-authors (2002) studied soil attributes of created wetlands and found that development trajectories may exist for above-ground biomass and macroorganic matter, although they caution that these trajectories probably are not linear. However, these authors are in the minority opinion among those commenting on trajectories in the literature reviewed for this report.

Simenstad and Thom (1996), Streever (2000), and Zedler and Callaway (1996), among others, are highly critical of the linear trajectory models proposed in current literature and assumed in some restoration projects. Simenstad and Thom's six year study of soil, algae, vegetation, HGM, geochemical, macroinvertebrate, fish, and bird community characteristics in a Puget Sound estuary led them to conclude that "only a few of the 16 ecosystem attributes analyzed show functional trajectories toward equivalency with natural wetlands, and many were inconclusive or suggested dysfunction relative to reference wetlands." These findings are not necessarily evidence that the trajectories aren't appropriate, but that the wetland was not showing early and rapid developmental trajectories. They further argue that simple trajectory assumptions are inappropriate because there is an "extremely tight coupling among estuarine HGM, soil development, physicochemical and biological disturbance, and plant physiology and survival, all of which tend to be unappreciated in most wetland restoration monitoring."

Streever (2000) reviewed the literature concerning the functionality of dredged material wetlands, discussing attributes of fish, birds, macroinvertebrates, soils, vegetation, and hydrology in dredged versus natural wetlands, and concludes that "cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time as a general rule." In a created wetland in San Diego, studied for 10 years by Zedler and Callaway (1996), examination of soil organic matter, soil nitrogen, and measures of plant growth led the researchers to conclude that although "hypothetical models in the scientific literature suggest that ecosystem restoration and creation sites follow a smooth path of development, rapidly matching natural reference sites…high interannual variation and lack of directional change [at the study site for the variables measured in the time period assessed] indicate little chance that targets will be reached in the near future. Other papers perpetuate the trajectory model, despite data that corroborate our findings."

A functional or habitat-based approach to wetland performance assessment seems to prefer trajectory-based performance standards. Many authors critically comment that it is easy to measure standing stock of fish or percent vegetative cover, but that these taxonomic assessments do not capture the quality or nature of community function. They often suggest monitoring of functional wetland components, such as fish breeding rates, over longer time scales, and the construction of developmental trajectories. Yet in the limited set of studies wherein authors have attempted to construct trajectories, many seem to have found their development impossible, or at least unwise.

LANDSCAPE PERSPECTIVES AND GENERAL MITIGATION LITERATURE

Much of the literature on biological and abiotic research, particularly amphibians, fish, birds, and developmental trajectories, highlight the importance of creation and restoration taking place within a landscape context.

In addition, a number of articles reviewed for this study contained general information or information that did not fit easily into the report's structure. They are important for a broad understanding of the science, as well as for specific recommendations they hold.

CONCLUSION

The theory of performance standards holds great promise, but the science in many areas is still quite new. Wetland restoration and creation itself is a relatively new scientific pursuit. In addition, the regulatory push for mitigation was not codified in federal guidance until 1990, with the release of the joint EPA/Corps 1990 Memorandum of Agreement on the Determination of Mitigation Under the Clean Water Act Section 404(b)(1) Guidelines. This document, for the first time, provided federal guidance on the elements of mitigation requirements for standard permit applications. The guidance established environmental criteria to be met for activities permitted under the Clean Water Act section 404 program, and it also catalyzed research in the area of wetland restoration and creation. It is therefore not surprising that the literature is dominated by studies of wetland mitigation sites younger than 10 years old.

Because created and restored wetlands are relatively young, the monitoring period of the studies themselves also tend to be short. Few long-term monitoring studies exist—research typically takes place over just a few growing seasons or two years. Even when different-aged wetlands are sampled over this short time frame, natural population fluctuations, stochastic events, and seasonal or annual variation may lead to misinterpretation of the data when only a temporal snapshot of the wetland is captured. Most long-term studies suggest that an appropriate monitoring time frame far exceeds the typical five-year regulatory time frame expected in mitigation projects. After 10 years or more, many mitigation sites have not conclusively attained reference values.

A review of the literature highlights some recurring themes that address the challenges and recommendations for potential performance standards:

- **Baseline information.** Perhaps the most widely asserted theme is the profound importance and critical deficiency of baseline information. A baseline provides a point from which to assess permitted loss and a point from which to plan for desired restoration. Indices of biological integrity require the collection of baseline data, as do functional assessments such as the hydrogeomorphic method of assessing wetland functions. A baseline is required for sampling of all types, and without it, subsequent monitoring is meaningless. However, collecting baseline information can be costly and time-consuming, and it therefore is less represented in the literature than its importance would predict.
- **Landscape-level perspective.** An emphasis on a landscape-level perspective for monitoring and assessment is widely endorsed by the scientific community. Many taxa, such as amphibians, birds, and fish, are intimately intertwined with the landscape beyond a particular wetland mitigation site.
- **Standardization.** Many studies advocate for a standardized system of data collection and access, uniformity of language and definitions, and better standardization of sampling protocols. Enhancing uniformity would allow for greater communication and sharing of results, as well as replication among studies for greater clarity of the applicability of performance metrics.
- **Transferability.** A challenge in the development of national performance standards is the limited transferability of findings from region to region or from wetland type to wetland type. A study of the application of the HGM method on similar wetland in Pennsylvania and Oregon illustrates the point that biological systems vary across the country. Caution should be taken when developing specific criteria in one location and attempting to transfer its usage to another location. Examination of the literature also suggests that the sampling method and location of sampling influences the outcome achieved. The sensitivity of research methodology may be particularly true for certain metrics, such as fish and invertebrate sampling, in which the location within the wetland and the sampling technique play a central role in the outcome of species and communities sampled. Therefore, performance standards requiring sampling of specific metrics will be influenced by the sampling design itself.

Given the challenges listed above, the findings in the scientific literature examined for this report leads to one other caution: The vast majority of studies do not ask the question that is being asked in this report—whether these specified metrics would make good performance standards. They also do not ask if the parameter can predict long-term performance. Rather, these previous studies endeavored to understand different issues, although these are often related issues. Studies often pair a natural wetland to a "treatment" wetland (e.g., a mitigation site) and attempt to understand the differences between them. If, for example, a study shows that the composition of macroinvertebrates is different between the two sites, should we conclude that the composition of macroinvertebrates is a good performance standard? Even the literature base for IBIs, which provides valuable information for performance standards, was not developed for use in a performance standard program. Retrofitting a new question to the existing literature base has its limitations.

The findings in the literature suggest that performance standards can be developed and implemented. As the articles reviewed for this report indicate, each biological and abiotic metric offers its own set of strengths and weaknesses for use as indicators of wetland condition and functional performance. However, the strategic use of a combination of metrics could accentuate the strengths in some while minimizing the weaknesses in others. Through a well-chosen collection of performance standard metrics, regulators may ultimately be able to measure the ecological viability of functions in created, restored, and enhanced wetlands to understand better whether the site is on its way to becoming a self-sustaining wetland to replace the one lost.

APPENDIX A. SUMMARIES OF BIOTIC ARTICLES REVIEWED

AMPHIBIAN ARTICLES

Adamus P, Danielson TJ, Gonyaw A. 2001. Indicators for monitoring biological integrity of inland, freshwater wetlands: a survey of North American technical literature (1990–2000).

The authors summarize the herpetological literature to determine whether amphibians could be used to develop IBIs. They note that most amphibians and many reptiles depend on aquatic habitats during a portion of their lifetime and are therefore vulnerable to impacts to wetlands. Despite this sensitivity to wetland alteration, few studies use amphibian assemblages specifically to address ecological health of a large series of wetlands in a landscape setting.

This publication reviews studies that address the effects of enrichment, contaminant toxicity, acidification, salinization, sedimentation/burial, turbidity, shade, vegetation removal, thermal alteration, dehydration/inundation, habitat fragmentation and other stressors. This review also addresses spatial and temporal variability of species richness and composition, monitoring techniques and equipment, and metrics for assessing impacts to amphibian communities. The authors note that the dual life history requirements of most amphibians and many reptiles highlights the importance of considering both wetlands and uplands in any monitoring effort.

The authors state that because most individual wetlands are occupied by few amphibian and reptile species, richness and species composition of wetland complexes at landscape scale may be the best metrics of ecological condition. Amphibian and turtle diversity at a local or regional scale is often severely affected by destruction of small isolated temporary or seasonally inundated wetlands—those that are often the first to be ignored by state and federal regulatory programs—or altered in exchange for protection/restoration of larger wetlands as part of mitigation banking.

The authors note that few long-term amphibian studies have been published, thus there is little material available to evaluate long-term population fluctuations in natural and altered settings. For example, they cite a study in Michigan of 14 amphibian species in 37 wetlands—in 2 surveys 20 years apart, 40 colonizations and 34 extinctions were recorded with little overall net-change in the breeding populations of most species (Skelly et al. 1999).

At the time of writing, the authors did not know of any amphibian IBIs developed or validated successfully, although some studies had begun to use amphibian assemblages specifically to indicate the ecological condition of wetland complexes (e.g., Richter and Azous 2000).

Babbitt and Tanner. 2000. Use of temporary wetlands by anurans in a hydrologically modified landscape. Wetlands 20(2):313–322.

The authors examined assemblages of larval salamanders at 12 temporary wetlands in southcentral Florida. The study site is an active cattle ranch and had been subjected to extensive ditching to create upland habitat and a series of isolated wetlands. The area had once been an extensive natural marsh system.

The authors examined the effect of wetland size and hydrology on anuran use and compared breeding activity across three summers that varied in rainfall amounts. Results showed that species richness was related positively to wetland size but not hydroperiod and that tadpole abundance was not related to wetland size or hydroperiod. Changes in annual rainfall resulted in significant changes in species composition. A drought resulted in no breeding activity. The extensive wetland alterations from the large freshwater marsh to the drier cattle ranch likely shifted the relative abundance of anuran species to those that favor predator-free breeding ponds.

The authors had to sample throughout the year to attain a representative picture of species richness and distribution. This represents a significant commitment in agency personnel and finances to conduct meaningful study of amphibian distribution at the landscape level. Although the study lacked historical information on amphibian species richness, the authors speculated that ditching resulted in a "probable shift in the relative abundance of anuran species toward anurans that associate more strongly with wetlands lacking fish predators."

It is important that an amphibian IBI addresses the great fluctuation in amphibian populations and distributions as a result of annual variation in rainfall. An IBI would also address the substantial time commitment to monitor anurans, in this case 17 months of continuous sampling was required to detect patterns of tadpole occurrence. Although this study did not include research on the relationship between upland habitat characteristics and wetland use, the authors state that such information is important to "increase our understanding of breeding use patterns, as well as our ability to provide guidance for managing anuran populations.

Cohn JP. 1994. Salamanders slip-sliding away or too surreptitious to count? Bioscience 44(4):219–223.

The author explores factors that may be responsible for amphibian declines. He covers the loss of habitat through clear-cutting activity, environmental stresses such as drought, and acidity levels in high-elevation ponds as possible explanations of annual amphibian population fluctuations.

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25–31.

The author created a simulation model of small legally unprotected freshwater wetlands in central Maine to compare metapopulation extinction probabilities before and after the loss of small wetlands for five major taxa found in the study area (salamanders and newts, frogs, turtles, small birds, and small mammals). The model contained 354 wetlands that ranged in size from 0.05–105.26 ha. The model showed that the loss of small wetlands resulted in a high risk of extinction for the most dispersive taxa following wetland loss. In contrast, the least dispersive taxa (salamanders, newts, and frogs) were the most extinction resistant, perhaps due to high population growth rates and high population densities.

The results of this study are relevant to the development of amphibian IBIs, suggesting that monitoring at the landscape scale is necessary to evaluate overall wetland health at the landscape level.

Gibbs JP. 2000. Wetland loss and biodiversity conservation. Conservation Biology 14(1):314–317.

The author examined the effects of human activities on wetland mosaics along an urban-rural gradient surrounding New York City, and compared them to those in a rural section of Maine with minimal human populations. A goal of the study was to capture the physiographic variability of wetlands between regions and the effects of varying levels of human land use.

The results show a strong relationship between human density and wetland density, proximity, and aggregate area. With increasing human density, there was a decrease in wetland clusters and an increase in isolated wetlands. A relationship between human density and wetland density, proximity, and aggregate area was observed with wetlands becoming increasingly isolated at < 1 wetlands/km^2 and an average of >500 m apart. Wetland clusters in more rural areas consisted of 2–5 wetlands/km^2, roughly 200–400 m apart. Dispersal abilities of most wetland animals averages about 300 m (Gibbs 1995, Semlitsch 1998). The author states that clusters of small wetlands are critical to "retain long-term metapopulations of most wetland organisms." Gibbs points out that adaptation to an aquatic existence has imposed severe constraints on the ability of many wetland animals to disperse across the uplands separating wetlands, and that the dispersal of aquatic plants is highly dependent on transport by wetland animals.

The results of this study are relevant to the development of amphibian IBIs and support the argument that amphibian monitoring should take place at the landscape level for collected data to be meaningful. This study also highlights the importance of protecting clusters of small wetlands and conserving wetlands from a landscape perspective.

Hecnar SJ, M'Closkey RT. 1996. Regional dynamics and the status of amphibians. Ecology 77:2091–2097.

The authors observed a decrease in amphibian diversity in the Huron-Ontario and Erie Ecoregions, reflecting population losses of those species. The authors point out that there is virtually no information on large-scale change amphibian population data. Colonization and extinction events may be frequent in an individual wetland that exists within a cluster of wetlands. The authors stress the importance of wetland clusters, upland habitats, and landscape traits for explaining amphibian distribution and abundance. Furthermore, amphibian protection needs to incorporate upland habitat monitoring within other conservation activities.

Kolozsvary MB, Swihart RK. 1999. Habitat fragmentation and the distribution of amphibians: patch and landscape correlates in farmland, Indiana, U.S. Can J. Zool. 77(8):1288–1299.

The authors studied the effects of agriculturally induced fragmentation of forest and wetland habitats on amphibian populations and distribution in Indiana. This study identified potential breeding pools and adjacent upland habitat in 30 forest patches that varied in size and degree of isolation. Amphibians were intensely sampled over two breeding seasons in these patches.

A variety of sampling techniques were used, including pitfall traps, calling surveys, coverboard, minnow traps, and dip nets. The authors found that anuran and salamander assemblages were non-randomly distributed across the landscape and some species were ubiquitous *(Bufo americanus, Hyla versicolor),* whereas others were positively associated with patch size *(Plethedon cinereus).* Several ranid frogs were positively associated with proximity of wetlands, and the degree of wetland permanency was positively correlated with two *Pseudacris* species and the small-mouth salamander.

The study revealed a non-random distribution by several amphibians, which suggests a response to landscape-level attributes. The study also suggests that some amphibians are sensitive to changes in percent cover of upland forested habitat surrounding the breeding pools. In part because of the limited length of the study (data were collected for only two years), the researchers could not conclude that the observed species distributions and densities were natural or human induced. Sensitivity to landscape, hydrological, and habitat variables may narrow the number of species of potential use to an IBI (or a performance standard).

Lehtinen RM, Galatowitsch SM. 2001. Colonization of restored wetlands by amphibians in Minnesota. American Midland Naturalist 145(2): 388–396.

The study monitored 12 wetlands (7 recently restored sites and 5 reference sites) in central and southern Minnesota for one breeding season in 1998 to compare colonization by amphibians and to identify the important factors influencing the probability of colonization.

The recently restored wetlands were colonized by 8 amphibian species and established breeding populations. The reference wetlands were inhabited by 12 species, including 4 not found in the restored wetlands. No amphibians were found only in the restored wetlands. There was evidence of successful breeding, determined by the capture of late-stage larva or metamorphs. Wetland size and spatial isolation were important predictors of species richness, while habitat variables such as water chemistry or aquatic vegetation cover were not.

This study represents only one breeding season in a recently restored wetland, so its predictive power is therefore limited. Although longer monitoring periods are generally required to determine success, the results do support other studies (Babbitt and Tanner 2000) that indicate the potential value of restored wetlands to amphibians.

Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349–3 77.

The authors studied 15 research sites along 14 low-order streams. Sites represented a land-use gradient from least to most impacted. Vegetation, aquatic macroinvertebrates, amphibians, fish, and birds were surveyed between July 1995 and September 1996. Insects and leeches were identified to family; snails were identified to the lowest level possible. Plants, fish, amphibians, and birds were identified to species. The study observes that "birds are the best indicator of landscape condition within the near vicinity of small stream riparian wetlands while fish community composition corresponded to broader landscape land use patterns. In contrast, vegetation, amphibian, and invertebrate communities are weaker predictors of land use impacts. For amphibians, low indicator potential is likely attributable to inherently low faunal diversity for the (five species in this study)." Amphibian abundance increased with percentage of open water in the landscape, this is interesting in that the species in the study tend to be more selective for open water. This study indicates that population parameters, rather than community composition, may be more sensitive for detecting land use relationships for amphibians.

Olson DH, Leonard WP, Bury RB (eds). 1997. Sampling Amphibians in Lentic Habitats. Northwest Fauna 4, Olympia, WA, USA.

This book presents standardized survey methods for pond-breeding amphibians in the Pacific Northwest. Because surveys for amphibian assemblages are complicated by the great diversity of lentic habitat types and species-specific factors affecting detection, this book is presented as a tool-box of methods and guidance. The authors stress that developing a standardized survey design and methodology at the regional scale is critical for species management and conservation.

The book includes methods for designing amphibian studies, including sampling methods, equipment, data collection and interpretation. The authors propose using multiple methods to achieve a comprehensive profile of lentic amphibian assemblages.

The book points out the numerous considerations that must be taken into account when sampling for amphibians. Factors that can affect species detection include temporal variation in breeding seasons, the potential for great fluctuation in population number, difficulty detecting rare or cryptic species, distribution based on life history stages and environmental factors such as habitat requirements, elevation, substrate, associated plants, presence of fish, land use history, weather, and water velocity and quality.

Paton PWC, Crouch WB. 2002. Using the phenology of pond-breeding amphibians to develop conservation strategies. Conservation Biology 16(1):194–204.

The authors monitored the timing of movements of adult and recently metamorphosed frogs and salamanders at seven small isolated wetlands in southern Rhode Island. Different species of amphibians required ponds to be flooded for 125 to at least 580 days. For species that breed primarily in seasonally flooded ponds, 95 percent of the metamorphs emigrated from breeding ponds by 31 July.

In contrast, species using semipermanent ponds required inundation for 4–9 months.

This study supports the importance of multiple years of monitoring if amphibians are used as a monitoring metric. Under optimal conditions in this study, pools in Rhode Island would be flooded for 4–9 months (from March to August) for successful reproduction of the majority of pond-breeding amphibians. The authors recommend that biologists collect data on amphibian movement phenology to help regulators and managers develop relevant legislation to protect temporary pools and adjacent uplands. The study also recommends that regulatory agencies consider wetland isolation, wetlands size, and pond hydroperiod to protect pond-breeding amphibians.

Pechmann JHK, Estes RA, Scott DE, Gibbons JW. 2001. Amphibian colonization and use of ponds created for trial mitigation of wetland loss. Wetlands 21(1):93–111.

The study examined amphibian colonization and use of four created ponds and compared them with populations observed at the original site before it was filled and to an undisturbed reference wetland to observe whether a specific wetland function (providing habitat for a selected group of animals) would be successful. The created ponds became permanent, but the other ponds were temporary. Toward the end of the study, the community structure of adult and juvenile amphibians differed, not only among the created ponds, but also between the created ponds and the original site and the reference site. The authors observe that "differences between the created ponds and the natural wetlands were likely related to differences in their hydrologic regimes, size, substrates, vegetation, and surrounding terrestrial habitats and to the limited availability of colonists of some species."

The amphibian community structure of the created wetlands differed. The study observed some compensatory mitigation (some amphibians colonized the pools) for the loss of the filled wetland. Three years of monitoring at the original site prior to construction showed considerable variation in breeding population size compared with the created sites. Some species at this site had no recruitment, while recruitment for others was low or sporadic.

This paper highlights the necessity of recreating hydrologic regimes, size, substrates, and surrounding terrestrial habitats in mitigated wetlands to ensure that the replacement wetland can function in a manner that is similar to those of the original wetland. Breeding population size varied greatly at both the created and reference wetlands, emphasizing the challenge in evaluating the success of mitigation projects using amphibian density, richness, and health as monitoring tools. It also points to the need for monitoring periods that exceed the typical three-year period.

Petranka JW, Murray SS, Kennedy CA. 2003. Responses of amphibians to restoration of a southern Appalachian wetland: perturbations confound post-restoration assessment. Wetlands 23(2):278–290.

The authors conducted an 8-year study to examine the demographic responses of two amphibian species to wetland creation at a mitigation bank in western North Carolina. The study compared juvenile recruitment in 10 reference and 10 constructed ponds to look at overall changes in breeding population size in response to restoration efforts.

The study used annual censuses of egg masses to assess changes in breeding population size and estimates of larval population size at hatching and onset of metamorphosis to assess embryonic and larval survival. Adults of both species bred in most of the constructed ponds within a few months after they had filled with water. Juvenile production from 1996 to 2002 did not differ significantly between created or natural pools, but drought and a pathogen caused a marked decrease in juvenile output from both pools from 1998 to 2002. Spotted salamanders remained relatively stable from 1995 to 2002, which the authors attributed to selection for delayed reproduction and iteroparity in that species.

The authors discuss the fact that regulatory agencies in the United States typically require 3–5 years post-restoration monitoring of biotic responses to wetland mitigation, however many researchers have argued that this is not long enough, particularly for amphibians. The authors state: "Because amphibians have significant population lags and are sensitive to site perturbations, monitoring exceeding five years may be required to assess demographic responses to site restoration."

Richter KO, Azous AL. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound Basin. Wetlands 15(3):305–312.

The authors studied patterns of amphibian distribution in 19 wetlands in the Puget Sound Basin in King County, Washington, from 1988 through 1991. Amphibian richness was analyzed relative to wetland size, number of vegetation classes, and the hydrologic characteristics of water flow, water-level fluctuation, water persistence, and urbanization. Results demonstrated that changes in water regimes associated with storm water retention limit reproductive potential.

Higher average water-level fluctuation and percent watershed urbanization were correlated with low species richness. However, species richness was not related to the seasonal persistence of water. The total number of species was not related to wetland size, distance to other wetlands favorable for breeding fish and bullfrogs, or the number of vegetation classes found at a wetland. The authors recommend that jurisdictions take a conservative approach to manage land use and storm water to minimize flow velocity in the developing watersheds of wetlands.

The authors suggest that reduced protection of small wetlands may be detrimental to amphibians. Small (between 0.2 and 2.0 ha) and structurally simple wetlands often have high value as amphibian habitat; however, historically these are the wetlands most frequently lost to development. They recommend that more consideration be given to evaluation within a landscape context to protect smaller wetlands.

This article underscores its relevance to the development of performance standards for mitigation of wetlands because it addresses hydrology and wetland diversity at the landscape level, and it makes an argument for the protection of smaller wetlands that have high value as amphibian habitat.

Semlitsch RD. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12(5):1113–1119

The author draws on data obtained from published literature and unpublished dissertations for six species of pond breeding amphibians in five states. He finds that adult salamanders use aquatic habitats for reproduction during specific seasons of the year—some species spend only a few weeks in the water before returning to upland habitats that are critical to their survival. In this study, adult salamanders were found in uplands an average of 125 m from wetland edges.

This study stresses the importance of protecting both wetland and upland habitats for amphibians that depend on both for their survival. This paper supports the argument that an IBI for amphibians should be conducted at the landscape level. It strongly recommends that managers consider the importance of buffer zones to "protect critical upland and wetland habitat assemblages required for survival in addition to reducing the potential for edge effect. This study further supports the importance of wetland clusters in close proximity that providing the opportunity to colonize new sites following an extinction event."

Semlitsch, RD. 2000. Principles for management of aquatic-breeding amphibians. J. Wildl. Manage. 64(3):615–631.

The author provides an overview of potential threats to local and regional amphibian populations, a summary of knowledge on population and landscape processes, and information required to develop effective management plans for amphibians. Three critical factors are highlighted for development of a management plan: (1) the knowledge of the number or density of individuals dispersing from individual wetlands, (2) the diversity of wetlands in terms of hydroperiod, and (3) the probability of dispersal among adjacent wetlands.

The paper addresses components of amphibian biology that would make the development of an effective IBI or a performance standard difficult. These difficulties include naturally wide fluctuations in amphibian breeding and larval populations and the consequent importance of long-term monitoring to collect meaningful data. The authors also discussed potential management conflicts, for example, fish introduction and hydroperiod alteration (flooding and draw-downs) for management of waterfowl will negatively impact amphibian populations. In addition, the time and financial commitment required to collect meaningful data are challenging for IBI or performance standard development. The importance of hydrology in maintaining or creating wetland diversity or complexes is discussed and lends support to the HGM method, suggesting it may be a consistent empirical method of collecting information.

Semlitsch RD, Bodie JR. 1998. Are small, isolated wetlands expendable? Conservation Biology 12(5):1129–1133.

The authors express concern that regulations drafted by the U.S. Army Corps of Engineers reduce protection for "headwater" or "isolated" wetlands. These small wetlands are critical breeding habitat for many amphibian species and are important for maintaining wetland flora and fauna.

The loss of small wetlands will limit amphibian dispersal and increase dispersal distances, thereby impeding the rescue effects at the metapopulation level. A reduction in wetland density could decrease the probability that a population could be rescued by a source population. The article supports the idea that use of amphibians as a performance standard would require a landscape approach for collection of meaningful data.

Snodgrass JW, Komoroski MJ, Bryan AL, Burger J. 2000. Relationship among isolated wetland size, hydroperiod, and amphibian species richness: implications for wetland regulations. Conserv. Biol. 14(2):414–419.

The authors surveyed larval amphibians and fish in 25 relatively pristine depression wetlands on the upper Atlantic coastal plain of South Carolina to look at the relationship among hydroperiod length, fish presence/absence, and larval amphibian assemblage structure. The highest amphibian species richness was found in wetlands that contained water for 8–10 months per year.

Wetlands with water for longer periods (those that dried only during extreme drought) often contained fish and had relatively low amphibian species richness. "Most species occurred along a restricted portion of the hydroperiod gradient, while some species were found almost exclusively in wetlands with fish. Their results identified 4 groups of wetlands with similar assemblage structure: (1) short (drying in spring), (2) medium (drying in summer), (3) long (drying in fall or semi-annually) hydroperiod wetlands without fish, and (4) long hydroperiod wetlands with fish.

This paper supports the importance of variety in hydrology functions as they relate to preserving or mitigating for wetland diversity to support a variety of species assemblages.

U.S. EPA. 2002. Methods for evaluating wetland condition: using amphibians in bioassessments of wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, D.C., EPA-822-R-02-022

The authors are cautious about the utility of amphibians as indicators of wetland health. They note that scientists are "still in the exploratory stages and should proceed to investigate amphibians as a useful taxon for monitoring the biological integrity of wetlands with care." However, of all the vertebrate groups associated with wetlands, amphibians may give the best opportunity to develop landscape level bioassessments. Suggested attributes for metrics include species richness, comparisons of species presence/absence, proportion of nonindigenous species, frequency of malformations, evidence of mass mortality, number and condition of egg masses, ratios of the relative abundances of different life stages, percent of tolerant and intolerant species, mensural characteristics, proportion of neotenic and metamorphosed adult salamanders, percent of individuals parasitized or diseased (by trematodes, fungus or iridoviruses), and presence and concentrations of contaminant residues in bodies.

The authors point out several problems with using amphibians as bioindicators. Species richness, for example, may not be a useful metric for amphibians because the diversity of amphibians in an individual wetland is often much smaller than that of other taxa (e.g., vegetation, fish, birds, algae, invertebrates) and thus are too small to provide meaningful comparisons. Similarly, another commonly used metric comparing species presence/absence using regional taxonomic lists is problematic because of unpredictable natural flux in amphibian population numbers. Reliable data on community characteristics may require multiple sampling within a year due to breeding phenology, particularly in southern regions where amphibians may be active throughout the year. This may require more work than using other taxa as indicators (e.g., macrophytes, fish, algae, aquatic invertebrates).

The authors caution against "regarding regional diversity and distribution patterns, using amphibians species and diversity or abundance in a single wetland as a surrogate for wetland health or as a tool for assessing the status of that species can be misleading without some knowledge about what is happening in adjacent wetlands."

FISH ARTICLES

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for monitoring biological integrity of inland, freshwater wetlands: a survey of North American technical literature (1990–2000), Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

The authors of this EPA publication review the attempts of others to construct fish-based IBIs for wetlands. The publication also discusses studies on the effects on fish of contaminant toxicity, enrichment, eutrophication, reduced DO, acidification, salinization, thermal alteration, vegetation removal, turbidity, shade, dehydration, inundation, and stressors. Many of the articles the authors review are discussed in greater detail in this report. The publication is a highly valuable annotated bibliography of studies that have attempted to create fish-based IBIs in wetlands.

Balderas S, Edwards R, Lozano-Vilano M, Garcia-Ramirez ME. 2002. Fish biodiversity changes in the Lower Rio Grande/Rio Bravo, 1953–1996, a review. Reviews in Fish Biology and Fisheries 12: 219–240.

The authors examined changes in water quality, flora, and fauna in the Lower Rio Grande/Rio Bravo (Texas and Mexico) over a 45-year period, focusing on fish community attributes. The study observed that progressive reductions in the amount of runoff to the river were correlated with reductions in the size and richness of fish communities, a connection that may be linked both to the direct effects of reduced runoff on fish communities and to the higher salinity conditions that runoff reduction generates. Water temperature increases led to an increase in euryhaline species at the expense of nearctic species relatively more sensitive to turbidity, siltation, salinization, dewatering, invasive species, and warming. Loss of quantity and quality of freshwater and habitat corresponded to decreases in primary fish populations and increases in secondary, peripheral, and marine fish populations.

Although the study does not address wetlands, its general observations about the impact of changing hydrologic conditions on fish communities are relevant for the development of wetland performance standards. It suggests that fish assemblages could be used to measure changes in wetland salinity and temperature, and that declines in fish population size or richness could indicate inadequately replicated or poorly functioning runoff patterns in a created/mitigated wetland watershed.

Beck MW, Heck KL, Able KW, Childers DL, Eggleson DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. Issues in Ecology 11 (Spring): 1–12.

The authors reviewed the literature (more than 200 papers) on salt and mangrove marshes and seagrass meadows as nurseries for fish and shellfish. Although the article focuses on nearshore wetlands as nurseries, some observations are applicable to general wetland assessment. Like many others, the article emphasizes that metrics that assess wetland health by stock recruitment, density, or any other single factor are not adequate. Rather, assessment metrics should focus on habitat function.

For a nursery wetland, a habitat function approach involves measuring fish and invertebrate growth by assessing total biomass of individuals added to the general population from the juvenile habitat. An appropriate metric also would measure the movement of juveniles to adult habitat.

The authors note that few studies have addressed the impact of wetland quality on either of the nursery functions described above. While these function metrics ideally would be included in a set of wetland performance standards, too little research may exist to operationalize them.

Chamberlain RH and Barnhart RA. Early use of fish in a mitigation salt marsh, Humboldt Bay, California. Estuaries 16(4): 769–783 (1993).

The authors compared one natural salt marsh and one created salt marsh located in northern California, sampling relevant variables for 16 months. The study found that the intertidal area of the mitigation marsh was dominated by euryhaline sticklebacks and topsmelts, whereas the natural salt marsh it was intended to replicate was used extensively by English sole. The natural marsh also was characterized by more stable water salinities and temperatures than the created marsh.

Only the abstract was available for this article; the complete article may contain more information and analysis that could inform performance standards.

Dionne M, Short FT, Burdick DM. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384–404.

The authors studied fish communities in three created and four restored salt marshes and seven natural marshes (paired comparison) in the Gulf of Maine over a two- or three-year period (depending on site), sampling twice annually and beginning one to five years following marsh creation or restoration (eight years after for one site).

The study found few significant differences in fish density, total length, or species number when paired sites were compared. Average density and average total lengths of large fish generally were similar, although there was a trend for larger average sizes for large fish in the reference marshes.

The article discusses considerations for site comparison relevant to the specification of performance standards, noting that marsh elevation, pattern of inundation, and low and high zones should be similar between the reference and created site for a valid comparison. This observation indirectly attests to the importance of hydrologic and geomorphic attributes in wetland performance.

The article is also valuable for its commentary on its weaknesses and what its findings cannot conclude: "Visitation is necessary but not sufficient evidence for the value of restored and created marshes as fish habitat. From the results of this study, we cannot determine how fish growth and survival in manipulated marshes compares to that in natural marshes…studies (indicate)…that invertebrate prey abundance and availability for fishes can be significantly reduced in created marshes during the first 10 to 20 years post-creation…Measures of fish feeding or growth should be added to the criteria…" In other words, the authors echo many others by arguing for biomass and habitat function metrics rather than simple, presence/absence-type standards.

Drake M and Pereira D. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. North American Journal of Fisheries Management 22: 1105–1123.

The authors studied fish attributes in natural lakes in Minnesota over two years, sampling twice annually. The lakes were selected to represent a watershed disturbance gradient, defined by percentage and type of land cover, population density, and hydrologic characteristics.

The article proposes an IBI that includes measures of insectivore relative biomass, relative abundance and biomass of tolerant fishes; omnivore relative biomass; top carnivore relative abundance and biomass; intolerant species relative abundance and biomass; native, insectivore, and cyprinid species richness; small benthic and vegetation dweller species richness; omnivore and intolerant species richness; relative abundance of intolerant species; and relative abundance of small benthic and vegetation-dwelling species.

Relevant to the construction of specific performance standards are the observations that biomass metrics generally showed a stronger response to differences in lake integrity than did abundance metrics, and richness and community composition metrics describing intolerant or habitat specialist species were most sensitive to human-induced stress.

More generally relevant to the performance standards issue is the authors' argument that effective lake evaluation matches IBI to lake class. Because multiple stressors influence aquatic ecosystems, an IBI will be most descriptively powerful when it can attribute lake conditions to a specific group of stressors; this connection can only occur if stressor/disturbance conditions have been assessed previously. This conclusion is particularly relevant to wetland evaluation because it suggests that more specific classification of wetlands—classification not only by wetland type, but also by disturbance type and extent—may be necessary before an IBI or other group of performance standards can provide accurate indications.

Fonseca MS, Kenworthy WJ, Colby DR, Rittmaster KA, Thayer GW. 1990. Comparisons of fauna among natural and transplanted eelgrass *Zostera marina* meadows: criteria for mitigation. Marine Ecology Progress Series 65: 251–264.

The authors studied fish and macroinvertebrate populations in one mature natural saltwater wetland (eelgrass meadow) and two created wetlands—one transplanted 1.9 years prior to the study and one seeded only 6 months prior—located on the Mid-Atlantic coast for alternating months, from January to September 1986.

The study found that fish abundance and composition at the created sites were "indistinguishable" from those variables in the natural bed, and that shrimp abundance at one created site varied significantly from the abundance at the reference site while abundance at the other created site was comparable. Despite these observations, the authors caution that "abundance data need to be interpreted through functional mechanisms such as predation which act to produce the observed abundances in order to separate habitat function from dysfunction…"

The faunal population structures between the 1.9-year-old transplanted marsh and the natural marsh seemed to converge around year two, when the eelgrass population stabilized; the authors interpreted this finding as indicating that faunal populations stabilize when eelgrass populations stabilize. They hypothesized that the rate-limiting factor for faunal development in eelgrass meadows is eelgrass shoot abundance.

The outgrowth of this conclusion is the innovative aspect of the article. The authors then used vector-graphical analysis to quantify and project marsh maturation. They measured functional equivalence not by a constant level, but rather in terms of the overlap between the faunal/shoot abundance ratios of the natural and mitigated sites. The key performance standards in this analysis were percentage similarity and percentage species shared.

The article illustrates how vector-graphical analysis might be used to develop performance standards, linking the dominant vegetation type with the fauna it supports and providing a basis for assessing wetland maturation. However, caution must be exercised: as other articles point out, researchers cannot assume that any floral or faunal wetland component follows a linear vector toward population maturity. (This article does not address this concern and seems to have followed a linear model in the vector analysis).

Hampet H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60: 278–289.

The authors studied one natural and one restored estuary located in the Netherlands, sampling five months out of a period of seven and, within that period, sampling every six weeks for two consecutive days, and beginning the investigation ten years following the dyke breach that restored the altered estuary.

The study found no clear differences in species composition in the fish or macroinvertebrate communities assessed; community structures were seasonally similar. However, biomass was significantly higher in the natural marsh, and species abundance and length of frequency distribution also varied significantly between the marshes. The restored marsh had relatively lower amounts of macroorganic material.

The authors suggest that food availability caused the observed difference in biomass and density of sampled species, and that food availability was linked to macroorganic matter quantity. Higher quantities of macroorganic matter provide more food resources for detrivorous benthic animals, influencing both numbers of macrobenthic invertebrates and fish consumers. They also suggest that the dissimilarities in frequency distribution between the marshes indicate "a different use of the marsh creek habitat by the estuarine nekton."

The article is relevant to the performance standards issue for three reasons. First, it illustrates the importance of macroorganic matter in wetland development and suggests that standards based on macroorganic matter presence and accumulation may be appropriate. Second, it supports other arguments that biomass measures are effective indicators of wetland condition. Third, it observes that "though rapid colonization of a new marsh habitat in high numbers seems the rule, fish assemblages do not develop in a linear fashion over time"—an observation that should be noted in the context of current interest in developing trajectories (typically linear) for wetland development.

Harig A, Bain M. Defining and restoring biological integrity in wilderness lakes. Ecological Applications 8(1): 71–87 (1998).

The authors studied 12 small lakes in the northeastern United States' Adirondacks region over a three-year period. The lakes represented an environmental gradient, and the authors sampled the resident fish, phytoplankton, and cladoceran taxa to create a region- and ecosystem-specific IBI.

The authors experimented with multiple indicators and found six that were sensitive to disturbance: dominance of native fish, relative abundance of the cladoceran *Daphnia,* dominant phytoplankton taxa, number of zooplankton species, dominance of large-bodied zooplankton, and zooplankton biomass. Lake communities with relatively high biological integrity were characterized by native fish communities, zooplankton communities with relatively greater species richness, biomass, and larger species, and phytoplankton communities with few dinoflagellates.

The article is most valuable for its description of the process of selecting indicators and IBI construction. It argues for the importance of species composition metrics as performance standards: "Species composition of the communities may be the earliest warning of disturbance because feedback mechanisms such as species replacement would buffer system functions against significant alteration." Also, as with other articles about small water bodies, the article notes that small systems often are species-poor which is problematic for IBI development, and an accurate IBI needs to include multiple taxa.

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21–27.

This article was one of the first to propose an IBI based on fish communities. Karr created the fish IBI based on years of study of fish behavior in streams and rivers; he and other scientists subsequently refined and employed the IBI in river, stream, and lake assessment projects.

The original Karr IBI included 12 fish community parameters, divided into two categories: species composition and richness, and ecological factors. While the specific parameters may not be directly relevant for the purposes of performance standards development, they are useful to discuss; the article highlights the importance of intolerant species and presence of hybrids as indicators of habitat degradation, and these observations are just as relevant to wetlands. Like scientists who wrote about or developed IBIs in later years, Karr discussed the importance of measurements estimating production and consumption dynamics. Although the fish IBI includes some of these types of metrics (for example, presence of top carnivores), it does not include measures that Karr suggests are meaningful but perhaps difficult to construct and employ: metrics assessing reproductive guilds, age structure, growth, and recruitment.

The IBI process relies on accurate baseline data collection, a sample representative of fish at the sample site and in the larger geographic area of interest, and a researcher's ability to adjust the IBI to local conditions. The IBI concept is directly relevant to the creation of performance standards, as is a quote from Karr: "…in the best circumstances, a biological monitoring program should be based on an integrative approach involving evaluation of several major taxa."

Langston MA, Kent DM. 1997. Fish recruitment to a constructed wetland. Journal of Freshwater Ecology 12(1): 123–129.

The authors studied fish assemblages in one created wetland located in east central Florida over a two year-period, sampling quarterly for three days per week in three consecutive weeks and beginning three weeks after wetland construction was completed. The authors compared the assemblages to data on fish assemblages in nearby natural and constructed marshes drawn from species lists and previous research.

The study found that some species in the created wetlands exhibited similar assemblages to the nearby natural and constructed wetlands, and other species exhibited dissimilar assemblages. It generally concluded that an abundant fish community with species richness that compared favorably to other constructed marshes and a composite of nearby natural and constructed marshes was achieved within one year in the created wetland examined.

Although likely valuable for other purposes, the article has limited applicability for performance standards.

LaSalle M, Landin MC, and Sims JG. 1991. Evaluation of the flora and fauna of a *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191–209.

The authors studied two created saltwater wetlands, aged four and eight years, located on the South Carolina Atlantic coast. They sampled the wetlands twice in September of 1988 and compared findings to descriptions in scientific literature of similarly located and constructed natural marshes.

The study found that the proportions of sand, silt, clay, and organic compounds in the created marshes were similar to the proportions observed in a nearby natural marsh, and the values of above- and below-ground biomass and species composition metrics compared well with those reported for natural *Spartina alterniflora* marshes on the Atlantic and Gulf coasts. Dominance and density of oligochaetes and polychaetes, fish and shellfish assemblages, and gut contents of dominant fish species were all within the range observed in nearby marshes. The authors concluded that any observed differences in density or distribution of macrofauna species probably "are largely related to age or perhaps the distance to open water."

The article supports claims that it is possible to establish a functionally similar marsh in a short time frame. However, this support may not be particularly substantial, given that the article bases conclusions on a small number of sampling events over a short time period, and only two created wetlands were compared to non-specific reference sites.

Layman CA, Smith DE. 2001. Sampling bias of minnow traps in shallow aquatic habitats on the eastern shore of Virginia. Wetlands 21(1): 145–154.

The authors studied 15 natural estuaries in eastern Virginia over a 14-month period, comparing minnow collection/sampling techniques (use of seines versus use of minnow traps). The article is highly critical of passive sampling devices in general and minnow traps in particular. It suggests that these devices are species-selective, have low and variable catch efficiency, and cannot make quantitative density estimates, among other biases. It notes that these biases have been observed previously, but usually in freshwater environments; nonetheless, the same problems arise when the devices are employed in wetlands. Specifically, in the estuaries sampled, the minnow traps biased toward the collection of *Fundulus heteroclitus* and biased against the collection of several other resident species and juveniles of estuarine transient species.

The article's relevant conclusions are that species-specific fish behavior must be taken into consideration when a researcher selects sampling tools, and that passive sampling devices should not be selected to measure fish density. These observations are relevant to the implementation of performance standards, although less relevant to their development.

Lyons J, Navarro-Perez S, Cochran P, Santana E, Guzman-Arroyo M. 1995. Index of biotic integrity base on fish assemblages for the conservation of streams and rivers in west-central Mexico. Conservation Biology 9(3): 569–584.

The authors studied 27 sites located in streams and small rivers in west-central Mexico from 1986 to 1991. The group of sites spanned a range of environmental quality, and their study allowed the authors to construct a fish-based IBI for the aquatic system.

The regionally applicable IBI consisted of ten metrics: number of native species, water column species, sensitive species, percentage benthic species, tolerant species, exotic species, omnivores, native live-bearing species, diseased or deformed species, and relative abundance. Fish assemblages at the least-degraded sites had relatively high numbers of native species, a mix of water column and benthic fish species, one or more sensitive species, low to moderate abundance of tolerant and exotic species, a small number of herbivores, carnivores, or both, and a high abundance of native live-bearing species. Degraded sites had relatively lower numbers of native species and native benthic species, had few or no sensitive species, had greater percentages of tolerant, exotic, and omnivorous species, and had fewer water column species.

The article is particularly valuable for its description of the process and considerations associated with IBI construction. Relevant to our current research is its observation that "versions of the index of biotic integrity also could be developed for…estuaries and nearshore marine environments…The use of a wider range of species-composition and trophic function metrics, including at least one for plankton or filter-feeding species, would probably be warranted in these waters."

Minello TJ, Able KW, Weinstein MP, Hays CG. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progress Series 246: 39–59

The authors reviewed 32 studies concerning salt marshes as nurseries for nekton. The authors intended to assess studies from around the world, but found that most of the relevant studies took place the in the U.S. Southwest (Galveston Bay, Texas) and Mid-Atlantic.

The study used meta-analysis to compare the nekton fostering capacity of salt marshes, seagrass meadows, and open water habitats. Although the mechanics and the conclusions of the study are less relevant for performance standards, the authors' observations on habit function metrics are relevant and reflect the arguments of other authors: "Relatively few studies have examined growth rates of transient nekton species in salt marshes…no single technique appears to adequately address experimental difficulties…encountered in the measurement of habitat specific growth rates for nekton….While habitat-specific growth should be an important measure of nursery value, there are insufficient data available to use growth rates for effectively comparing marshes with other habitat types."

Minello TJ and Webb JW Jr. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. MEPS 151: 165–177.

The authors compared five natural salt marshes and five created salt marshes located in the U.S. Southwest, sampling relevant variables twice annually in 1990 and 1991 and beginning 3–15 years after marsh creation. They found that the size and density of macroinfauna were significantly lower in the created marshes.

The study found that daggerblade shrimp size was significantly smaller in the created marshes relative to the natural marshes. Shrimp, fish, mollusc, macroorganic matter, and macroinfauna density were significantly lower in the created marshes relative to the natural marshes. Macroinfauna species richness also was relatively lower in the created marshes, but the two marsh groups did not differ significantly in nekton species richness.

Although marsh age explained some variance in macroorganic matter density, it did not explain the variance in nekton densities. Rather, the authors conclude that tidal flooding was an important explanatory factor for nekton and decapod crustacean densities because tidal flooding (often in combination with elevation) determined the availability of marsh surface for nekton. The natural marshes in the study had flooding durations in the 74–80 percent range, but the created marshes were flooded over the wider range of 43–91 percent.

Sediment macro-organic matter was also lower in the created marshes, which also had wider flooding duration ranges and ranged to a much lower level. The created marshes "exhibited much higher variability in monthly flooding durations than the natural marshes," whereas the tidal flooding regime in the natural marshes had consistently low elevations and high flooding durations. The flooding regime affected nekton densities at the marsh surface.

The article's relevance to the development of performance standards for mitigation wetlands is its suggestion that an ideal tidal flooding duration range might exist for particular types of wetlands in particular regions—that is, a range that generally supports macroinvertebrate and nekton populations similar to those in natural marshes. If these ranges could be developed, they could be later applied to mitigation wetlands as performance standards.

Moy LD and Levin LA. Are *Spartina* marshes a replaceable resource? a functional approach to evaluation of marsh creation efforts. Estuaries 14(1): 1–16 (1991).

The authors compared two natural salt marshes and one created salt marsh located on the Mid-Atlantic coast over a three-year period, beginning one year following marsh creation.

The study found that sediment organic content and fish numbers (abundance) were lower in the constructed marsh relative to the natural marsh. Natural marsh sediments were inhabited primarily by subsurface, deposit-feeding oligochaetes, but the constructed marsh was dominated by tube-building, surface-feeding polychaetes. Natural marsh fish diets contained more detritus and insects, but polychaetes and algae were major components of fish diets in the constructed marsh. *Spartina* stem densities also were relatively lower in the created marsh.

The authors suggest that fish abundance was lower because the *Spartina* stem density provided insufficient protection from predation or insufficient spawning sites. The article also discusses the importance of tidal flooding to wetland community composition.

While the article does not explicitly address performance standards, possible standards could be extrapolated from its findings: standards based on assessments of fish diets, for example, or on *Spartina* (or other dominant plant, depending on region and type) stem densities. These types of standards would rely on baselines, such as those for "ideal" fish diets and"ideal" stem densities.

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606–627.

The authors assessed previously collected fish, HGM, and hydrological data spanning 21 to 55 years (median 45 years) for 34 streams representing a gradient of hydrologic variability in Minnesota and Wisconsin. They sought to determine if fish assemblages and stream hydrologic characteristics could be correlated.

The study found that hydrologic data clearly separated sampled fish assemblages into two groups, one associated with hydrologically variable streams and the other associated with hydrologically stable streams. Variable habitats supported weakly interactive resource opportunists with generalized strategies for exploiting changing resources, while stable habitats were characterized by relatively higher proportions of highly interactive specialist species limited by stable resources. Variable streams were characterized by slower fish, more silt-associated fish, and more small stream fish, while more stable streams had more fast and medium velocity, rubble-associated fish. Species were more wide-ranging in variable streams.

The study supports the idea that is the basis for fish based-IBIs in lakes, streams, or wetlands—that fish can be indicators of water body condition: "Certain hydrological factors, particularly fluctuations in baseflow, can indicate habitat persistence for fish and thus provide information on the suit of species traits (and corresponding species) most likely to be favored under a particular hydrologic regime."

Rulifson RA. Finfish utilization of man-initiated and adjacent natural creeks of South Creek Estuary, North Carolina using multiple gear types. Estuaries 14(4): 447–464 (1991).

The authors compared two natural creeks and one created creek located on the Mid-Atlantic coast over a five-year period, beginning one year following creek creation.

The authors measured fish numbers (abundance) in each creek type, but found that results highly depended on the sampling gear type used. With trawl sampling, the total numbers of finfish collected in both types of creek were statistically similar, and spot fish were more abundant in the constructed creek relative to the natural creeks. However, Wegener ring analysis indicated a greater finfish catch in the created creek relative to the natural marshes, and found that spot was more abundant in the created creek relative to one natural marsh but statistically equivalent to the spot numbers in the other natural marsh.

The article underscores the point that decisions about the sampling techniques used in data-gathering for performance standard assessment can have a significant impact on assessment results. These decisions must be made by experts familiar with sampling techniques and the species to be sampled, as well as the region and wetland type generally.

Simenstad CA, Cordell JR. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3–4): 283–302 (2000).

The authors studied wetland restoration sites of various ages located in multiple Pacific Northwest river estuaries. They evaluated wetland performance based on the restoration site's ability to provide functional habitat for salmonid species. The article focuses on their recommendations for functional assessments and performance standards rather than on the site-specific findings.

The authors propose a three-tier functional habitat assessment framework that evaluates wetland performance based on salmonid use, rather than a framework based on short-term variables (such as occurrence or abundance) that do not indicate whether the wetland is or will be functional in the longer term. The framework includes (1) capacity metrics—habitat attributes that promote juvenile salmonid production and include quantity and quality of invertebrate prey and physicochemical conditions that maintain prey communities; (2) opportunity metrics—assessments that measure the capacity of juvenile salmonids to access and benefit from the habitat's capacity and that include tidal elevation, flooding, and geomorphic features, as well as strength of cues that might attract juveniles; and (3) realized function metrics—direct measures of physiological or behavioral responses to habitat, including habitat-specific residence time, foraging success, and growth. All these metrics would depend on baselines constructed from historical information about salmonid structure and function. Also, the authors stress the importance of evaluating landscape and system attributes.

This framework for performance standards and the theory underlying it could be applied generally to other types of wetlands and other fish, macroinvertebrate, bird, or even mammal species. The article contains valuable theoretical arguments for habitat-based, functional assessment metrics.

Simon TP. 1998. Modification of an index of biotic integrity and development of reference condition expectations in dunal, palustrine wetland fish communities along the southern shore of Lake Michigan. Aquatic Ecosystem Health and Management 1(1): 49–62.

The authors studied 36 fish community characteristics in 27 dunal and palustrine wetlands over a three-month (summer) period to develop reference expectations for dunal wetlands less than 35 ha in surface area.

Based on their observations, the authors modified the Karr IBI to describe palustrine wetlands. Modifications included replacing sucker species with a number of minnow species, combining darter measures with measures of other species with similar niche requirements, including the number of centrarchid species in the number of sunfish species metric, replacing percentage of carnivores and percentage of hybrids with percentage of pioneers and percentage of lake obligate species, and eliminating the percentage of carnivores metric for measuring trophic structure. They described necessary modifications to the IBI's implementation, such as using DELT anomalies only if adult specimens were collected and scoring percentage metrics as "one" if fewer than 25 fish were collected. Finally, they described the metrics from the Karr IBI that they retained as valid for palustrine wetlands.

The authors noted problems with using fish-based IBIs to assess small wetlands, noting that wetlands between one and two ha often possess two or fewer fish species and, in small wetlands in general, low catches may cause IBI scoring problems because at low population levels, the normal population of a community is unpredictable and often generates index score over-rating.

The article is useful to the discussion of performance standards because it is one of the few that proposes a fish IBI metric for a wetland rather than for streams or lakes, and comments on the substantial considerations necessary for modifying a fish IBI assessment tool for use in wetlands.

Simon TP, Jankowski R, and Morris C. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3): 407–418.

The authors studied 62 natural palustrine wetlands and vernal ponds located in the northern Midwest, evaluating them per reference conditions drawn from 25 similarly located wetlands selected to represent wetland conditions along a land disturbance gradient. The authors studied the wetlands over a one-month period and used their observations to construct an IBI based on fish, amphibians, and macroinvertebrates.

The article indicates that small wetlands often possess low species richness, may be unable to sustain reproducing fish assemblages, often have greater numbers of omnivores than larger wetlands, and generally have few pioneer species and sensitive species and either all or no tolerant species. These conditions distinguish small wetlands from both larger wetlands and lakes and streams (the latter of which form the basis for most IBIs), and suggest necessary IBI modifications:

IBIs for small palustrine wetlands and vernal pools should incorporate a mix of taxonic groups, should include substitutes for niche-specific benthic species used in other IBIs, and should consider relative amphibian and crayfish species densities as indicators of wetland conditions. Also, an IBI that uses “0 and 1” classifications rather than low-end scoring gradations is effective for small wetlands, although not generally appropriate for larger ones. The authors particularly noted that crayfish species are infrequently used as indicators but, in small wetlands, exhibit well-structured assemblage differences along a disturbance gradient.

Both the authors’ specific suggestions for a small-wetland IBI and the observations which informed its construction are relevant to the study of performance standards.

Streever WJ, Crisman TL. 1993. A comparison of fish populations from natural and constructed freshwater marshes in central Florida. Journal of Freshwater Ecology 8(2): 149–153.

The authors compared fish populations in eight natural freshwater marshes and eight created marshes located in central Florida over one year, sampling quarterly for three-month intervals and beginning 2–10 years after wetland creation.

The study found that some species were more abundant or frequent in the constructed marshes and others were more abundant or frequent in the natural marshes. The authors particularly noted that differences in Everglades populations between the two types of marshes could not be explained by seasonal variation (a plausible explanation for differences in other populations); numbers for the fish were consistently and significantly higher in the natural marshes relative to the created marshes. The authors conclude that “if fish communities differ but species pools are similar, differential conditions must be present.”

Willams GD and Zedler JB. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: relative influence of channel morphology and restoration history. Estuaries 22(3A): 702–716 (1999).

The authors compared four natural tidal marshes and four created tidal marshes (study began 1–12 years after marsh creation) located in the Southwest, sampling relevant variables annually over an eight-year period.

The study found that fish species richness and density did not vary significantly between created and natural marshes, although California killifish were significantly more dense in the created marshes. The article focuses on the importance of physical channel characteristics in determining fish assemblage and composition, arguing that these factors are in some cases more important to fish use than the channel’s restoration status. The authors emphasize that creation projects should be designed to replicate natural hydrologic features, and effective performance standards must measure fish habitat function.

The article adds weight to arguments (voiced by many authors) in favor of habitat function-based performance standards. It suggests that metrics measuring fish residence time, feeding, growth, and community-based species trends all could be effective performance standards.

Zampella R, Bunnell J. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645–658.

The authors studied 17 streams in New Jersey’s Mullica River basin, sampling one site three times annually over a two-year period and another site three times annually over the immediately subsequent two-year period. The sites represented a gradient of stream disturbance as measured by land-use and hydrologic characteristics. The authors constructed a fish-based IBI with observations from the site gradient.

The study found changes in composition of fish assemblages associated with the watershed disturbance gradient, but the changes often were subtle. The major difference was the occurrence of non-native species in more degraded waters. It also found that species composition could be measured equally well by either presence/absence or relative abundance.

The article's main purpose is to highlight the use of PCA and DCA ordination, statistical methodologies that can be employed in constructing a fish-based IBI. The article discusses the disadvantages of the multivariate techniques typically used to create IBIs, but notes that methods that produce ordination results may be difficult to interpret when "strong environmental gradients are lacking." A researcher or policymaker interested in the mechanics of IBI construction would find this article useful, but it is less relevant to a more general discussion of performance standards.

Vose FE, Bell SS. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: evaluation of habitat restoration by hydrologic modification. Estuaries 17(3): 585–596.

The authors studied two mangrove-rimmed habitats (bayous)—one natural and one mitigated—in Tampa Bay, Florida, over a period of 35 months. An impounded bayou was compared to a reference site before and after berm removal with "Before and After Control and Impact" (BACI) analyses.

The study found that fish abundance, biomass, and average monthly number of species decreased after tidal flow was established. Low tide exposure increased dramatically following berm removal. Community similarity (relative to reference site) of fish, amphipod, and polychaete assemblages increased during the last year of post-breach sampling, but remained generally low.

The authors conclude that distinct faunal responses to alteration of tidal periodicity can be detected less than two years after the reestablishment of tidal flow, but extended study probably would reveal further changes. This study may be relevant to performance standards in that it suggest measurable wetland response to alteration can be observed within a short time period. The article's utility is limited, however, because it cannot conclude that the observed changes will lead to similarly altered long-term conditions, or that they relate to measurable trajectories. This information was drawn from an abstract; the full-text article might be more useful.

INVERTEBRATE ARTICLES

Blocksom KA. 2003. A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic highlands streams. Environ. Manage. 31(5):670–682.

This study demonstrates that methods for scoring metrics affects the outcome of the final index, particularly variability, and should be kept in mind when developing an index. There is some indication that Macroinvertebrate Biotic Integrity Index (MBII) might be more sensitive to temporal variation than desired. The variation could result in misinterpretation or abuse of final scores of wetland health.

Cao Y, Williams DD, Williams NE. 1998. How important are rare species in aquatic community ecology and bioassessment? Limnology and Oceanography 43(7):1403–1409.

The authors used a data set created from a previous study of a river system in the United Kingdom. The data set included information from three sites ranging in water quality from clean to seriously impacted. All taxa were identified to the species/genus level, except water mites, chironomids, and oligochaetes; these groups were treated as a single species. Forty-eight "species" were recorded. The study focused on the effects of excluding rare species in the comparison of species richness because many other bioassessment metrics depend on species richness and species composition.

The authors found that species abundance patterns differed significantly different among sites of varying water quality, with the most rare species being found the least impacted site. As sample size increased, the differences in species richness among the sites increased greatly. The exclusion of rare species at the same level of rarity substantially reduced the reported species richness at the least impacted site but had little effect at the most impacted site. This result led to a serious underestimation of differences in species richness among the sites in terms of both absolute numbers and species loss percentages.

The authors state that rare species may be excluded from samples for a variety of reasons, including field and lab sample methods that miss or delete rare species (e.g., EPA'a Rapid Bioassessment Protocols [RBPs], a fixed count method in which 100–300 individuals are counted at random and identified), small sample sizes that may be the result of financial restraints that require rapid sampling techniques, a desire to minimize site disturbance, sample techniques that miss rare species that exist in small numbers, or exclusion for statistical reasons.

This article is critical of the EPA's RBP. The authors argue that the standard RBP sample size is too small to provide information on macroinvertebrate community structure and that it may grossly underestimate differences between reference and impacted sites. The authors caution that species abundance patterns are likely to vary among sites and samples in any study, and rare species are critical for accurate community studies and bioassessment.

Chessman BC, Trayler KM, Davis JA. 2002. Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research 53(5):919–930.

The authors developed a macroinvertebrate pollution sensitivity biotic index for wetlands near Perth, Australia. Grades between 1 and 100 were assigned to macroinvertebrates at the family and species levels to reflect the sensitivities of these taxa to human impacts.

Scores for both family and species levels detected strong correlation with cultural eutrophication and other human disturbances, but the correlations were generally higher for species-level scores. The species-level index was also better at distinguishing between individual wetlands. The authors assert that the method they developed would work well in routine and rapid wetland assessment and monitoring.

This study supports the use of macroinvertebrates identified to the family or species level as a useful rapid wetland assessment tool.

Chovanec A. 1994. Man-made wetlands in urban recreational areas: a habitat for endangered species? Landscape and Urban Planning 29(1): 43–54.

The author describes an artificial pond built in Vienna in 1989/1990. The pool was studied for a three-year period following construction. The pond was designed according to the ecological requirements of amphibians and dragonflies. The design called for structural diversification of the shorelines and the near surroundings of the pond. Special measures were taken to control visitors and otherwise minimize disturbance and human impacts from recreational activities. Based on the colonization by amphibians and dragonflies in the three years following construction, the author concludes that constructed and successfully managed artificial wetlands can offer refuges for endangered species in high-density urban areas.

This article may be notable for consideration of an urban wildlife habitat performance standard. The author considers the artificial pond to represent a success for an urban setting, although the study does not compare the pond with a natural wetland in the same setting.

Davis S, Golladay SW, Vellidis G, Pringle CM. 2003. Macroinvertebrate biomonitoring in intermittent coastal plain streams impacted by animal agriculture. J. Environmental Quality 32(3):1036–1043

Little data is available on the ecology of intermittent coastal plain streams in the southeastern United States, according to this study. Here the authors compared differences in biomonitoring metrics between reference and agricultural streams. The sites were physically and biologically similar during the intermittent period when natural stresses (i.e., stagnant water, high temperatures, and low dissolved oxygen) were high. The study compared biomonitoring metrics during the flow and intermittent flow periods.

Percentages of crustaceans, isopods, and Ephemeroptera-Plecoptera-Trichoptera (EPT) were significantly higher at the reference site and the two most impacted sites, probably due to abundance of leaf litter and lower temperatures. Conversely, percentages of diptera were significantly higher in the agriculturally impacted sites; due probably to the presence of silty, nutrient-rich water. There was no overlap in four metric values (percent Crustacea, Isopoda, Diptera, and EPT) between the most- and least-impacted sites during the flow period. During the intermittent period when natural stresses were high, the sites were more similar in percentages of dominant family, burrowers, chironomids, and diptera.

Results from this study are consistent from other studies on the development of macroinvertebrate IBIs or (performance standards), which conclude that a better understanding of freshwater macroinvertebrate ecology will enhance data interpretation.

Doberstein CP, Karr JR, Conquest LL. 2000. The effect of fixed-count subsampling on macroinvertebrate biomonitoring in small streams. Freshwater Bio. 44(2):355–371.

The authors collected data in the autumn of 1995 from streams in the Puget Sound lowlands in Washington State as part of a larger study on the effects of urbanization on stream ecology.

The authors state that the success of a biological monitoring and biological assessment program depend on rigorous quality control starting from the sampling stage and on through the data analysis stage. The authors also present some of the challenges of developing and using a macroinvertebrate IBI. First, the foundation for the macroinvertebrate IBI is different from a fish IBI (on which it is theoretically based), in which every stream habitat is sampled producing a single, representative sample from each stream studied. In contrast with macroinvertebrates, researchers must decide what habitats to sample, what area to sample, what method to use to collect samples, how many samples to identify and count (whole sample or fixed-count), and how to approach data analysis.

The researchers then test the controversial technique of subsampling. Random subsamples were computer generated for subsamples ranging in size from 100 to 1,000 individuals and compared with whole-count samples. The results show that subsampling significantly decreases the maximum number of distinguishable stream classes for the benthic IBI (B-IBI), from 8.2 classes for whole samples to 2.8 classes for 100-individuals subsamples. Thus, the authors state that the arguments in favor of subsampling are flawed and that the power of the subsamples with 100–300 individuals was low enough to mislead managers.

The authors point out that as of 1996, 44 U.S. states were using macroinvertebrate bioassessment in their water resource management programs, and of these, 30 reported using subsampling methods. The authors found that variance increased as sample size decreased. Therefore, they caution that "the potential inability of small subsamples to differentiate between true differences and differences due to sample variability illustrates a problem with subsampling."

Dodson SI, Lillie RA. 2001. Zooplankton communities of restored depressional wetlands in Wisconsin, U.S.A. Wetlands 2(2):292–300.

The authors sampled wetlands for zooplankton communities and collected data on water chemistry in 56 wetlands in Wisconsin. Twenty-five sites had no impact, 14 were restored sites, and 17 were impacted sites. Taxonomic richness, abundance, and sex ratios of *Daphnia* were compared to detect differences in wetland zooplankton community structure. The effect of age of restoration on taxon richness was examined, and 40 species of zooplankton taxa were identified.

The study found that taxon richness was lower in wetlands with agricultural impacts compared with least-impacted and restored sites. Taxon richness was not affected by water chemistry, duration of water on the sites, the size of the open water, nor presence of fish. The authors found that *Daphnia* populations only produced males in least-impacted and restored sites, but the authors did not know the mechanisms responsible for lack of sexual reproduction in agricultural sites. Many rare species did not occur in the agricultural sites.

The authors found that wetlands in agricultural settings had lower species richness and densities per site than non-impacted or restored wetlands. They found that the reduction in diversity disappeared within roughly six years following restoration, after agriculture was removed from the watershed.

Karr JR, Chu EW. 1999. Restoring Life in Running Waters: Better Biological Monitoring. Washington, DC: Island Press.

The authors discuss freshwater ecosystems and describe the way in which multimetric biological indices are used to assess ecological health. The authors explain that assessment of species richness, species composition, relative abundance of species or groups of species, and feeding relationships among resident organisms are the most direct measure of whether a water body meets the Clean Water Act's biological standards for aquatic life. The authors stress that in biological monitoring it is very important to determine if the variation observed is natural or human induced. They describe attributes are that are poor candidates for monitoring metrics because of their underlying biology. These attributes include abundance, density, and production—all of which vary too greatly for multimetric biological indices, even when human influence is minimal. Population size is not viewed as the best measure of ecosystem health because it can vary enormously in response to natural environmental changes and in response to intrinsic dynamics such as lag times between developmental stages. The authors suggest that a better approach is to measure taxon richness and relative abundance. This book provides a wealth of information for managers interested in developing IBIs.

Llanso RJ, Scott LC, Dauer DM, Hyland JL, Russell DE. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the Untied States. I. Classification of assemblages and habitat definition. Estuaries 25(6A):1219–1230.

This paper covers the process of developing an index for assessing the benthic community condition in estuaries of the Mid-Atlantic region of the United States. Metrics include species diversity, composition, life history, and abundance of pollution-sensitive taxa. Salinity and sediment composition were found to be major factors structuring infaunal assemblages in Mid-Atlantic estuaries. Nine habitat classes were identifies as a combination of six salinity classes and two sediment types. The authors state that "assemblages corresponding to each of the nine habitats were identified in the context of widely recognized patterns of dominant taxa." Sites were categorized as degraded or non-degraded, based on dissolved oxygen, sediment contaminant, and sediment toxicity criteria. Various benthic community structure and function metrics were selected for each of the five major habitat types. The study's final index integrated the average score of the combination of metrics that performed the best according to several criteria. The index correctly classified 82 percent of all sites. The authors suggest that the index "was expected to be of great utility in regional assessments as a tool for evaluating the integrity of benthic assemblages and tracking their condition over time."

Llanso RJ, Scott LC, Hyland JL, Dauer DM, Russell DE, Kutz FW. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the Untied States. II. Index Development. Estuaries 25(6A):1231–1242.

This paper discusses the development of a benthic index of integrity for use in estuaries of the Mid-Atlantic region of the United States. Reference sites were selected and ranked as degraded or non-degraded based on dissolved oxygen, sediment contamination, and sediment toxicity criteria. The index correctly classified 82 percent of all sites. The authors caution that the application of the index to low salinity habitats requires care, but overall, the index appeared to be quite reliable with a high probability of correctly identifying both degraded and non-degraded systems. They expect this index to be useful for evaluating the integrity of benthic assemblages and for tracking their condition over time. This paper represents another successful benthic IBI for use in estuarine systems.

Lockwood JL. 1997. An alternative to succession: assembly rules offer guide to restoration efforts. Restoration and Management Notes. 15:45–50.

This paper looks at community assembly theory as a basis for restoration efforts, rather than the more commonly used succession theory. Assembly theory involves the addition and subtraction of species in a community through time. The author cautions that this is "a high-maintenance approach" and a theory still in its infancy, but she suggests that it is better to understand and incorporate information over time rather than abandon a project.

This approach may be too open ended. For example, she talks about introducing species not present in a system, because they may have been a feature in the system historically, or not. However, she does not address the issue of what a manager would do if there were no historical baseline data (which is perhaps very common). She mentions that the majority of restoration projects she reviewed were "end-oriented (often an economic choice)," low-intervention and short term projects that involved attempts to mimic the process and composition of extant communities with little or no attempt to bring the community together through steps and stages normally involved in the assembly of ecological communities. She points out that restoration efforts could improve if we had a better understanding of community dynamics.

This paper is relevant because it incorporates some of the concepts of adaptive management. A project could benefit from adjustments in its design while it is being monitored.

Lougheed VL, Chow-Fraser P. 2002. Development and use of a zooplankton index of wetland quality in the Laurentian Great Lakes basin. Ecological Applications 12(2):474–486.

The authors developed a wetland zooplankton index (WZI) that could be used to assess wetland quality in marshes on the Laurentian Great Lakes basin. Seventy coastal and inland marshes that ranged from pristine to highly degraded were sampled during 1995–2000.

Results indicated that plant-associated taxa were common in high-quality wetlands while more open-water, pollution-tolerant taxa dominated degraded wetlands. The WZI was found to be a good indicator of water quality. The authors assert that further research is required to confirm the suitability of this method in other regions and other vegetated habitats, but the wide environmental and geographic range in the study indicate that the index could be broadly applicable to wetlands in the Laurentian Great Lakes basin.

This study is relevant as it describes a successful zooplankton index that can be used to test water quality. Modifications of this index may make it applicable in other regions.

Ranasinghe JA, Frithsen JB, Kutz FW, Paul JF, Russell DE, Batiuk RA, Hyland JL, Scott J, Dauer DM. 2002. Application of two indices of benthic community condition in Chesapeake Bay. Environmentrics 13(5–6):499–511.

This study compared the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) to the Environmental Monitoring and Assessment Program's Virginian Province Benthic Index (EMAP-VP BI). Both indices are designed to identify benthic invertebrate assemblages in systems that have been degraded by low dissolved oxygen concentrations or high concentrations of chemical contaminants. The indices were applied to 294 sample events.

The two indices yielded similar results, suggesting that either index is suitable for evaluating benthic conditions.

Muzaffar SB, Colbo MH. 2002. The effects of sampling technique on the ecological characterization of shallow, benthic macroinvertebrate communities in two Newfoundland ponds. Hydrobiologia 477(1):31–39.

This study investigated the influence of two sampling techniques on the characterization of benthic macroinvertebrate communities from two water bodies with similar substrates and depths in Newfoundland. The ponds were within 1 km of each other, and at approximately the same elevation. Sweep-net and rock-bag sampling techniques were used to collect macroinvertebrates. This was a one-year study.

The sampling techniques provided different estimates of diversity and density. The authors conclude that neither method truly represented the benthic community because neither collected all taxa. Each method typically over- or under-estimated the abundance of taxa. Although the ponds were relatively similar, a number of factors were different, including depth, substrate depth, and presence of emergent vegetation, any of which may have accounted for the differences in invertebrate communities. The authors conclude that all sampling techniques have problems in their ability to provide accurate estimates across sample areas.

This study addresses variation inherent in different sampling techniques, which could have implications for development of performance standards. These sampling differences are important to consider when designing a monitoring study. Furthermore, the authors emphasize the importance of recognizing when confounding factors affect inter-site comparisons of benthic macroinvertebrate communities and caution against simply attributing between site differences to human disturbance.

Sacco JN, Seneca ED, Wentworth TR. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17(2): 489–500.

The authors studied seven natural salt marshes and six sites in seven created salt marshes, aged 1–17 years, located on the North Carolina coast. They collected soil cores from each marsh in the first week of July 1986 and compared attributes of infaunal organisms, soils, sediments, and soil organic matter in the natural versus created marshes.

The study found that the created marshes exhibited lower average total infaunal densities than the natural marshes, although both types of marshes exhibited similar proportions of surface feeders and sub-surface deposit feeders. The natural marshes had significantly greater average soil organic content than the created marshes, while the created marshes had significantly sandier soil than the natural marshes.

The authors suggest that greater infaunal densities in the natural marshes may be related directly to their greater soil organic matter content, and therefore while created marshes are able to support infaunal structures similar to those in natural marshes, they cannot support the same level of density. They stress that age is not the only factor controlling soil organic matter accumulation, because similarities in infaunal density were found between created marshes ages 10–17 and natural marshes, and correlation analyses did not reveal any interpretable relationships among marsh age, soil organic matter, and infaunal community attributes. The authors also note that if a created marsh lacks organic matter, macroorganic matter can be an important determinant of infaunal community growth.

The article implies that performance standards (although this may be more in the realm of design standards) which assess (or specify) the factors controlling soil organic matter accumulation may be valid indicators of wetland health.

Scatoloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16: 24–37.

The authors studied a four-year-old created marsh and a nearby natural marsh, both located in San Diego Bay, California. They conducted sampling and assessment of relevant variables eight times over a period of two years.

The study found that the natural marsh had two to three times as many epibenthic invertebrate individuals as the constructed marsh, although species composition between the marshes was fairly similar, and most variance in this area was attributable to rare species rather than to dominants. The authors speculate that coarser sediment, lower organic matter, and more sparse vegetative cover in the created marsh were potential causes of the lower infaunal abundance. On the question of whether the abundance difference was attributable to environmental differences between the marshes or the difference in age, the authors state that the "study…suggests that time is less critical for *Spartina* canopy development than the shortcomings of the constructed marsh sediment and its poor capacity to retain nutrients."

The article is valuable to the discussion of performance standards because it suggests that *Spartina* canopy development is limited by environmental attributes rather than time, indicating that *Spartina* may be valuable as an indicator of relative wetland condition. The article also emphasizes the influence of soil organic matter on marsh function, suggesting the utility of performance standards that assess organic matter development.

Spieles DJ, Mitsch WJ. 2000. Macroinvertebrate community structure in high-and low-nutrient constructed wetlands. Wetlands 20(4):716–729.

The authors studied constructed flow-through wetlands receiving secondarily treated domestic wastewater and lower-nutrient river water in Ohio. They found that macroinvertebrate community structure was related to physical, chemical, and biological gradients in the wetlands. The study involved collecting macroinvertebrates using two different collection techniques and then analyzing the samples with diversity, biotic, and combination indices. They were then related to 17 parameters of water quality, substrate characteristics, and primary productivity in the wetland systems.

Macroinvertebrates nearest to the wastewater source in the wastewater wetland had significantly lower Simpson diversity and Community Index scores than those in other locations. Macroinvertebrates in middle and outflow sites in the wastewater wetland were statistically more similar to sites in the river-fed wetlands. Average diel dissolved oxygen and specific conductivity were the best environmental predictors of invertebrate community metrics. In combination with chemical oxygen demand and nitrate-nitrogen, these variables described nearly 90 percent of the ICI variation.

This study suggests that a problem with developing a macroinvertebrate IBI or performance standard is that many of the indices were developed for stream analysis. In contrast, temperate freshwater marsh wetlands, such as observed in this study, are generally highly productive, accumulate organic carbon, and generally have lower dissolved oxygen and higher temperatures during summer months than do streams. The macroinvertebrate analysis used in this study was a valuable tool for demonstrating change in community structure along a complex pollution gradient in constructed wetlands, and it highlights differences in water quality between sites and at the inflow.

Streever WJ, Crisman TL. 1993. A preliminary comparison of meiobenthic cladoceran assemblages in natural and constructed wetlands in central Florida. Wetlands 13(4): 229–236.

The authors compared eight natural wetlands and 11 created wetlands located in Florida, sampling meiobenthic cladocerans, chydorid cladocerans, and allied taxa over two years and beginning approximately 15 years after the oldest created wetland was constructed.

The study found no relationship between the age of the constructed wetland and the richness of the sampled species. Rare species seemed to occur more frequently in the natural wetlands relative to the constructed wetlands. Meiobenthic cladoceran assemblages in the natural wetlands were more variable than those in the constructed wetlands, suggesting that environmental and ecological conditions that control assemblages may be relatively more variable in the natural wetlands.

The findings indicate that the range of cladoceran assemblage types might be a viable performance standard—specifically, the extent to which the assemblage range in a constructed wetland mimics the range in a reference site or falls within a range indicated by a sample of reference sites. The article also notes, like most others, that a broad range of biotic assemblages and driving conditions should be considered in an effective wetland IBI (and performance standard).

Tangen BA, Butler MG, Michael JE. 2003. Weak correspondence between macroinvertebrate assemblages and land use in Prairie Pothole Region wetlands, USA. Wetlands 23(1):104–115.

The authors studied 24 semipermanent wetlands in each of three land-use categories. Each wetland was sampled once in June, July, and August 2000 to collect data on the macroinvertebrate community and various environmental variables such as water quality characteristics. In addition, each wetland was sampled for fish in June and August, and for benthic sediments in July. Invertebrates were identified to either genus or subfamily.

Fish had a strong impact on the macroinvertebrate community. Most invertebrate taxa were less abundant in wetlands with fish. There was not a strong relationship between macroinvertebrate community structure and land use. Temporal patterns and among-wetland variation accounted for 62 percent of the total variation in the invertebrate community. The authors documented a distinct seasonal change in the invertebrate community over the course of the summer. They caution that this temporal change is important to recognize and address in sampling design.

Biotic and abiotic conditions heavily outweighed the impact of land-use practices on the invertebrate community. This is in keeping with another study that found the great variability in the hydrology and vegetation in Great Lakes wetlands did not make invertebrate metrics useful indicators of water quality. The authors mention that the Prairie Pothole wetlands support a very low diversity of aquatic macroinvertebrates compared with other wetlands, perhaps as a response to the high variability in biotic and abiotic factors. In summary, the authors "identified numerous potential limitations to biological assessment in the Prairie Pothole wetlands." They recommend that metrics for amphibians or birds may show more potential as functional assessment tools.

U.S. EPA. 2002. Methods for evaluating wetland condition: developing an invertebrate index of biological integrity for wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, D.C., EPA-822-R-02-019.

This publication discusses the use of invertebrates as indicators of wetland health and the development of an invertebrate IBI. The document reviews an extensive array of research papers and discusses the advantages and disadvantages of using aquatic invertebrates in wetland assessment, as well as considerations to address:

Advantages:

- They are common and widely distributed in many types of wetlands.
- As a group they respond with a range of sensitivities to many kinds of stressors, and they are commonly used for toxicity testing and ecological assessment in water bodies.
- Because many aquatic invertebrates complete their life cycles in wetlands, they are exposed directly to physical, chemical, and biological stresses within the wetland.

- Aquatic species play an important role in wetland ecology and food webs.
- Aquatic invertebrates have public appeal and work well in citizen monitoring programs.

Disadvantages:
- Their use as indicators require extensive staff time and expertise to collect, process, and identify organisms.
- Organizations may lack facilities for processing and identifying invertebrates and may have to contract out for the work.

Considerations:
- Where to sample, what strata/habitats and how often to sample;
- The appropriate number of samples to take and the sampling method to use;
- The optimal time of year to sample to obtain the most representative, mature invertebrate community and maximum number of identifiable taxa; and,
- The number of samples that can be processed in the lab.

The authors recommend to identify invertebrates to the lowest possible taxonomic level, ideally to species because of the different sensitivities among species within some taxonomic groups. In addition, it is a good idea to know functional feeding groups for each taxon so that functional feeding group attributes can be tested. An IBI is more robust if it is composed of 8–12 metrics selected from different categories of attributes that represent patterns of responses to changes in the physical, chemical, and biological integrity of the wetland and its surrounding landscape. These can include measures of taxa richness (decrease with stress); tolerance (increase) and intolerance (decrease); trophic structure and functional feeding groups (varies); life cycles, such as longevity and reproduction (decrease); and poor condition or poor health of individuals (increase).

This publication highlights the need for much additional work in the development of regional invertebrate IBIs and a commitment to funding staff working with invertebrate IBIs.

Wilcox DA, Meeker JE, Hudson PL, Armitage BJ, Black MG, Uzarski DG. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: a Great Lakes evaluation. Wetlands 22(3):588–615.

The authors evaluate the potential for development of an IBI for three coastal wetland types (barrier beach, drowned-river-mouth, and open shoreline wetlands) of the Great Lakes. The three wetland types were selected based on their geomorphic features. The wetlands were located on the south shore of Lake Superior, the east shore of Lake Michigan, and in Saginaw Bay of Lake Huron. Six sites representing each of the three wetland types were studied. Plant, fish, and invertebrate communities were sampled from Lake Superior in 1993, Lake Michigan in 1995, and Lake Huron in 1994. Fish were identified to species, and invertebrates to genus with the exception of caddisflies, which were identified to species. Plant data were evaluated using measures of species richness and composition, community composition, and community health. Fish measurements included species richness and composition; number and percent of native/non-native species, sensitive species, tolerant species, centrarchids, and native cyprinids; trophic composition; fish abundance; and diversity. Invertebrate data were evaluated using density by groups, relative abundance, species richness, number of rare or uncommon adult Trichoptera, and sensitivity.

The wetlands in this study were all subject to extreme changes in water level. The effects of severe hydrologic instability has been documented on plant and faunal communities by other research referenced in this study. Levels of disturbance were documented and metrics were selected to use in the IBI. Metrics proposed for an IBI for barrier beaches appeared as if they might be developed further to be used as measure of wetland integrity, however metrics for the drowned-river-mouth wetlands were inconsistent in identifying disturbance gradients. Metrics for the open shoreline wetlands held little promise and were abandoned. The authors conclude that an IBI for use in the Great Lakes wetlands would not be valid unless separate scoring ranges were developed for a variety of water-level histories.

The authors examined the outcome of their results against six criteria defined by Herricks and Schaeffer (1985) and found that their attempted wetland IBI satisfied some of the criteria but failed others. The criteria that failed: (1) the measure must be reproducible and precise within defined and acceptable limits for data collected over time and space, and (2) the variability of the measure must be low. The authors conclude that annual variation in lake hydrology will likely produce variability in data in response to water level induced changes in plant and invertebrate communities. Changes in water level in this study were not a reflection of human disturbance. The authors cited additional problems with developing a working IBI for the Great Lakes, or in general, including a limited number of comparable sites, the potential lack of undisturbed reference sites, and variable effects of different disturbance types. The authors identified additional factors that would require the development of differing scales of measurement to reflect water-level histories.

These factors influencing hydrology include climate-induced long-term high water, drought, drought-related fire, weather-related floods, and high winds.

The authors suggest that a functional assessment of wetlands using an IBI may be better suited for wetlands with relatively stable hydrology (deepwater swamps not prone to flooding from rivers, inland marshes supplied by ground water, vernal pools not subject to wide variability in hydroperiod, and tidal marshes not threatened by periodic hurricanes), than wetlands with natural variability (e.g., floodplains of rivers, bottomland hardwood forests of the Southeast, tidal freshwater marshes, wetlands near the coast). The authors mention the importance of classification of wetland types by geographic, geomorphic, and hydrologic features to reduce variability. In systems as highly variable as those in this study, the study suggests that an IBI is not a realistic indicator of environmental health or stress.

BIRD ARTICLES

Adamus PR. 1995. Validating a habitat evaluation method for predicting avian richness. Wildlife Soc. Bull. 23(4):743–749.

The study applied the new (1995) avian richness evaluation method (AREM) to 10 created/restored lowland and riparian habitats of the Colorado Plateau. The author found that AREM was able to predict the species presence or absence 88 percent of the time. The evaluation method proved to be a useful tool for mitigation calculations, detecting impaired wetland quality, targeting habitat enhancements, and classifying wetland habitats. The application of the AREM is also easy to use and provides a rapid form of assessment of a avian richness for a particular region

At time of the study, AREM had only been developed for the lowland riparian and wetland areas of the Colorado Plateau; however, the authors discuss the potential adaptation of the AREM to other types of habitats and other taxa. According to the author, AREM can be directly related to performance standards, because it provides an assessment of the number of birds and number of species and relates them to an assessment of wetland health.

Austin JE, Sklebar T, Guntenspergen GR, Buhl TK. 2000. Effects of roadside transect width on waterfowl and wetland estimates. Wetlands. 20(4): 660–670.

In the course of a study on the effect of transect width on estimates of wetland and waterfowl density, the authors discovered that higher density clusters of wetlands attracted more wetland birds than lower density clusters.

Although this study may not have a direct bearing on performance standards, it raises an important point about the significance of wetland placement on the landscape and size of wetlands. Smaller wetlands located near to other small wetlands were seemingly more attractive to birds than larger ones, even when the smaller ones were nearer to roads.

Balian LV, Ghasabian MG, Adamian MS, Klem D Jr. 2002. Changes in the waterbird community of the Lake Sevan-Lake Gilli area, Republic of Armenia: a case for restoration. Biological Conservation 106(2): 157–163.

This study analyzed the waterbird community of Lake Gilli and its surrounding wetlands before and after the water level was significantly reduced. The authors found that draining the lake led to a significant decrease in breeding bird populations and an increase in non-breeding bird populations.

Eventually, however, commercial fish ponds were constructed in place of the lake, and these ponds did bring back the populations of breeding and non-breeding birds that previously inhabited Lake Gilli.

Although the manipulation of Lake Gilli may have been an extreme example, the study demonstrates how changes in water levels and other alterations to natural wetlands or replacement wetlands through mitigation can change the composition of the communities that occupy it.

Blair RB. 1996. Land use and avian species diversity along an urban gradient. Ecol. Appl. 6: 107–112.

The authors examined avian species diversity in wetlands along a gradient of urbanization. They surveyed 16 study plots eight times each in June 1993. They also conducted surveys of human activity in the spring of the same year. Results indicate that moderate levels of urbanization causes a decrease in native species diversity. More severe urbanization resulted in decreased total and native species diversity.

Although some bird species did persist in the most urbanized wetlands, the study concluded that species that are poor dispersers or that mature slowly are less able to persist in highly urbanized settings. It is therefore important to consider the surrounding urban matrix for its potential effect on the health of wetland-dependent birds when siting a wetland for mitigation. A highly urbanized matrix may negatively affect bird survival, either because of the degradation of the wetland itself, or because of hazards associated with the surrounding urban habitat.

Bolscher B. 1995. Niche requirements of birds in raised bogs: habitat attributes in relation to bog restoration. In: Wheeler BD, Shaw SC, Fojt WJ, Robertson RA, eds. Restoration of Temperate Wetlands. John Wiley & Sons Ltd. pp. 359–378.

This study analyzed bird-habitat relationships in natural raised and restored bogs in southern Sweden and the central European Plains.

The results indicate that natural bogs had lower vegetation structure relative to the restored bogs. As a consequence, the restored bogs did not provide suitable habitats for species requiring habitat characteristics of the natural bogs, although the possibility remained that these differences were the result of geographic variation. This study emphasizes the importance of reference wetlands for mitigation efforts.

Brown SC. 1999. Vegetation similarity and avifaunal food value of restored and natural marshes in northern New York. Restoration Ecology 7(1): 56–68.

The author studied 13 restored marshes and 4 reference wetlands with similar features in New York over four years. Restored wetlands were generally larger than the natural ones, and although more plant species were found in the restored wetlands, plant coverage was significantly lower in restored sites. Plants valuable as food of birds increased more rapidly in restored wetlands because there was no competition between the woody plants and the (non-woody) food plants. The abundance of food resulted in a greater abundance of birds in restored wetlands; however, once the woody plants begin to grow, the cover by food plants was expected to decrease and become more like that of the reference wetland.

The author found that initial seeding of plants during construction increased establishment of wetland plants and increased the diversity of species. Although seeding was a method mentioned for plant establishment and diversity, natural colonization was also successful in the re-establishment of some wetlands.

Buffington JM, Kilgo JC, Sargent RA, Miller KV, Chapman BR. 2000. Effects of restoration techniques on the breeding bird communities in a thermally impacted bottomland hardwood forest. Ecol. Eng. 15: S115–S120.

The authors surveyed in 24 habitat plots five times a year for two years along a corridor of a forest divided into upper and lower sections. The sections were based on the hydrology of an associated creek. The upper sections consisted of three control and three treatment sites; all treatment sites received application of herbicide and were planted with a variety of oak and hickory species. The same was done in the lower sections.

The authors found that avian abundance and richness were negatively correlated with canopy closure and with canopy height. Only species richness differed between upper and lower treatments. Nearly all birds species detected, except the hooded warbler and the rufous-sided towhee, were found in more than one treatment type. Red-winged blackbirds were exclusive to the lower control and treatment plots, probably as the result of shorter vegetation and abundant grassy openings downstream.

Buffington JM, Kilgo JC, Sargent RA, Miller KV, Chapman BR. 1997. Comparison of breeding bird communities in bottomland hardwood forests of different successional stages. Wilson Bull 109:314–319.

In this study, birds were surveyed five times a year for two years on 36 plots, which were divided into three bottomland riparian corridors of different ages (early-, mid-, and late-successional bottomland forests). Each site was sampled for percent ground cover, water cover, shrub density, canopy height, percent canopy closure, and basal area.

The authors found significant differences in the vegetation among the three age groups of bottomland forests—canopy height, percent canopy closure, and basal area all increased with age. Avian species richness and diversity also positively correlated with wetland age. However, avian abundance correlated negatively with canopy closure and thus negatively with wetland age.

The authors emphasize the importance of maintaining mature bottomland forests as a suitable habitat for neotropical migrant bird (many species of which are in decline). However, management to maximize avian species composition over would require maintenance of a successional gradient of habitats. The numerous habitats along a gradient, according to the authors, would promote bird diversity. Although the study found that all ages of wetland habitats can contribute to the persistence of a variety of birds, the older wetlands seem to be the most important for maintaining species diversity.

Cole CA. 1997. Study raises questions about use of restored mangroves by birds, suggests value of organic soil amendments (Florida). Restoration and Management Notes 15(2):190–191.

In this study, the author assessed bird usage of three newly created mangrove wetlands in Florida. He observed that although the new wetlands should have been attractive to the birds, they were not. The birds mainly concentrated on the periphery of the wetlands and roosted in the large trees along the edges of the wetlands.

The author observed that only the peripheral areas of the wetlands contained a well-developed substrate suitable for burrowing crabs, which was an important food source for the birds in the study. Therefore, the birds were more often found in the areas that contained the appropriate burrowing crab substrate. The author suggests that adding organic matter to mitigation sites could to improve the presence vegetation and prey items for birds, which would in turn improve their use of the site. The author recommends that mitigation projects be required to incorporate organic matter into the soil of mitigation sites and that projects be subject to long-term monitoring of wildlife use.

The study emphasizes the interconnected relationship between various inhabitants and attributes of wetland sites. It suggests the importance of incorporating a number of taxa as well as other carefully selected biotic and abiotic elements into a potential monitoring regime or performance standard.

Cooper CB, Anderson SH. 1996. Significance of invertebrate abundance to dabbling duck brood use of created wetlands. Wetlands 16(4): 557–563.

In this study, the authors examined created wetlands in Wyoming that had been in existence for more than 40 years. The study looked at dabbling duck brood count, vegetation, and invertebrate abundance at various levels in the water column.

The researchers found that when a wetland had a high density of invertebrates, there was a concomitant high number of duck broods supported by the wetland. However, invertebrate densities in the top 25 cm of the water column did not seem to have any relationship to brood densities, even though dabbler foraging is limited to the top 25 cm of the water column. Rather, dabbler population abundance seemed to depend on the total availability of the invertebrate population throughout the water column. The authors suggest that invertebrate populations become available to the dabblers by such means as migrating vertically throughout the water column.

Delphey PJ, Dinsmore JJ. 1993. Breeding bird communities of recently restored and natural prairie potholes. Wetlands 13: 200–206.

Researchers in this study compared species richness and abundance of breeding birds between 18 recently restored and natural prairie potholes in Iowa for two years, five times each year.

Overall, vegetative coverage among the restored wetlands varied widely. Species richness of breeding birds was greater in natural wetlands than in created wetlands during both years of study. The authors speculate that the absence of trees in and around the created wetlands probably led to a lower abundance and richness of breeding bird populations than in the natural wetlands. Unlike the created wetlands, the natural wetlands contained all four vegetation zones typical of an undisturbed semi-permanent prairie pothole.

The results of this article reflect similar results found in other studies, in which the lack of woody vegetation was considered the reason for the lack of bird abundance and diversity. The study additionally suggests that the results could also relate to the limited monitoring period typical of studies such as this one, in which the amount of time that is allotted to study the growth of the vegetation in newly restored wetlands fails to capture the progress of more slowly growing woody species. More monitoring time may be needed to determine whether woody vegetation will ultimately grow in the created wetlands and whether these wetlands will become more similar to natural wetlands.

Dobkin DS, Rich AC, Pyle WH. 1998. Habitat and avifaunal recovery from livestock grazing in a riparian meadow system of the northwestern Great Basin. Conservation Biology. 12(1):209–221.

Scientists sampled birds and vegetation in three paired 1.5-ha 1-year-old riparian meadow plots along a stream corridor in southeastern Oregon over four breeding/growing seasons. Three plots were within an enclosed area and three were outside the enclosure. The entire area had been historically grazed by livestock. After the enclosure was erected, livestock were completely restricted from the enclosure but were allowed to graze outside of it.

The plots inside the enclosure were characterized by dense sedge-dominated vegetation, containing only a scattering of shrubs. Outside of the enclosure, the plots had very little vegetation, little sedge cover, and a high density of shrubs. Inside the enclosure, the vegetation showed a good recovery from grazing. Concomitantly, bird species richness and relative abundance was greater inside the enclosures than outside of them. The study found that removal of livestock resulted in a higher water table, which encouraged plant development. In this case, removal of livestock and restoration of the water table were an essential component of restoration of the site after grazing impacts.

U.S. EPA. 2002. Methods for evaluating wetland condition: biological assessment methods for birds. Office of Water, U.S. Environmental Protection Agency, Washington, D.C., EPA-822-R-02-023.

This report comprehensively reviews the advantages and disadvantages of using birds for biological assessment. The report also suggests guidelines for study design and data collection for use in creating and testing an IBI based on birds. The document points out that few studies exist on the development of IBIs using birds; therefore, the report relies heavily on ecological theory and monitoring experience.

Birds are useful in wetland evaluation for a variety of reasons. An IBI incorporating birds can indicate the integrity of a landscape in addition to the integrity of individual wetlands, which helps provide an assessment of cumulative impacts of human activities. Birds are relatively straightforward to survey, and detailed keys and extensive laboratory work are not necessary for species identification. Birds are known to be sensitive to vegetation conditions, hydrology, water chemistry, water quality, and human and animal disturbance. Although the specific reason a given site might have a low IBI value is not always known in the absence of additional detailed study, the report asserts that the value of birds as indicators lies with their role as integrators of the cumulative effects of multiple environmental influences.

One disadvantage of using birds as indicators is that their migratory habit presents the problem of knowing whether the status of a population is influenced by the status of the local wetland or by events occurring away from the study area.

The scale of the area being represented by a bird IBI depends on the home range size of the birds occupying the site. It is recommended that bird IBIs be segregated into different scales—for example, both birds with restricted local movements (e.g., rails and sparrows) and birds that occupy large areas (e.g., raptors or waterfowl). Alternatively, data can be restricted to species that characterize a scale appropriate and interpretable to the intended users.

Suggested metrics that indicate wetland degradation include bird abundance, frequency of occurrence, duration of wetland use, and bird behavior. The application of various standard survey techniques are discussed in this document. The recommended survey method depends on the species being surveyed and the objectives of the study. The authors point out that future work is needed to develop and test bird IBIs.

Fairbairn SE, Dinsmore JJ. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21(1):41–47.

The authors endeavored to relate wetland bird communities and relative density estimates of individual species to local wetland habitat characteristics and those of the surrounding landscape. The authors assessed these factors to discuss how they may play a role in helping to determine the priority with which to mitigate wetlands within the landscape. The authors conclude that mitigation should prioritize selecting for a diverse bird community with the greatest species richness. Selection priority should also be given to those wetlands that are located near existing wetland habitats.

Farley GH, Ellis LM, Stuart JN, Scott NJ Jr. 1994. Avian species richness in different-aged stands of riparian forest along the middle Rio Grande, New Mexico. Conservation Biology 8(4):1098–1108.

The authors examined three riparian restoration sites in the middle Rio Grande Valley, with the objective of determining how the vegetative structure of sites differ and quantifying the patterns of avian use among sites of various ages (2, 3, 5, and 30 years old), compared with mature riparian forests. The study found that as wetland age increased, so did plant community complexity, vegetation structural diversity, plant density, number of breeding bird species, and bird species richness. The 30-year-old site supported the most species. The species that used the oldest site typically were different from the species using the younger-aged stands. Overall, avian assemblages varied among the different-aged riparian woodland sites, such that each site hosted a different suite of species. The authors state that this illustrates the habitat specificity of some bird species. They suggest that bird species seem to be choosing their preferred stands based on preferred vegetation structure. The authors emphasize the importance of maintaining stands of riparian vegetation of different ages in order to support the greatest diversity of bird species.

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1): 25–31.

The author evaluated the effect of the loss of small wetlands on the geometry of freshwater wetlands in central Maine, and he assessed the way that changes in the wetland mosaic would affect the extinction rate of meta-populations of wetland-associated animals.

The study found that the extinction rate rose as small wetlands were destroyed in three of the five wetland taxa studied. Meta-populations of small birds showed a slightly elevated extinction risk with the loss of small wetlands. This study suggests that small wetlands play a greater role in the survival of meta-populations of certain taxa than their size and expected function would seem to predict. Small wetlands located in patches with small inter-wetland distance had more successful dispersal than wetlands with larger inter-wetland distances.

This study reveals that small wetlands play integral roles in meta-populations of certain taxa. Although mitigation in many cases favors large wetland projects over smaller ones, this study asserts that larger is not always better, but rather smaller and closer can be more important for certain species.

Lechisin DA, Williams GL, Weler MW. 1992. Factors affecting waterfowl use of constructed wetlands in northwestern Minnesota. Wetlands 12:178–183.

This two-year study examined 109 created wetlands in northwestern Minnesota in four different Wildlife Management Areas. The goal of the study was to understand the factors that affected waterfowl use of these wetlands. The results indicate that larger surface area and longer shoreline lengths correlated to greater breeding pair use by almost all the waterfowl studied. The birds seemed to use most heavily the constructed wetlands with surface areas ranging between -0.25 and 0.50 ha. The authors suggest that the breeding pairs' attraction to the larger surface area and longer shoreline lengths may indicate that pair use is a function of wetland size for most of the breeding species of ducks in that area.

McKinstry MC, Anderson SH. 1994. Evaluation of wetland creation and waterfowl use in conjunction with abandoned mine lands in northeast Wyoming. Wetlands 14(4):284–292.

The authors developed a wetland habitat value (WHV) model to assign waterfowl habitat functions to 886 wetlands in Wyoming. The wetlands in the study were part of a project in which the state filled, modified, or had previously filled the wetlands, then enhanced or created them as part of the mitigation. The authors applied the WHV model to the wetlands to predict creation/enhancement outcomes before the wetlands were altered (using preconstruction engineering plans and plans submitted for 404 permit approval), then compared their results to what actually took place on the ground (over a two-year post-construction study period). Their final study consisted of 92 created palustrine wetlands, in which they surveyed plant types and abundance as well as migrating, breeding, and brooding birds.

The model found generally that waterfowl habitat value increased with increases in wetland size, shoreline sinuosity, associated marsh zone size, presence of islands and bays, terrestrial vegetation quality, and number of nearby small wetlands. The value also increased with decreases in sedimentation rates, proximity to nearby small wetlands, and proximity to associated marsh zone. Finally, value increased as the proportion of the wetland covered by emergent vegetation approached 40 percent, and as drawdown approached an optimum for the size of the wetland.

When the authors compared the preconstruction plans to the wetlands actually mitigated, they found that the constructed wetlands had a significantly lower WHV than planned—"In all cases, habitat quality predicted by the wetland designers was greater than that determined during our observations." The study found 19 species of migrating waterfowl on 59 wetlands, but the only breeding waterfowl were Canada geese, mallards, and blue-winged teal. Mallards and blue-winged teal broods were the most abundant. In addition to these breeding species, the study found redhead and ring-necked ducks to be present among more than 12 wetlands.

They also found that the aerial extent of the new wetlands was significantly smaller than planned. After two years of monitoring, the preconstruction plans were found to be 86 percent larger than the actual constructed wetlands. The authors mention that another study discusses building mitigation wetlands larger than the original wetland for many reasons, including the value of a greater number of habitats to promote a greater number of bird species.

Overall, the model and the WHV was found by the authors to be effective for rapid assessment of existing wetland conditions, and for reliably predicting the presence of selected migrating bird species. One note, however, that the values returned by the model were highly correlated to size of the wetland.

Melvin SL, Webb JW. 1998. Differences in the avian communities of natural and created *Spartina alteriflora* salt marshes. Wetlands 18:59–69.

In this study, bird usage was studied on seven created salt marshes and compared with birds on seven natural wetlands. The parameters studied included bird density, type, abundance, species richness, species diversity, and comparison of richness and diversity. Overall, bird density was highest in the created salt marshes. That, however, was the only parameter in which the created wetlands differed positively from the natural salt marshes. Bird species richness was greater in natural salt marshes (during all months except May, June, and July). The natural salt marshes also had a more even distribution of bird composition—in the natural wetlands all groups made up 10 percent of the total, while in the created wetlands a tern species dominated and other groups contributed no more than 6 percent each. The natural wetlands also supported a greater number of migratory birds and greater species diversity, while created wetlands mainly supported gulls and terns.

The authors suggest that the difference between the bird populations in the created and natural wetlands can probably be attributed to the lack of habitat diversity and lack of microhabitats in the created wetlands. The article reinforces the importance of wetland design in created wetlands. To the extent that microhabitats and habitat diversity can improve over time, a performance standard for birds might address aspects of avian species richness and distribution, as well as presence of migratory species.

Naugle DE, Johnson RR, Estey ME, Higgins KF. 2001. A landscape approach to conserving wetland bird habitat in the Prairie Pothole Region of eastern South Dakota. Wetlands 21(1): 1–17.

This study investigated the role of local and landscape-level attributes of wetlands for predicting habitat suitability for 20 wetland bird species. The authors found that certain bird species depended more heavily on local vegetation characteristics, while others seemed more influenced by landscape-level attributes. Prairie landscapes with wetland complexes imbedded in grasslands contained more wildlife species than did wetlands in landscapes impacted by agriculture. The study also found that small wetlands are critical for the sustainability of larger wetlands. This article suggests that a mosaic of small and large wetlands are important for optimal bird habitat, and that strategic placement of mitigation sites is crucial for the ultimate value of the wetland.

Ratti JT, Rocklage AM, Giudice JH, Garton EO, Golner DP. 2001. Comparison of avian communities on restored and natural wetlands in North and South Dakota. Journal of Wildlife Management 65(4): 676–684.

This study compared the breeding bird usage of paired natural and restored wetlands (all were approximately 5.7 years old, ranging from 1 to 11 years) in the Prairie Pothole region. The study found that the restored wetlands had greater overall average densities of birds when compared with natural wetlands. There was no significant difference, however, in species abundance, species richness, or diversity between the natural and restored wetlands.

Overall, the authors found that restored wetlands in the Prairie Pothole region provided excellent habitats for wetland and upland bird species. Restored wetlands in this study had 6 percent higher cover of emergent vegetation than the natural wetlands. The authors note, however, that further study is needed on soils, hydrology, and water quality, aquatic invertebrates, fish, amphibians, and reptiles before concluding that these restored wetlands are equivalent to the natural ones.

Rottonborn SC. 1999. Predicting the impacts of urbanization on riparian bird communities. Biological Conservation 88:289–299.

In this study, the author examined 68 sites in the Santa Clara Valley to assess the relationships between variables associated with urbanization and bird species richness, density, and community structure. The study took place along an urban gradient, with the goal to predict the effects of urban sprawl on the riparian bird populations in the valley. The author found that most of the species observed at the study sites were either rare or sparsely distributed in the study area. Only 19 species were observed on slightly more than half of the 68 plots.

The study found that as the distance to a building and the width of a riparian corridor decreased, total species richness decreased significantly. Plots closer to developed areas generally had lower species richness than those farther from development, and the densities of number of species was negatively correlated with proximity to roads. The author concluded that broader buffers better maintain riparian bird species richness. The study also points to the importance of mitigation site placement in an urbanizing setting.

Shuwen W, Pei Q, Yang L, Xi-Ping L. 2001. Wetland creation for rare waterfowl conservation: a project designed according to the principles of ecological succession. Ecological Engineering 18(1):115–120.

The authors created and then studied a 240-ha reed wetland on a biosphere reserve in China. The wetland was designed to provide habitat for red-crowned cranes and other rare birds. After creation, the wetland was allowed to develop on its own—the only human intervention allowed was the maintenance of the water level within the wetland. After four years, the former grassland turned into a reed wetland, and total primary production increased three-fold. The researchers concluded that mitigation can be simple and need not imitate the environment, but preparing the environment for wetland creation can reap successful results.

Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.

The researchers studied eight deciduous forested wetlands to determine a relationship between habitat and breeding bird densities. They examined a range of habitat parameters, including vegetation structure, hydrologic patterns, and geographic location. They observed and recorded more than 2,600 singing male birds, comprising 46 species. Total breeding density correlated positively with small shrub density, surface wetness, and soil depth. Bird species richness was correlated positively with small shrub density and soil depth, and was correlated negatively with tall shrub density. Foliage-gleaning birds were positively correlated with surface wetness and soil depth, and they inversely correlated to percent crown closure. Ground and herb foragers were positively correlated to the number of dead trees. There was no significant correlation in habitat variables for trunk and branch foragers.

The authors conclude that numerous vegetation variables had a significant effect on breeding bird communities in forested wetlands. They suggest that the relationship between the moisture regime and breeding bird density and diversity may be due to greater understory vegetation and more diverse vegetative structures. Opening the canopy of the forest would increase structural heterogeneity and enhance diversity of the bird community.

VanRees-Siewert KL, Dinsmore JL. 1996. Influence of wetland age on bird use of restored wetlands in Iowa. Wetlands 16:577–582.

On a total of 40 restored wetlands (1–4 years old), researchers conducted a general survey of wetlands as well as an analysis of waterfowl species richness over the course of two years.

The authors found that wetland age, area, percent emergent vegetation, and vegetation cover pattern were recorded. In all, 42 species of birds were detected and 15 of the species observed were nesting in restored wetlands. The number of breeding bird species was positively correlated with wetland age. The species composition of the breeding waterfowl changed after the first two years (e.g., Canada geese, mallards, blue-winged teals dominated in the first two years, but ruddy ducks and red heads appeared in later years). Species richness did not change with wetland age, but species composition did. The researchers suggest that a change in species composition is probably a response to vegetation changes. They also suggest that the quantity and quality of upland vegetation and invertebrates may be more important than the vegetative development of wetlands.

The authors suggest that the finding that the number of breeding bird species and percent cover of vegetation increases with age of wetland suggests that management activities should promote long-term restoration efforts through conservation easements and outright purchases of wetland habitat.

ALGAE ARTICLES

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for monitoring biological integrity of inland, freshwater wetlands: a survey of North American technical literature (1990–2000), Office of Water, U.S. Environmental Protection Agency, Washington, D.C.

The authors of this publication generally are not positive about the utility of algae as reliable indicators of wetland condition. Their primary concerns are the difficulties associated with algal sensitivity and construction of algal metrics.

The authors note that algae often respond to common pollutants before the pollutants reach levels where they begin to affect vascular plant growth, which would seemingly make algae valuable first-warning indicators. However, algal responses are complex: “The exact nutrients that contribute to algal community shift is often difficult to identify due to correlations among many nutrients…other chemical constituents of water, particularly pH altering bicarbonates, can regulate the response of algae to nutrient additions…(and) shifts in nutrients can alter macroinvertebrate populations…this shift in trophic levels can mask the effects of nutrient additions.” Moreover, current techniques for measuring algal biomass, volume, and density are time consuming. Analysis of diatoms in soil cores is a reliable technique but also is very involved.

Addressing these and other concerns, Adamus and coauthors note that workable metrics can be constructed with algal components identified at the genus level or coarser. They recommend assessing species composition rather than biomass, and recommend using weighted average regression analysis to create indicators based on species grouped per their reputed tolerances.

Dixit SS, Smol JP, Charles DF, Hughes RM, Paulsen SG, Collins GB. 1999. Assessing water quality changes in the lakes of the northeastern United States using sediment cores. Canadian Journal of Fisheries and Aquatic Science 56(1): 131–152.

The authors studied 257 sites in a mix of natural lakes and historically created reservoirs located in the northeastern United States in three ecoregions (the Adirondacks, New England Uplands, and the Coastal Lowlands/Plateau) from 1991 to 1994. They employed core sampling to analyze top and bottom layer sediments and their diatom assemblages and then correlated the assemblages with environmental conditions using canonical correspondence analysis. This analysis allowed the authors to infer historical condition and environmental change in the water bodies.

The authors created an environment-species biplot showing the position of individual taxa relative to specific environmental variables; the plot allowed them to estimate the optimum value of the taxon associated with a given environmental condition and “ascertain the indicator potential of certain diatom taxa by examining their position with respect to multiple environmental gradients.” The authors developed inference models for pH, TP, and Cl.

The authors’ conclusion is relevant to development of performance standards based on analysis of diatoms in sediment soil cores: “This study provides strong evidence that paleolimnological monitoring approaches, coupled with statistical sampling design, are effective in assessing background or reference water quality of lakes and in estimating regional status and trends.” A wetland performance standard might specify core sampling of top and bottom layers in a restored wetland, or in reference and created sites, and then assess wetland health per comparison of the diatom assemblages. The authors support the utility of the core sampling technique, noting that samples can be collected at any time during the year, integrate diatoms from many habitats within the water body, and contain autoecological information that can be used to characterize environmental conditions based on species composition.

Mayer PM, Galatowitsch SM. 1999. Diatom communities as ecological indicators of recovery in restored prairie wetlands. Wetlands 19(4): 765–774.

The authors studied eight natural glaciated prairie wetlands and eight wetland sites restored after drainage (drainage occurred more than 50 years prior to the study and restoration took place 3–15 years prior), located in South Dakota. The authors collected diatoms on artificial substrates that were placed in wetlands and then transported from natural to restored wetlands and vice-versa in order to assess diatom community change; community changed was assessed after 5 and 10 weeks.

Although the authors predicted that diatom species diversity and equitability would be lower in restored wetlands relative to reference wetlands, and that restored wetland communities would illustrate incomplete species recovery, the study actually found that diversity, species composition, and equitability did not significantly distinguish restored wetlands from natural wetlands. Diatom communities did not seem more similar among reference wetlands than among restored wetlands.

In fact, when substrates were transferred, the transplanted communities changed in response to relocation in ways that mirrored the composition of the receiving wetland. The authors concluded that this response suggests strong environment control of diatom communities. They noted that "the utility of using diatoms as ecological indicators in prairie wetlands may be limited…[and, moreover] high variability in diatom assemblages among reference wetlands also may increase the difficulty of interpreting the results of multivariate community analyses."

The article pertains to the advisability (or lack thereof) of using diatom community attributes as performance standards. However, while this article discourages using diatoms in multivariate approaches because they cannot effectively distinguish between reference and restored wetlands, the sensitivity of diatoms suggests they may still be viability components of an IBI or other metric that relies on a baseline, rather than relative, comparison.

Mayer PM, Galatowitsch SM. 2001. Assessing ecosystem integrity of restored prairie wetlands from species production-diversity relationships. Hydrobiologia 443 (1–3): 177–185.

The authors studied eight natural glaciated prairie wetlands and eight wetland sites restored after drainage (drainage occurred over 50 years prior to the study and restoration took place 3–15 years prior), located in South Dakota. The authors collected diatoms on artificial substrates that were placed in wetlands and then transported from natural to restored wetlands and vice-versa in order to assess differences in production and diversity in each diatom community; substrates were assessed after 5 and 10 weeks.

This study looked at (1) the relationship between production and species diversity, (2) whether production-diversity relationships can distinguish between restored and reference wetlands to assess ecological integrity, and (3) are production-diversity relationships influenced by species composition. The study measured production as total cell biovolume and diversity as species richness. The authors found that neither variable alone significantly differed between the two wetland types, but that production and diversity were negatively related in restored wetlands and that a similar relationship did not exist in the natural wetlands.

The authors inferred that production was dependent on species composition: production of some species differed between the wetland types—particularly, two species seemed to be superior competitors in the restored wetlands that were not similarly dominant in the natural wetlands, and their frequency created the negative relationship. The authors concluded that a performance standard for wetland health based on diatom assemblage could specify that restored wetlands displaying the relative highest production/diversity ratio in a given sample could be considered most impaired. The authors mention that their study "demonstrates the difficulty of assessing the condition of disturbed ecosystems when using single measures of ecosystem structure or function." The authors conclude that examining production-diversity relationships can provide a rapid measure of restored wetland integrity with respect to baseline conditions observed in reference sites.

U.S. EPA. 2002. Methods for evaluating wetland condition: using algae to assess environmental conditions in wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, D.C., EPA-822-R-02-021.

The EPA publication reviews many studies on the viability and practice of using algae to assess wetland condition. The authors generally are positive about using algae as indicators because sampling and laboratory testing of algae typically involves less time, and perhaps less staff expertise, than analyses of other variables. However, they are hesitant about recommending the use of algae indicators because of concerns of variability, sensitivity, and measurability.

The authors caution that spatial heterogeneity of algal communities can be high, with specific algal formations affected by site-specific nutrient or disturbance gradients. They also note that because algae are highly sensitive, and different types are more or less sensitive to a host of variables over different time scales, the selection and isolation of desired algal indicators is important for an accurate assessment, though arguably difficult. Finally, they note a pressing need for more precise characterizations of expected algal community conditions in wetlands, characterizations that could provide measurable baselines for performance standards.

To partially mitigate the above concerns, the authors suggest that composite sampling may control the effects of heterogeneity. Alternately, researchers could select a single algal community as the indicator (rather than sampling many sites within a habitat), or grow communities on introduced substrates to reduce the effects of substrate-specific nutrients. They recommend that taxonomic (structural) assessments, which can measure changes in species composition, relative biovolumes, and relative abundance, be employed instead of metabolic (functional) assessments, which are more variable because algae communities are responsive to so many variables. However, the authors caution that taxonomic assessments typically are thought to require precise characterization of the taxonomic conditions of the wetlands; they contend, however, that such precision may not be entirely necessary—comparisons of the relative abundance of organisms and the number of taxa in general that are common in reference wetlands yet rare in disturbed wetlands can be valid indicators. Finally, on the issue of measurability, the authors note that quantitative measures of biomass are difficult to obtain—and biomass measurements are of limited use in any case because biomass varies in space and time and in response to enrichment. They suggest that biomass be measured in terms of presence/absence or per semi-quantitative measures, like percent cover.

MAMMAL ARTICLES

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetlands associated animals. Wetlands 13(1): 25–31.

The author created a simulation model to compare metapopulation extinction probabilities before and after loss of small wetlands for five major taxa of animals (frogs, newts and salamanders, turtles, sparrows, and water shrews). As inputs, the model used 354 small freshwater wetlands located in three counties in central Maine and animal taxa typical of the area.

The model showed that, following a loss of small wetlands, three of the five taxa (turtle, birds, water shrews) exhibited elevated extinction risk. The probability of successful taxa dispersal decreased as a negative exponential function of inter-patch distance, and the most dispersive taxa studied—turtles and birds—were among the most prone to extinction following wetland loss. Salamanders, newts, and frogs—among the least dispersive—were the most extinction-resistant.

The article is a somewhat extended extrapolation that might suggest that a valid performance standard could be found in the density or abundance of non-dispersive taxa—that is, the higher the numbers, the more likely that the wetland is resilient. However, "resilient" is not equivalent to either "healthy" or "natural."

VEGETATION ARTICLES

Amoros C, Bornette G, Henry CP. 2000. A vegetation-based method for ecological diagnosis of riverine wetlands. Environ. Manage. 25(2):211–227.

The authors promote the use of aquatic macrophytes and helophytes as a method of ecological health of riverine systems. Plant communities were recommended because they are easy to survey and provide information on the origin of water supply (groundwater, seepage, surface river water), water nutrient content, effects of flood disturbances, and the terrestrializaton processes.

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423–428.

The authors present a strong case for the value of using hydrology to assess relative function over a range of wetlands in a watershed or region. This study assessed the relationship between biomass and soil organic matter to see if created wetlands are functioning similar to natural wetlands.

The biomass was about the same for created and natural wetlands, "although the below-ground component was somewhat higher" in created wetlands. Soil organic matter (SOM) was comparatively very low for most created wetlands in the study area. The authors conclude that plant biomass in created wetlands is seemingly not contributing to organic matter accumulation, and therefore wetland function is not developing appropriately. The authors also reference other studies that indicate that SOM is generally lower in created wetlands. No relationship was found between biomass and age of the wetland, nor between biomass and SOM, and no relationship was found between SOM and median depth of water on a site.

The study suggests guidance that could be implemented for measuring biomass as a performance criteria, and a possible way to obtain (better) averaged data. They suggest that it may be better to look at overall biomass, rather than separating results based on species composition because created and natural wetlands usually do not have the same plant communities for direct comparison, noting that "as such, we were more interested in community biomass production rather than a direct comparison of certain species." They also suggest to sample and average spring and fall samples "to reduce inter- and intra-annual variations." However, the authors assert that biomass by itself would not be a good performance measure because the composition of plants seems to play an important role in biomass values. For example, created wetlands with monoculture stands can have greater biomass than created wetlands with more varied plant composition. Most created wetlands in Pennsylvania are dominated by clonal dominants such as *Typha* and *Phalaris* and do not have much plant species diversity. The authors also point out (citing another study) that biomass is also problematic because of the difficulty in obtaining the below ground measurement, such as the problem with separating live and dead roots.

Cole CA. 2002. The assessment of herbaceous plant cover in wetlands as an indicator of function. Ecological Indicators 2:287–293.

This review paper questions the use of vegetative structure (e.g., percent cover) as an indicator of wetland function. Overall, the author asserts that geomorphology, tree density, or tree basal area would be better performance measures than percent herbaceous plant cover for six functions he reviews. He further argues that modifying percent cover in regulatory permit conditions to target hyrdophytes or to exclude exotics/invasive species is not enough because there is not enough information to link percent herbaceous plant cover to wetland functions. Other structural measures that may be better performance indicators include basin morphometry, soil organic matter, hydroperiod, and vertical structure.

The author reviews vegetative structure indicators for six wetland functions that "are processes (and not manifestation of processes)," including (1) short-term surface water storage, (2) long-term surface water storage, (3) maintenance of high water table, (4) transformation and cycling of elements, (5) accumulation of inorganic sediments, and (6) retention/removal of dissolved elements. He argues that percent herbaceous plant cover is not a good indicator for five of these six functions, and only one function (removal of dissolved elements) strongly relates to plant cover.

Citing other studies, the paper concludes that short-term surface water storage is more a function of "basin morphometry, the interaction of woody vegetation, flood flow, or microtopography. Percent cover of herbaceous vegetation by itself is not a good indicator of this function; percent cover of trees or stem density of woody plants along with basin morphometry would be better indicators. Long-term surface water storage is driven more by morphometry (basin or cut-off channel) and tree structure than by herbaceous plant cover. Regarding maintenance of a high water table, the "evidence is mixed, and sometimes contradictory," which makes percent herbaceous plant cover a poor indicator for this function. Transformation and cycling of elements is "often regulated by the amount and type of soil organic matter, as well as by aerobic or anaerobic soil conditions (as determined by local hydrology)". While there is a "strong positive correlation between soil nutrient density and plant biomass, "high percent cover does not necessarily translate into high biomass, either above or below ground." Accumulation of inorganic sediments: Different wetland types perform this function to various degrees. One study cited found that in Pennsylvania "headwater floodplain wetlands accumulated the highest levels of mineral sediments while riparian depressions accumulated highest levels of organic sediments." While some studies showed that wetlands were traps for sediments, other studies found them to be merely temporary storage areas "until the next high energy flood." Sediment removal in nondepressional wetlands was linked more closely to vegetation structural diversity of vegetation and site microtopography. Better performance measures would be geomorphic characteristics and tree density.

Regarding retention/removal of dissolved elements, much of a wetland's ability to remove sediment and "attached chemicals" is related to the density of plant herbaceous cover. Because it is the microorganisms attached to the surfaces of the plant's stems, leaves, and roots that remove or transform the dissolved elements, percent herbaceous cover is related to the surface area available for microorganisms. Percent cover can therefore be considered a "reasonable" indicator of this function (although a better understanding of which plants "better support microbial communities would allow for a better relationship between percent cover and this function"). Other findings in this study include that vegetation structural parameters can be used for short- and long-term water storage by measuring basal area and tree density.

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248–258.

This study measured vegetation and soil development in a constructed wetland. The study found that aboveground (AG) biomass and macro-organic matter (MOM; measured at 0–10 cm) depended on elevation and frequency of tidal inundation. The AG biomass of *Spartina alterniflora* in lower elevations that was inundated frequently developed to levels similar to natural reference wetlands within 3–5 years and maintained those levels for the 15 years of the study. This agrees with studies reporting 3–5 years. AG biomass in interior areas (dominated by *S. cynosuroides*) were less frequently inundated and took 9 years to consistently reach similar levels as the reference wetland. AG biomass at the highest elevations (dominated by *S. patens*), which were seldom flooded, never reached "comparable" reference target values in the 15 years studied. As with vegetation, wetland soil development was correlated with increased flooding.

MOM developed at approximately the same pattern (but more slowly) as AG biomass; MOM consistently reached reference site equivalence in the *S. alterniflora* stands after 2 years, *S. cynosuroides* stands took 5 years, *Juncus roemerianus* stands took 8 years, and MOM was still "consistently less" in *S. patens* stands 12 years after creation. In soil development, only *S. cynosuroides* showed a significant positive relationship with age—it increased over time then leveled off after 10 years. MOM in the 10 to 30cm depth increased over time, but never reached equivalence with reference values. The authors cite other studies that link duration of inundation with accelerated marsh ecological development. Many studies found links between soil development and elevation, suggesting that a performance standard may need to address the need to sample soils be from varying elevations, not just lowest elevations. While constructed marshes showed this "strong gradient in wetland soil characteristics," this gradient did not exist in the natural reference marsh, "due to the fact that the natural marsh is underlain by 2–3 m of peat". Conversely, constructed wetlands had mineral soil with high sand content and low silt, clay, and organic matter.

The study also contained valuable commentary on functional trajectories for soil: Simenstad and Thom (1996) only found a few trajectories that tracked with age of wetland (7 years), even though they studied 16 parameters. Zedler and Callaway (1999) found only weak correlations between organic matter (OM) and nitrogen (N) with age after 12 years. OM increased for 5 years before it began to plateau. Other vegetative estimates (density of tall stems, total stem length (estimator of AG biomass) were not related to age of wetland. On the positive side, Craft et al. (1999) found AG biomass and organic matter of *Spartina* to follow non-linear trajectories with age before reaching "equivalence." Zedler and Callaway (1999) and Zedler and Lindig-Cisneros (2000) support "the idea that trajectories…if they exist, are better represented by non-linear rather than linear curves." This study found non-linear trajectories for AG biomass and MOM, but it depended on the species (related to elevation zone). *S. cynosuroides* (AG biomass and MOM), *J. roemerianus* (AG biomass) both showed positive trends with age that reached equivalency with ref values. Neither *S. alterniflora* nor *S. patens* showed relationship with age.

The authors point out that most created marshes are young (<10 yrs, as of 2002), and usually vegetation (if any) is the only parameter consistently measured, so it is unclear how long some ecological parameters take to develop. Most long-term created coastal wetlands studies are limited to salt marshes dominated by *S. alterniflora,* and usually along the Atlantic Coast and *S. foliosa* along the Pacific Coast. For example with soil development, estimates for streamside and interior zones suggest that a created marsh would require an additional 30 to 90 years to develop soil characteristics similar to natural wetlands within the upper 30 cm of the soil profile, and in higher elevations the estimates are 200+ years for soil development.

Craft C, Reader J, Sacco JN, Broome SW. 1999. Twenty-five years of ecosystem development of constructed *Spartina alterniflora* (Loisel) marshes. Ecol. Appl. 9:1405—1419.

Aboveground biomass for the two constructed wetlands in this study initially overshot the reference wetland values (after 3 years), then dropped to the reference wetland values. "Macro-organic matter (a measure of the living and dead root and rhizome mat) values increased steadily toward reference values, reaching them much earlier (after 3–5 years) in one site than in the other (after 20+ years). Sediment C:N ratios appeared to follow a linear trajectory, reaching reference site ratios in 10 to 25 years." (as cited, quoted from Morgan and Short 2002).

Dawe NK, Bradfield GE, Boyd WS, Trethewey DEC, Zolbrod AN. 2000. Marsh creation in a northern Pacific estuary: is thirteen years of monitoring vegetation dynamics enough? Conservation Eco. 4(2):12.

This study examined planted, unplanted, and natural salt marshes using principal components analysis and transects over time to study plant cover and species richness in mid-to-low marsh communities on created islands over a 13-year period. Cover and species composition reached reference marsh values by 6 years after planting, and aboveground biomass took 13 years after planting to attain reference site values. Even with these indicators of success, however, the researchers were concerned with "large areas devoid of vegetation" that developed between years 6 and 13 on 3 out of 4 of the islands, which was thought to be the result of water ponding (higher salinity and longer inundation affecting the plants). This study found that sustainability success couldn't be concluded even after 13 years.

The authors outline some of the design flaws common to failed constructed marshes. They identify Canadian studies in which constructed wetlands achieved "varying degrees of success, but even in 'successful' cases, species diversity and total vegetation cover remain below those of comparable, naturally occurring marshes." Failures in design problems with surface elevation, exposure to strong currents, and grazing by Canada geese. This study and another earlier study found that elevation was shown to be a major factor in whether planted vegetation was successful or not, and it mentioned yet another study's observation that "substrate elevation is probably the most agreed-upon factor in determining vegetation zonation in brackish and salt marshes."

This study brings up the issue that the presence of vegetation is not an adequate indicator of a functioning, sustainable marsh. Vegetation can survive for many years in poor conditions before dying off. For example, the study found that one *Carex* species decreased in cover but continued to be present for the first 6 years after planting. However, it disappeared by the final year of study (13th year). Other studies found similar results were *Carex lyngbyei* stands, which showed a stable presence in the first 5 to 6 years and then died off 7 to 10 years afterwards. This highlights the importance of long monitoring periods, or the need to look for more immediate response indicators (such as reproductive capacity/seeds). The authors discuss the importance of proper placement of plantings with regard to elevation and inundation (salinity). The authors cite other studies that suggest (depending on the study) a 10–20-year monitoring period for created freshwater marshes, with possible longer periods for coastal wetlands. Monitoring time periods will differ by wetland type and site-specific conditions, depending on annual variation in species composition, cover, and productivity.

Ettema CH, Coleman DC, Vellidis G, Lowrance R, Rathbun SL. 1998. Spatiotemporal distributions of bacterivorous nematodes and soil resources in a restored riparian wetland. Ecology 79 (8): 2721–2734

Although useful for other purposes, this study was limited in its applicability for examining soil and vegetation performance standards and no reference sites were used for comparison.

Galatowitsch SM, van der Valk A. 1996. The vegetation of restored and natural prairie wetlands. Ecol Appl 6:102–112.

The authors looked at 10 restored and 10 natural reference wetlands for three years in northern Iowa. The 10 restored wetlands in this study were selected from 62 restored wetland that were being monitored as part of a general study of restored prairie wetlands. The 10 wetlands were on hydric soils similar to those of a predrainage seasonal or semipermanent water regime. The restored wetlands had been drained 25–75 years earlier for agriculture. The study sites were restored in 1988 by removing the drainage tiles. The natural wetlands were nearby and of similar size and water regime. The authors questioned whether the efficient-community hypothesis—that vegetation composition does not reflect dispersal ability, rather, all species that could become established and survive under the restored conditions would be found growing at the site or their seeds would be found in the seed bank.

The study demonstrated that "simply bringing the water back" was not enough to support all the native species after three years. After restoration the natural wetlands had a mean of 46 species compared to 27 species in restored wetlands. Plant species distribution and abundance at different elevations were significantly different in natural and restored wetlands. In addition, the seed banks of restored wetlands contained fewer species and fewer seeds than natural wetlands. The two sites were similar in emergent species richness, but the restored wetlands had fewer shallow emergent species. Seed banks differed between the two sites.

The patterns of recolonization appeared to be a factor of seed dispersal ability rather than an efficient-community situation. This suggests that revegetation and restoration recovery will be affected by proximity to a propagule source and by additional seeding or planting. The authors mention the prairie potholes of today are much more isolated today than they were prior to drainage. This makes present day "dispersal of propagules to restored wetlands effectively is impossible for restored wetlands that have no surface connections to natural wetlands or other restored wetlands because they are surrounded by farmland." This supports revegetation as a restoration tool.

Galatowitsch SM, van der Valk AG. 1996. Characteristics of recently restored wetlands in the Prairie Pothole Region. Wetlands 16(1):75–83.

This study described the site selection, basin construction, and hydrologic design practices of 62 restored Prairie Pothole wetlands to determine if the design practices resulted in restorations resembling the hydrology, basin morphometry, and vegetation of natural wetlands. The authors also assessed whether pre-drainage wetland patterns were being restored. They found that the most common types of restored wetland were seasonal wetlands. According to this study, the mitigated wetlands resulted in a larger wetland than had occurred naturally, but the wetlands were not disproportionately deeper than the natural wetland. The water regime for 24 of the wetlands corresponded to predictions from soil types. The authors concluded that it's reasonable to assume that the closer a restored wetland comes to resembling a natural one, the more likely its function are similar to the natural wetland. Therefore, site selection, basin construction, and hydrologic design practices are three characteristics of wetlands that are crucial to wetland function.

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass *(Spartina foliosa)* to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.

The study examined *Spartina foliosa* in a newly constructed wetland after the addition of both organic matter and nitrogen (organic and inorganic forms) to the soil. The authors concluded that the AG biomass of the plant "responded to soil amendments in proportion to the amount of nitrogen added." In the second year of the study, biomass increased more than density, and most of the biomass increase was due to an increase in height. The study further found that "organic amendments did not increase soil organic content." The soil used for the created wetland consisted of dredge spoil from San Diego Bay. The authors suggest that "the sandy nature of the soil explains its low nutrient retention and the rapid loss of organic matter in the decomposition experiment."

The authors point out that when a target function of the mitigation is to provide habitat for particular species, it is important to determine if/what structural parameters are important for their habitat requirements and include those as performance criteria. For example, a study found that a mitigation site in California failed because the height of the cordgrass was wrong for the target species. The mitigation involved creating a wetland for the endangered light-footed clapper rail *(Rallus longirostris levipes),* and even eight years after planting, the marsh was not used by the birds for nesting. This lack of function was attributed to "inadequate canopy architecture"—the planted cordgrass *(Spartina foliosa)* was shorter than in the natural marsh. The shorter vegetation was completely inundated at high tides, "leaving no cover for birds or their floating nests." Furthermore, the authors point out that many studies have found low N and OM in constructed marshes, indicating that they are not providing adequate sustainable function, and that comparable levels of N and OM may take 15–30 years to develop in created wetlands.

The authors point out that soil functions are important for performance standards because, for example, deeper SOM layers recycle nitrogen better, SOM improves water retention and cation exchange capacity, may affect nitrogen supplies, provides a food source for nitrogen fixing organisms, and affects macroinvertebrate communities. This study and a review of the literature may be an argument for a performance criteria that either requires soil amendments added during construction, a careful look at the type of soil added to a site, and for extending the monitoring period to 15–30 years.

Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305–315.

The study examined various elements of constructed and natural wetlands, including soil organic carbon, vegetation composition, and use by benthic and avian species. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush *(Iva frutecsens* and *Baccharis halimifolia),* and use by birds.

Regarding soil organic carbon, the authors report that has been generally assumed that organic matter will accumulate as a marsh matures, and that this is an important reflection of function, because "organic matter supplies the base for higher trophic levels." Conversely, this study found that organic carbon on the marsh surface (0–2 cm) did not significantly differ between the three marshes. However, the authors mention that microtopography formation within a constructed marsh may be affected by the significant lack of organic matter in the soil, but "the abundance of fish, blue crabs and benthic infauna appears not to be affected." The authors recommend adding soil amendments to the soil during construction to speed up the development of a soil profile similar to a natural wetland.

Saltbush vegetation was found to be difficult to establish in a created wetland, and the authors suggest setting it as a permit condition to encourage permitees to focus on enhancing its development. Conversely, no significant difference was found between species composition, stem density, and percent cover estimates for *Spartina* communities.

No apparent difference was detected in blue crab, total fish, and commercial fish abundance between the three marshes, although a 1992 study "showed seasonal differences of blue crab and fish abundance…and a higher species diversity and richness in the constructed marsh," The greater species richness could be due to the larger subtidal area, findings which are supported by other studies that found that hydrogeomorphology may be more of a factor for fish than whether the site is natural or created.

Bird sampling revealed that 20 of the 31 species found in the natural wetlands were not found in the constructed wetland, but none of the species in the constructed wetland were unique to the constructed wetland. Species richness and diversity of neotropical migrants were greatest in the natural marshes. Furthermore, the study observed evidence of breeding in the natural marshes but not in the constructed marsh. The authors suggest that the difference in bird use is related to the lack of structural complexity in the created wetland.

A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. Attention may also be needed to ensure a limit to the ratio of vegetated verses nonvegetated area (the vegetated:nonvegetated area was 1:1 in the constructed wetland, as compared to 6:1 and 11:1 in the natural wetlands). In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.

Kellogg CH, Bridgham SD. 2002. Colonization during early succession of restored freshwater marshes. Canadian Journal of Botany Review 80(2):176–185.

This study looked at natural colonization vs. planting effects in restored freshwater wetlands. After 5–6 years, results showed only small differences in the parameters of species richness, diversity, and aboveground biomass between reference sites and restored sites (planted and unplanted). The study did not find significant differences between planted and unplanted sites in terms of species richness, diversity, and aboveground biomass. The authors compared their study to others that found higher species richness in seeded restoration vs. unseeded during approximately the same monitoring period. The authors recommend a longer monitoring period to take into account stochastic events such as drought, which may be important for seed germination.

Magee TK, Ernst TL, Kentula ME, Dwire KA. 1999. Floristic comparison of freshwater wetlands in an urbanizing environment. Wetlands 19(3):517–53.

The authors evaluated the floristic condition of freshwater palustrine wetlands dominated by wet meadow, emergent marsh, aquatic vegetation, or open water near Portland, Oregon. The goal of the study was to characterize plant species richness and composition of 45 naturally occurring wetlands and 51 mitigated wetlands.

The study found that overall species richness was high with a total of 365 plant taxa (306 on mitigated wetlands and 274 on natural wetlands) with an average of about 50 percent native species. Ninety-five taxa were documented on 10 or more sites, but only 14 species were found on more than half (> 47) of the sites. Nine of the 14 most common species were introduced species and aggressive competitors that are known to become dominant or form monocultures that eventually exclude native species and seriously reduce biodiversity. Naturally occurring and mitigated wetlands had significantly different species assemblages. Statistical analysis showed a strong relationship between percent cover of water and HGM class. This is of interest in that 44 of 51 of the mitigated wetlands were ponds. Finally, the floristic composition of the mitigated wetlands was found to vary in relation to the level of urban/human development in the surrounding landscape and the age of the wetland.

The cumulative conversion of natural wetlands to open water ponds in the urbanized area around Portland, Oregon, resulted in a decrease in wetland diversity and a degraded floristic condition of wetlands.

Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: a whole-ecosystem experiment in self-design. Bioscience 48(12)1019–1030

This three-year study looked at the effects of management of two created wetlands with similar hydrology. One wetland was seeded while the other was not. Their hypothesis was that the two would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. This hypothesis was based on concepts of self-design and self-organization.

The seeded site had 65 species after three years compared to the unplanted site with 54 species. Forty-nine species were common to both sites. The authors do not mention if these were native plants. Nutrient levels were essentially the same after three years at both sites. The benthic taxon richness was higher in the planted wetland with 38 taxa than in the unplanted wetland with 32 taxa, but the diversity indices were similar. Of 42 total taxa in the third year, 28–67 percent were common to both wetlands—they don't mention what these were. The authors do state that "clean-water" invertebrates were more numerous in the unplanted wetland in the second year, but had similar clean-water diversity indices by the 3rd year, although the unplanted wetland had 12 percent more clean-water taxa.

This study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward becoming a functional wetland, but the results do not support that this study was a success.

Reinartz JA, Warne EL. 1993. Development of vegetation in small created wetlands in southeastern Wisconsin. Wetlands 13(3):153–164.

This study looked at natural colonization of by vascular plants of 11 created wetlands in southeastern Wisconsin.

In this study, the 11 created wetlands (small, depressional and isolated from other wetland sites) with naturally colonized vegetation were sampled over a 2-year period providing samples from wetlands aged 1–3 years. Vegetation in the 11 naturally colonized sites was compared with 5 wetlands that were seeded with 22 species of native wetland plant seeds. Diversity and richness of native wetland plant species increased with wetland age, size and proximity to nearest established wetland. *Typha* spp. increased from 15 percent in 1-year-old wetlands to 55 percent in 3-year-old wetlands. Seeded wetlands had much higher diversity and richness of native wetland species than unseeded wetlands after 2 years. Seventeen of 22 seeded species were established in as least 2 wetlands after simply scattering seeds.

This is yet another paper that discusses the problem with created wetlands and monocultures of *Typha* spp. Naturally colonized wetlands were colonized by 82 native obligate or facultative wetland plant species. Individual naturally colonized wetlands had an average of 22 native species (range 11–29) after 2–3 years of colonization. However, *Typha* spp. quickly became the dominant plant in every constructed wetland. By the third year *Typha* spp. comprised 38 percent of the total plant cover and 55 percent of the total cover of native wetland plants. In contrast, seeded wetlands had an average of 42 native wetland species, and after 2 years *Typha* spp. accounted for only 22 percent of the cover of native plants. "Many restoration ecologists include cattails and willows in their list of problematic species for wetland restoration....[they] discuss fringe wetlands around ponds and reservoirs and state that natural colonization is usually an inappropriate technique for wetland restoration because these sites have a tendency to become monotypic stands, usually of cattails. Or what Odum (1998) describes as the "cattailization of America."

Trajectory implications: the diversity and richness of native plants and the proportion of total plant cover comprised of native wetland species increased over time (naturally colonized increased from 28–85 percent in 1–3 years in this study). The diversity and richness of native wetland species increased with wetland age, size, and proximity to the nearest established wetland. Many of the native species that became important components of the naturally colonized wetlands had obvious adaptations for wind dispersal.

Talley TS, Levin LA. 1999. Macrofaunal succession and community structure in *Salicornia* marshes of southern California. Estuarine, Coastal and Shelf Science 49(5):713–731.

This study examined macrofaunal community structure succession and the effect vegetation and sediment attributes have on those assemblages in natural and created *Salicornia* marshes. The results suggest that *Spartina* and *Salicornia* marshes are not interchangeable with respect to fauna—*Salicornia* marshes are more arid, often dominated by succulents. Comparing natural examples of these two habitats within the same bay, the *Salicornia* marsh had "lower macrofaunal density (San Diego Bay only), proportionally fewer oligochaetes and more insects, and no differences in species richness." Because of the difference in habitat structure (e.g., natural *Salicornia* marshes had higher SOM, salinity, BG biomass, and lower sand content than constructed marshes), it may not be advisable to transfer *Spartina* marsh research to another type of wetland. On the other hand, there seemed to be little difference in macrofaunal species richness, but 40–50 percent of the species composition was unique to each habitat type.

This study asserts that physical disturbance (e.g., high and low energy systems), rather than marsh age, may have more to do with differences between created and natural wetlands. The authors emphasize the importance of finding reference wetlands in same bay. They also suggest that faunal development in created *Salicornia* marshes requires 10 years or more.

The trajectories in this study indicate an increasing similarity between created and natural marsh assemblages over time. However, even with similarities in macrofaunal densities or assemblages "composition between created and natural systems, functional characteristics such as food web support, nutrient cycling, population size structure or parasites loads may remain different."

U.S. EPA. 2002. Methods for evaluating wetland condition: using vegetation to assess environmental conditions in wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, D.C., EPA-822-R-02-020.

This comprehensive EPA report discusses, among other things, the contributions that vegetation makes to wetlands, including its fundamental role in the food chain as the primary energy pathway in wetlands, its effect on other taxonomic groups (through factors of composition and diversity), its influence on wetland chemistry (e.g., through uptake and incorporation/sequestration of nutrients, metals, other contaminants), and its influence on hydrology and sedimentation (through soil/ground stabilization, current modifications and flood peak desynchronization).

The report argues that plant communities reflect the biological integrity of wetlands. They are effective as indicators of environmental condition because they are present in all wetlands, are immobile, can reflect chronic stress on the system, are well studied, and information to identify wetland plants is readily available. Limitations to using vegetation as indicators, however, include the lag time that occurs between the introduction of a stress and a plant's response, especially in long-lived woody species; plant identification can be laborious, or restricted to narrow seasonal periods; while sampling techniques are available and well documented, techniques for some assemblages such as submerged species can be difficult and can result in missing or erroneously sampling parts of the population; and individual species' response to specific stressors (as opposed to general response to anthropogenic changes) is not well understood.

The report divides vegetation metrics into three groups: "community-based metrics, metrics based on plant functional groups, and species-specific metrics." An example of a community metric is the Floristic Quality Assessment Index (FQAI), a method originally developed for the Chicago region but has since been adapted and modified for other regions. The FQAI was originally developed to quantify the "degree of 'naturalness' of an area based on the presence of ecologically conservative species." It is thought to "reflect the degree of human disturbance to the area" as more conservative species are less prevalent in disturbed areas. Higher "coefficients of conservatism" are given to species that are typical of "stable or 'near climax' conditions," and those that are usually found in areas with a narrow band of ecological conditions.

The report cautions against parameters that do not give "consistent, ecologically meaningful indications of wetland integrity," including forestry canopy species (they give limited signals because of long response time), metrics quantifying individual health of plants (they do not show a "clear dose-response pattern" as have been found in other taxonomic groups, such as measures of tumors on fish and tumors)," plant indicator status (OBL, FACW, FAC, FACU—this information was "not designed to provide information on the condition of a wetland"—for example, some exotic invasive species are categorized as OBL).

Weiher E, Wisheu IC, Keddy PA, Moore DRJ. 1996. Establishment, persistence, and management implications of experimental wetland plant communities. Wetlands 16(2):208–218.

The authors examined the importance of seed banks in wetland restoration. They inoculated 120 wetland microcosms representing 24 different environmental treatments with seeds from 20 wetland plant species. The seeds were selected to represent a range of morphologies and life history types representative of eastern temperate riverine and lacustrine wetlands. Soil texture, litter, moisture, and burial by sediment were listed as environmental factors that can affect germination.

After five years only six plant species were found in large numbers on the microcosms and Lythrum was one of those species. The rapid loss of species suggests that in the absence of disturbance, competitive exclusion by *Lythrum salicaria* can occur within five years. Flooding and fertility remained the main factors affecting species composition. Study results suggest that high diversity, low biomass wetlands will be difficult to create; therefore, protection of such wetlands may deserve a higher priority.

Zedler JB. 1993. Canopy architecture of natural and planted cordgrass marshes: selecting habitat evaluation criteria. Ecological Applications 3(1)123–138.

This study looked at bird nesting vegetative requirements of intertidal cordgrass *(Spartina foliosa)* marshes for the endangered light-footed clapper rail *(Rallus longirostris levipes)* that could be used for mitigation performance standards. The study compared natural (both with and without nesting) and constructed wetlands, as the rails were not using the constructed wetlands. The author found that nest failure was primarily caused by tidal inundation (due to cordgrass being too short) and predation. The tall cordgrass (>60 cm) "appears necessary" for the nests to "float upward, but not away, as the tide rises." The study found that constructed marshes had few stems >60cm, unlike most stems in natural marshes, and that "in natural marshes, cordgrass heights increase with freshwater flooding and nitrogen enrichment." In addition, the study found that cordgrass height distributions and density parameters were better measures than previously used canopy structure measures, which included cover, biomass, total stem length (TSL), and maximum height (biomass measurement is destructive in an endangered species habitat area fails to capture the fact that "high values can derive from the presence of many short stems or fewer tall ones"; TSL is too variable for use alone; and cover estimates for habitat value suffer from errors and biases due to rapid evaluation methods such as visual estimates). The study also found that density and height distribution data must be included together, as the constructed marshes studied showed that just meeting one was not attracting the rails.

"Suitable habitat" threshold criteria for the rail would entail that cordgrass density should be at least 100 stems/m2 with at least 90 stems/m2 >60cm and 30 stems/m2 >90cm; the standards specifically use density rather than percentages to ensure adequate stem numbers. The largest number of rails occurred in a marsh with 316 stems/m2, and data suggest that taller stems will improve chances of nest success.

The author mentions recommends monitoring for several years, and that 20 years is not unreasonable. Long-term monitoring is important because of high variability interannually and spatially, and because of the "lag effects of 'immature' ecosystems," She suggests meeting standards for "at least five consecutive years that lack major floods or nutrient inflows (or other unusual disturbances)" and recommends the use of many reference wetlands. The author points out that sampling methodology is critical for accurate assessment and makes suggestions and gives scientific justification for choosing quadrant size, site selection method, plot sizes, number of quadrants, best time of year and conditions to sample, and monitoring time period.

Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restor Ecol 7:69–73.

Both the constructed and reference sites had high interannual variation, with only soil organic matter fitting a trajectory model. "They warned against making long-term predictions using trajectories developed from short-term observations (as cited in Morgan and Short 2002)."

APPENDIX B. SUMMARIES OF ABIOTIC ARTICLES REVIEWED

HYDROLOGY ARTICLES

Barry WJ, Garlo AS, Wood CA. 1996. Duplicating the mound-and-pool microtopography of forested wetlands. Restoration and Management Notes 14(1): 15–21.

This is a predominantly non-scientific description of a wetland mitigation (creation) project in which the mitigation attempted to duplicate the mound-and-pool microtopography of a ground-water fed forested wetland. The authors reference scientific papers, books, and reports for reference values of slope (20 to 1 in forested/shrub zones, and up to 10 to 1 in upland boundary transition areas), mound heights (15cm to 1m for red maple swamps), and hydrology (depth to groundwater and planting zones from high and low water marks). The study area was designed to allow 50 percent of the area to be mounds and 50 percent of the area to be pools—to avoid adding or removing material (doesn't seem to be based on science). The study does not provide quantitative assessments of success, only qualitative statements such as "virtually all of the planted stock was doing well due to the irrigation" (one year after construction) along with a list of species present on the site. This study would need followup to see if the design parameters used are effective and quantitative evaluation measurements.

Bedford B. 1996. The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. Ecological Applications 6:57–68.

This paper focuses on hydrology as the basis of a landscape approach to mitigation, with the assertion that hydrologic criteria are the single most important set of variables for determining the proper functions of a wetland (with climate driving the entire hydrologic system). The author concludes that landscape properties should influence mitigation projects more than they currently do because landscape properties dominate the development and define the distinctive hydrochemical character of wetland ecosystems. The natural diversity of freshwater wetland plant communities and ecosystems is derived from the myriad combinations of hydrologic factors and climate interacting and combining on the landscape. She states that the best way to make mitigation decisions would be to consider and integrate both the ecoregions and the hydrologic units.

Budelsky RA, Galatowitsch SM. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971–985.

The researchers in this study explored the limiting factor regarding recolonization of native sedge meadows in restored wetlands. Data on monthly measurements of survival, above-ground tiller numbers, and tiller height were collected. The study compared rising water basin and falling water basin scenarios on the growth of native sedges, with and without competition from other plant species, to determine which set of parameters most affected biomass.

During the first 2 years, native sedge biomass in the rising water basin was greatest when competition was excluded but lowest when competition was not controlled. By the third year, biomass in the falling water basin was greater than in the rising water basin, and it did not differ between competition and non-competition treatments.

In the absence of competition, native sedge growth varied significantly with changes in elevation, but in the presence of a competition sedge, growth did not vary significantly. This experiment illustrates that immature sedges are sensitive to hydrology and competition. Therefore environmental control during the establishment year could be a critical aspect of native species' long-term survival. This may suggest that first year performance standards may need to be especially tailored to measure establishment conditions and success.

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265–278.

The goal of this study was to determine if hydrologic characteristics of three HGM subclasses (slope, headwater floodplain, mainstem floodplain) were similar between two different geographic regions (Pennsylvania and Oregon). In addition, if similarities did exist between subclasses and regions, could aspects of model development be transferred between regions in an effort to shorten the time required to develop appropriate data sets and functional assessment models.

It didn't work! The study found major differences in the three HGM subclasses between Oregon and Pennsylvania, although there were some similarities between slope wetlands, although measurements such as water depth and root zone saturation differed. The study documented a difference in patterns of maximum and minimum water levels among the three subclasses and between regions. The two regions were considered similar in climate (precipitation and temperature), but there were very different water regimes. In addition, precipitation patterns differed with Pennsylvania having evenly distributed precipitation in contrast to Oregon's highly seasonal pattern. Soils were similar between the two regions although Oregon wetland soils appeared to have better water retention. Testing functions (nutrient cycling and export of organic matter) found a difference between sites. Functional differences (redox-sensitive compound cycling, nutrient cycling, export of dissolved organic matter) were attributed to the "constant saturation in Oregon wetlands versus the cyclic wetting and drying in Pennsylvania.

The results of this study were disappointing because "sharing models could lower costs and greatly improve implementation of HGM classification and assessments nationwide." This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models—up to 4 years in PA but estimated to take one to two years for each subclass in each region. However, because of some similarities between slope wetlands, the authors felt that there may be aspects of the slope model that could be successfully applied in both regions. In general, the study demonstrated that using a regionally developed HGM in another region could lead to serious errors in the interpretation of wetland functions between sites or among a group of sites. They agree that the "regional modification of national models was designed into the HGM process for good reason."

Cole CA, Brooks RP. 2000. A comparison of the hydrologic characteristics of natural and created mainstem floodplain wetlands in Pennsylvania. Ecol. Eng. 14(3):221–231.

This study compares the hydrology of created versus naturally occurring mainstem floodplain wetlands in central Pennsylvania. These wetlands are found along third or greater order streams and receive their water input from overbank flow during floods. The study emphasizes the strong influence of hydrologic processes on all other ecological functions in a wetland, and it stresses the importance of restoring, establishing, developing, and managing the appropriate hydrology for the long-term success of restoration and creation projects. It also cautions that hydrologic data on natural wetlands is needed for building functional mitigation wetlands. The study points out that data on wetland hydrology are only recently becoming available for different sites and through time. "For created wetlands, the data that are available are either predictive in nature or come primarily from sites with a significant open water component." Another study by the same author examined natural wetlands of various HGM subclasses in Pennsylvania and found differences between wetland subclasses in the median depth to the water table. For example, the water table in riparian depressions (mainly supplied by groundwater) was within the root zone most of the year, while the water table in slope wetlands (supplied by a combination of surface- and groundwater) was less predictable and "was within the root zone less frequently than for groundwater-dominated sites." Floodplain wetlands (fed primarily by surface water) were generally driest, "but water levels also increased very rapidly due to storm events."

Compared with created wetlands, natural wetlands in the area normally had a deeper median depth to water, shorter saturation/inundation periods, and shorter time during which water was in the root zone. Created wetlands generally had less vegetation and more open water, and water stayed in the root zone longer following inundation, whereas water in natural wetlands "typically [drop] out of the root zone quickly following inundation," and only remained on the site and within the root zone for a few days or weeks at a time. Overall, the created wetlands were "much wetter than one would expect given their location within the landscape." Another study also supports this study's findings, noting that "created wetlands typically had many more open water patches than did natural reference wetlands in Pennsylvania."

Regarding performance measures, it is important to tailor the hydrologic requirements to ensure correct functioning. Simply stipulating that the hydrology must meet jurisdictional requirements is not enough. For example, stable ponded water typically found in created wetlands creates anaerobic conditions that affect soil chemistry and changes the vegetation make-up. This combined with common construction practices that lead to soil compaction deters plant community establishment. Conversely, in the case of natural floodplain wetlands, the naturally variable hydrologic cycle results in dry, aerobic conditions in the summer and fall, which promotes development of a "more mixed plant community"

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423–428.

A set of 24 reference wetlands (selected from a larger sample of 51 wetlands) was categorized from 1993 to 1994 by HGM subclass. In addition, the authors installed monitoring wells and piezometers, and collected monthly data on local water-table levels, pH, and specific conductance. Four subclasses were identified (riparian depression, slope, mainstem floodplain and headwater floodplain). Results demonstrated that each of the subclasses identified showed different hydrologic behavior.

The authors found hydrogeomorphic characteristics of each subclass to be predictable and consistent. Consequently, they argue that it is a good approach for characterizing the hydrology in reference wetlands in Pennsylvania. In this study, the authors were able to "distinguish between slopes and riparian depressions using hydrologic data when these sites are often seen as a single wetland type."

This study is very supportive of the HGM approach to classifying wetlands. The authors conclude that "this study contributes to the development of the requisite data needed for the generation of a performance criteria matrix, from which a suite of ecological and design criteria would be available, by HGM subclass, for use in functional assessment, impact analysis, and designing mitigation wetlands."

David PG. 1999. Response of exotics to restored hydroperiod at Dupuis Reserve, Florida. Restoration Ecology 7(4): 407–410.

The author examined the effect on native vegetation success over nonnative species when natural hydroperiods were restored to a wetland. The authors used ditch plugs to restore the hydrologic cycle. Restoration of the hydroperiod eliminated the invasive bahia grass from all study sites. Conversely, pickerelweed and maidencane, both native species, increased significantly when the hydrology was restored. It is thought that dense stands of Maidencane may out compete torpedo grass, an exotic, aggressive species that can create dense, monotypic stands in response to increased hydroperiod. The ditch plugs proved to be a useful mechanism for restoring natural hydroperiods and, thereby, increased native species and decreased/eliminated invasive species.

Delaney TP, Webb JW, Minello TJ. 2000. Comparison of physical characteristics between created and natural estuarine marshes in Galveston Bay, Texas. Wetlands Ecology and Management 8(5):343–352.

The researchers compared physical differences and structural complexities of natural and created coastal salt marshes in the lower Galveston Bay system. They did not find significant differences in relative abundance of microhabitat types. However, the natural and created marshes did differ in their marsh:water-edge ratio and area-perimeter ratio. The marsh:water-edge ratio in natural marshes was higher than in the created marshes, indicated that natural marshes had highly irregular or undulating edges whereas created marshes had relatively straight edges.

Those differences in shoreline undulation and reticulation amounted to differences in vegetation growth. Created marshes had expansive areas of regular even growth while natural marshes exhibited more clustered and clumped growth.

Hunt RJ, Walker JF, Krabbenhoft DP. 1999. Characterizing hydrology and the importance of ground water discharge in natural and constructed wetlands. Wetlands 19:458–472.

The authors studied hydrology and ground water discharge at two constructed and two natural wetlands along the Kickapoo River in southwestern Wisconsin. The reference sites were selected to typify the two dominant wetland vegetation communities. They acknowledge the HGM classification system but direct their study to investigate how linkages between hydrology and other environmental conditions function. In addition, they created hydrographs to characterize hydrology and investigated the importance of groundwater to physical and geochemical conditions. This study did identify factors that connect hydrology to wetland plant establishment and persistence.

The study demonstrated that sites with greater groundwater discharge had high water tables and more stable hydrographs. The authors compared soil-moisture-potential measurements to the water-table-hydrograph at one site and found that the amount of root-zone saturation was not necessarily driven by the water-table hydrograph, but could result from other soil parameters. Groundwater discharge was not a determinant of temperatures in the root zone, however it was associated with the earliest date of thaw. Groundwater direction, magnitude of shallow groundwater flow and areas of higher groundwater discharge all played an important role in understanding wetland function. The amount of groundwater discharge influenced other environmental factors: physical hydrology, root-zone saturation, root-zone temperatures, and porewater chemistry. Age of wetland was linked to soil temperature, with sites 2 years post construction having consistently higher temperatures. The authors attribute higher soil temperatures to reduced shading resulting from smaller/less dense vegetation cover.

In this study, constructed wetlands had root zones that remained frozen longer post-construction due to increased plant cover and litter accumulation. The authors state that this demonstrates that constructed wetlands are slow to develop and that monitoring should exceed the mandatory 3–5 years. They suggested that it was difficult to compare created and natural wetlands because created wetlands were slow to mature. Further, they emphasize that successful wetland construction requires the ability to characterize wetland hydrology by collecting appropriate data from the wetland slated for development, and those data should be included in design goals for the replacement wetland. Further, based on the theory that hydrology is the most important determinant of wetlands vegetation and function, that managers may want to consider an initial seeding of native pioneer species while collecting data on hydrology. Once hydrology is determined, managers could initiate an second phase planting plan using more expensive species. The authors agree with other studies that assert that our understanding of hydrology is not advanced enough to predict wetland hydrology, and that groundwater discharge can be variable at both the site and regional area. These findings do not bode well for wetland restoration projects.

Kolka RK, Singer JH, Coppock CR, Casey WP, Trettin CC. 2000. Influence of restoration and succession on bottomland hardwood hydrology. Ecological Engineering 15:S131–S140.

The researchers in this study aimed to characterize the important hydrologic flows in four bottomland hardwood sites, and they compared key hydrologic parameters of flow across a successional gradient. All bottomlands had higher water tables than their respective uplands. All bottomlands were sources of water to the associated stream system, although seasonal variability was high.

The authors found vegetation to be an appropriate and important indicator of hydrologic character. Bottomland interflow and losses to the stream were functions of higher water tables present in both the upland and bottomland. They conclude that although hydrologic fluxes on land are important determinants to assess the effect of restoration on the recovery of hydrology, streamflow is the dominant flux in all sites.

Odland A. 2002. Patterns in the secondary succession of a *Carex vesicaria* L. wetland following a permanent drawdown. Aquatic Botany 74:233–244 235.

This study analyzed the vegetative secondary successional changes that occurred (particularly in regards to the sedge species *Carex vesicaria*) for 13 years following a permanent drawdown of a lake. As the lake dropped, the sedge cover gradually decreased including a linear decrease in the number of fertile shoots. The cover was replaced by *Phalaris arundinacea* and *Calamagrostis purpurea*. The author concludes, however, that although the drawdown resulted in a nonoptimal hydrologic regime for the sedge, the study showed that "a clonal wetland sedge may obviously survive a major drawdown for more than 14 years." The study demonstrates that permit conditions should probably take into account the effect of hydrologic extremes over the years on species compositions in floodplains. Furthermore, the study cites other recent research that extremes in "water level fluctuations and inundation during extremely wet years strongly controls species composition on floodplains," as well as lakes and wetland vegetation zonation. A few studies that looked at drops in water levels showed loss of sedge species. Other studies showed that grass species can be more competitive and replace "tall-sedge communities subject to disturbance."

Regarding performance standards for vegetation, it may be important to look at number of fertile shoots, but might be a problematic performance measure, because although flowering shoots indicate plant health, according to this study the flowering is greatly influenced by "external environmental factors" as well, causing variability and perhaps reducing its use as a good performance measure. However, the study suggests that the number of "fertile shoots may be a more accurate measure of species performance than cover in stressed environments," and that percent cover by itself was not a good indicator of sustainability of the species in the area.

Schwartz JS. 2002. Stream Habitat Characterized by Stage-Specific Flows and Three-Dimensional Geomorphological Complexity: Development of Ecological Criteria Stream Restoration Design. PhD Dissertation.

The objective of this study was to combine principles from geomorphology, engineering, hydraulics, and stream ecology to make a new characterization of stream habitat to support development of ecological criteria for stream restoration design. The researcher was able to incorporate current concepts on the relationships between geomorphic process characterizing habitat units by elements of channel morphology and hydraulics. The author states that the ecological relationships developed in his research illustrated the importance of the maintenance of fish diversity and bed and bank morphology.

Zedler JB, Langis, R. 1991. Authenticity: comparisons of constructed and natural salt marshes of San Diego Bay. Restor. Manage. Notes 9(1): 21–25.

Several attributes of the Connector Marsh (a mitigation site) were compared to those of Paradise Creek Marsh (a natural site) over a two-year period. Many deficiencies were identified with the Connector Marsh, and their cause-effect relationships were tested with another mitigation site called Marisma de Nación. The Connector Marsh had been constructed to provide a habitat for the endangered light-footed clapper rail. *Spartina* (cordgrass) production was crucial, because the rails prefer it for nesting, it is important in invertebrate production, and it is key for proper nutrient composition of the wetland. After five years, 50 percent of the Connector Marsh was covered in cordgrass. Although the density of the cordgrass was similar to that of Paradise Creek Marsh, the plant stems in the Connector Marsh were much shorter. The short height of the cordgrass was insufficient for light-footed clapper rail nesting requirements. The birds will not nest in cordgrass plants that are covered at high tide. In addition, cordgrass is limited by nitrogen concentrations, which were significantly lower in the substrates in the Connector Marsh than in Paradise Creek Marsh. The shortness of the cordgrass stems may have been due to poor substrate quality and low nitrogen levels. However, nitrogen concentrations were higher in the soil around cordgrass roots in the constructed marsh. Because microbes fix nitrogen at low levels and cease to do so at high N levels, the high levels found around the root may have caused the low N levels in other parts of the substrate. There was also a low abundance of invertebrates at the Connector Marsh, which may indicate that the food chain was not functioning properly. At Marisma de Nación, conditions were more favorable. Soil amendments improved the substrate and may be helpful in promoting vegetation growth.

This is an example of a failed wetland project. Hydrology was not replicated properly, consequently nutrient loads and vegetation did not function as wildlife habitat for the light-footed clapper rail.

SOIL, SEDIMENT, SUBSTRATE, NUTRIENT ARTICLES

Bishel-Machung L, Brooks RP, Sharon SY, Kevin LH. 1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. Wetlands 16(4): 532–541.

The authors studied 20 natural palustrine wetlands and 44 created palustrine wetlands aged between one and eight years, located in Pennsylvania's Susquehanna River watershed. During summer months they collected soil samples via coring and compared soil and nutrient attributes at two soil depths between the two wetland groups.

The study found that natural sites contained a greater percentage of organic matter (at both levels), less mean bulk density, a greater median percentage total nitrogen, and a higher percentage of silt than created wetlands. The created wetlands had higher percentages of sand than the natural sites and relatively higher pH values. Whereas soil organic matter in natural wetlands was greater at the top depth (5 cm) than the bottom depth (20 cm), it was distributed relatively uniformly in the created wetlands. The median matrix chroma differed significantly between the two groups of wetlands.

Interestingly, these authors argued that "time elapsed since construction was an insignificant factor in soil organic matter content of creation projects," and neither landscape position nor dominant cover type had significant influence on differences in soil organic matter. Rather, they said that created wetlands are prone to a homogeneous soil column because of the nature of the creation process.

The authors suggest that 3 percent minimum organic content in soils is necessary for redox, a process important to wetland function; this percentage, or a threshold like it, could serve as a performance standard. Degree of soil column homogenization also could be a performance standard, though the authors do not suggest that a created wetland soil column becomes more homogeneous over time—a condition necessary for the degree of homogenization indicator to assess wetland performance rather than design.

Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecology and Management 8: 197–201.

The author studied six to seven created salt wetlands of varying ages (between 1 and 25 years) located in North Carolina, sampling soils, benthic invertebrates, and macroorganic matter (via soil cores, subsequently sectioned and analyzed) between 1984 and 1985.

The study found a strong relationship between wetland soil characteristics and marsh age (contradicting results described above). Macroorganic matter increased with age in the created marshes, as did soil organic C and N. Bulk density in the surface layer of the created marshes decreased with marsh age. There was no clear relationship between marsh age and bulk density, or between marsh age and soil phosphorus. Invertebrate density was only modestly related to marsh age, but was strongly related to macroorganic matter, soil organic C, and total N.

The author concluded that development of a benthic invertebrate community in a created marsh depends on macroorganic matter and organic matter inputs, and the quality of organic matter (based on soil and N content) also may be significant. It may take more than 10 to 15 years for the organic-rich surface layer characteristic of natural marshes to develop in created ones, though the time period depends on duration and frequency of inundation, NPP of emergent vegetation, tidal amplitude, and other factors.

These conclusions have implications for performance standards: invertebrate communities depend on organic matter, so efficient performance standards might best assess soil content rather than macroinvertebrates. Soil organic matter itself seems to be dependent on hydrology, suggesting that performance standards based on tidal flooding or inundation (duration, saturation, elevation) might be valid as well.

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2): 248–258.

The authors studied a created marsh and a nearby natural marsh located in North Carolina's Pamlico River estuary, sampling relevant variables via soil coring between 1983 and 1998. They assessed the development and maintenance of above-ground and below-ground biomass, soil characteristics, macroorganic matter, and benthic invertebrate density.

The study found that, 15 years after creation, the created marsh still had significantly greater bulk density, higher soil acidity and extractable Fe and Mn, and lower porosity, organic C and N, and macroorganic matter relative to the natural marsh. The created marsh exhibited strong gradients in wetland soil characteristics that the natural marsh did not. Though above-ground biomass of some marsh grasses increased over time, others did not change in a predictable manner.

The authors concluded above-ground biomass and macroorganic matter associated with *Spartina* increased predictably over time before achieving equivalence with the reference marsh. Soil organic C also increased predictably over time. However, the nature of the study—it involved only two sampling events—made it impossible for the authors to specify whether the trajectories of these variables were linear. They note that "Fifteen years of data…support the idea that trajectories exist for some ecological attributes and that, for attributes of biomass, the trajectories are not linear."

Craft CB, Seneca ED, Broome SD. 1991. Porewater chemistry of natural and created marsh soils. Journal of Experimental and Marine Biology and Ecology 152(2): 187–200.

The authors studied a created marsh established two years prior to the study and a nearby natural marsh located in North Carolina's Pamlico River estuary. The natural wetland was characterized by approximately 50 percent organic matter, while the created marsh had low (approximately one percent) organic matter. The authors compared the chemistry of the wetlands' porewaters and soils by sampling via soil cores and well drilling.

The study found that natural marsh porewaters generally contained higher concentrations of nutrients than created marsh porewaters. Fe and Mn porewater concentrations were significantly higher in the created marsh (weatherable minerals more characteristic of upland soils), and soil organic matter content in the created marsh contained significantly lower concentrations of the sampled nutrients than the natural marsh. The natural marsh had relatively lower bulk and particle densities, resulting in higher porosity and lateral conductivity.

The authors concluded that "mitigation of wetland disturbance by creating wetlands on graded upland sites, initially, may not duplicate the hydrologic and nutrient cycling functions associated with natural wetlands that have developed over many years," and "five years after emergent vegetation was established, the conversion from upland porewater and soil properties to typical wetland characteristics was incomplete." These conclusions suggest that performance standards assessing porewater and soil chemistry need to evaluate over the long term, because, with respect to these components, created wetlands simply will not function like natural wetlands in the short run.

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass *(Spartina foliosa)* to soil amendments in a constructed marsh.

The authors studied sites modified with soil organic matter and nitrogen amendments, and control sites, within a created San Diego Bay wetland opened to tidal flooding one month prior to the start of the study. They sampled the sites from April to October 1990 (excluding August) and from January through March and June and October of 1991. The authors hypothesized that the amendments could accelerate the development of soil organic matter and nitrogen pools.

Neither mean plant height nor foliar nitrogen responded to soil organic matter or nitrogen amendments (though these findings conflict with other studies), and sediment organic carbon did not increase relative to the control sites. Biomass did increase, leading authors to conclude that "plants apparently took up enough nitrogen to stimulate growth overall, but not enough to exceed control plots." Although aboveground biomass responded to soil amendments in proportion to the amount of nitrogen added, maximum biomass in the amended sites at the end of each year of the study still was less than half the biomass in the control sites.

The authors concluded that "it is not clear when or if nutrient pools and plant canopies of constructed marshes would match those of natural marshes. The development of nitrogen pools may be very slow, and it may take several decades to achieve functional equivalency with natural marshes." While the substance of the article is not relevant to performance standard development, this last commentary is valuable because it echoes the doubt of other authors concerning whether it is even possible to specify trajectory-based performance standards except in the very long term.

Nair VM, Graetz DA, Reddy R, Olila OG. 2001. Soil development in phosphate-mined created wetlands of Florida, USA. Wetlands 21(2): 232–239.

The authors studied one natural and one 15-year-old created wetland located in central and northern Florida in 1994, February through June. They used soil cores to sample along a hydrological gradient and then sectioned the cores into depths by soil horizon in order to compare soil characteristics and nutrient accumulation in the wetlands.

The study found that while organic matter increased with age in both studies, the natural wetland had significantly greater organic matter accumulation. Bulk density of the soils increased logarithmically with increasing total C. Density of the surface layer, nitrogen concentration, and organic C accumulation generally increased with age, though nitrogen concentration increased at a faster rate than C concentration. The created wetland was more acidic than the natural wetland, had relatively greater bulk density at all horizons, and had relatively less total C content, and had relatively less total N than the natural wetland, though both wetlands showed similar concentrations of available nutrients. The authors suggest that the wetland was developing toward conditions found in natural wetlands, and that time was the main driver in the development process.

On the issue of performance standards, the authors suggest that the C:N ratio of soil organic matter might be a useful indicator, noting that the ratio should decrease with created wetland age and, in the created wetland in question, approach values commonly found in natural wetlands within 15 to 20 years—assuming a healthy development trajectory. A decreasing C:N ratio could indicate increasing stabilization of soil organic matter composition and amount. However, they also urged caution in using the ratio as a standard, noting that its use "requires due consideration of other indicators and parameters such as organic matter content and accumulation, soil development, and established vegetation."

Poach ME, Faulkner SP. 1998. Soil phosphorus characteristics of created and natural wetlands in the Atchafalaya Delta, LA. Estuarine, Coastal and Shelf Science 46(2): 195–203.

The authors studied wetlands created with dredge and natural wetlands in three age classes (less than 1 year old, 5–10 years, 15–20 years) in five sampling events. They used sediment cores to collect soil from three elevational strata and compared the sediment phosphorus fractions of the samples from both groups of Louisiana wetlands to determine whether the differences usually found between constructed and natural wetlands with the same hydrologic regime was due to age differences or "our inability to mimic wetland functions." The study mentions that in created wetlands that have a natural flooding cycle in the Atchafalaya delta area, sediment deposition during river flooding contributes over time to the development of natural phosphorus characteristics 10–20 years after creation.

The results generally suggested that the dredge sediment was lower in phosphorus than the suspended sediment in the natural wetlands, but that the created wetlands seemed to develop natural phosphorus characteristics over time, due to sediment deposition. The authors projected that, given a natural flooding cycle, natural phosphorus characteristics could begin to appear in created marshes in ten to 20 years.

The finding suggests that an increasing trend in phosphorus fractions, observed over time in a created wetland, could be an indicator of progressive convergence toward natural wetland condition. (The authors do not discuss whether the trend toward natural phosphorus characteristics would be necessarily linear, however).

The study leads to the possibility of grain size as a good performance/design criteria, because grain size is important for P and OM accumulation. The sediment used in the youngest created wetland was coarse-grained dredged material, and because "Phosphorus is associated more with silt and clay than sand," this may be the reason that the youngest created wetland had (considerably) less P accumulation. Studies support the findings that P and OM tend to be lower in created marshes. In river-dominated systems, phosphorus accumulations depend on the deposition of sediments during flooding; therefore it is important to design the correct hydrology.

When measuring P during sampling, this study suggests taking into account P on an aerial basis as well as P by weight/bulk density. The reason for this is that the intermediate-aged constructed wetland had a berm that helped OM to accumulate along with ponded water. This resulted in lower bulk density and greater P by weight, which was misleading. Measuring on P on an aerial basis will account for such a situation. The study suggest that created wetlands develop natural P characteristics measured by weight in 5–10 years, while looking at an aerial basis shows that the P levels take 10–20 years to develop.

Shaffer PW, Ernst T. 1999. Distribution of soil organic matter in freshwater emergent open water wetlands in the Portland, Oregon, metropolitan area. Wetlands 19(3):505–516.

The authors measured soil organic matter (SOM) concentrations in 45 naturally occurring and 50 mitigated freshwater emergent and open water wetlands in the area surrounding Portland, Oregon during the summer of 1993. This was part of a larger on-going study.

This study found that SOM concentrations were higher at the 0–5 and 15–20 cm soil depths in naturally occurring wetlands than in mitigated wetlands. Study results showed that accumulations of SOM were not significantly related to land use, but were related to soil series, texture class, and association, and to hydrogeomorphic class. There was some indication that mitigation might be directly responsible for loss of SOM as a result of soil management practices during construction.

The authors offer several suggestions to make mitigation more effective in replacing wetland structure and function in relation to SOM. First is moving away from the construction of ponds to mitigate for the loss of slope and riverine wetlands. As second step is to eliminate exchange or "enhancement" because the end result is wetland loss (and loss of wetland diversity). And finally, to improve mitigation projects so that project designs do a better job of managing soils and SOM.

This paper is relevant because the authors acknowledge that "it remains a question whether mitigation can fully replace the functions of naturally occurring wetlands. It seems perfectly clear, however, that there is little reason for optimism until we do a better job designing replacement wetlands, including doing a more conscientious job of managing SOM in design and construction."

Stauffer AL, Brooks RP. 1997. Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1): 90–103.

The authors studied four amended plots in one created wetland located in central Pennsylvania, beginning sampling approximately six months after wetland creation and sampling monthly in July and August of 1991 and 1992. The plots were amended with salvaged marsh surface (SMS), composted leaf litter, and vegetation, and a fourth plot was left as an unplanted control; the authors sought to test the efficiency of each revegetation method in prompting development toward natural wetland soil and vegetative conditions.

The article describes in great detail the responses of each plot to the amendments, but the information while valuable for other pursuits, is less relevant to this investigation of performance standards. It generally concluded that SMS can be used to successfully revegetate created wetlands, though long-term monitoring would be required to see if the hydrophytic vegetation it seemed to support could persist.

In their analysis, the authors return to a relevant argument made by authors writing about soils, fish, macroinvertebrates, and other wetland components: "Without correct hydrology, failure of the new created wetland is likely."

Wigginton JD, Lockaby BG, Trettin CC. 2000. Soil organic matter formation and sequestration across a forested floodplain chronosequence. Ecol. Eng. 15:S141–S155.

This study looked at soil organic matter formation and carbon sequestration in a "site-for-time replacement" (note, however, that the study did not look at an even spread of ages of wetlands but rather involved a cluster of young wetlands [7, 9, 11 years old] and one older wetland [75 years old] that naturally recovered from disturbance and was used as "a minimally disturbed reference site"). The study found that soil carbon accumulation was significantly lower in restored sites, macroagregate soil structure did not increase during the first 11 years, and that forest floor organic matter and carbon content increased early (7 years) on but then steadily decreased in later years (9,11, 75 years). The study suggests that forest floor mass increases rapidly after disturbance, then slows, then reaches an equilibrium in approximately 25 years. They cite another study to support the assertion that constructed wetland functional trajectories of carbon accumulation during succession of forested wetlands involve an increase and then decrease of carbon storage. Regression analysis shows that the wetlands will require 25 years to reach 50 percent of the reference wetland values for soil C and 50 years to reach 75 percent of reference wetland.

APPENDIX C. SUMMARIES OF LANDSCAPE PERSPECTIVE AND METHODOLOGY ARTICLES REVIEWED

HYDROGEOMORPHIC (HGM) ARTICLES

Brinson M. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13(2):65–74.

This is a fundamental paper describing HGM as a functional classification system based on the continuum on depth and frequency of flooding in wetlands in a landscape setting, its source of water, and water dynamics or flow. Brinson argues that "functioning of wetlands can be separated into two broad categories: (1) landscape-based transitions that occur within a wetland or group of similar wetland types, and (2) resource-based transitions that allow comparisons of the flow of water and processing of nutrients among very different wetland types." The author stresses that less frequently flooded or saturated portions of wetlands are no less functionally active than wetter portions of wetlands, they just function differently. Therefore, classifying wetlands according to their hydroperiod does little to identify their fundamental properties. Further, hydroperiod duration and timing of flooding does little to address non-flooded conditions in which the saturation zone migrates vertically with water table fluctuation.

This paper has several important conclusions related to the functions of wetlands. (1) When a factor such as wetness becomes the focus for explaining changes in wetland function, there is a tendency to overlook alternative sources of variation such as source of water, position of wetland within the landscape, wetland size, and biogeochemical inflows and outflows. (2) "Headwater streams tend to set the biogeochemical state (or nutrient content) of the larger drainage network." Consequently, attention to riparian aquatic-to-terrestrial transitions adjacent to lower order streams should be subject to scrutiny in evaluating overall wetland function as its impact on water quality is much greater than the buffer zone at higher order streams. (3) Terminology describing the primary source of water will enhance the description of wetland pattern at the landscape scale. And, (4) Attention to wetland function beyond water quality (nutrient and sediment sinks) to include the "enormous degree of variation that exists within a wetland, between wetland types, and among individual nutrients and compounds."

This paper is relevant because it creates a strong argument for landscape-based functioning. A hydrogeomorphic approach emphasizes position of the wetland in a drainage system, the size of the wetland and the source of the water as factors explaining wetland function. Such an approach may work to promote wetland diversity in mitigation projects and move away from the tendency to create ponds and open water systems.

Brinson M. 1995. The HGM approach explained. National Wetlands Newsletter 17(6):7–13.

The HGM approach is an effort to merge science and management in assessing regional wetland functions. Functional assessment of wetlands is an estimate of wetland performance of hydrological, biogeochemical, and plant and animal properties and processes. Brinson states that functional assessment is needed for two reasons: (1) Wetland function and area do not have a one-to-one correspondence. Impacts to a wetland may be severe enough to convert wetlands to non- jurisdictional status or result in incomplete losses that go unregulated. (2) Functional assessment will apply equally to detecting gains and losses due to mitigation.

The HGM approach is a three step process: (1) Wetlands are classified based on their similar structure and function and assumes that these functional attributes are different from wetlands in other classes. This is the hydrogeomorphic part, for example, a depressional wetland dominated with emergent vegetation is functionally different from river floodplain wetland with emergent vegetation. Functions are broken down into four major categories: hydrologic, biogeochemical, plant habitat, and animal habitat. (2) Articulate wetland functions clearly such that science and policy are not confused. (3) Identify reference wetlands.

The HGM approach can avoid the tendency to maximize functions by identifying a continuum of reference wetlands that represent the range of functioning in natural wetlands in the region from least to highest functional performance.

Brinson states that a goal of developing the HGM approach was to make it a rapid assessment tool. The Corps and the NRCS formally adopted the HGM approach because it was based exclusively on the wetland

and not social processes and that it targets hydrology, which is the driving, force behind wetlands. This article is relevant in that the development of the HGM approach received a lot of initial support from the Corps, but there has been little follow-up or enforcement of its use as a mitigation tool.

HGM is often viewed as a cumbersome tool that is time consuming and, since it's use is not required in many states, it is not used by those involved with wetland mitigation. In his 1996 *National Wetlands Newsletter* article, Brinson states that he "worries that the legitimate complaints about the time and cost required to implement the approach will lead to either rejection of the approach or its misuse through taking shortcuts." He is concerned by the low level of support for implementing the procedure relative to the need for a functional accounting system for the nation's wetlands."

Brinson M. 1996. Assessing wetland functions using HGM. National Wetlands Newsletter 18(1): 10–16

Brinson discusses the importance in distinguishing between natural and human induced variation in wetland function. Natural variation referring to "variation in wetness, water sources, species composition, soils, and other properties." This variation is generally a reflection of where the wetland is positioned in the landscape—or its geomorphic setting—and is not a measure of change in function by the HGM approach. Variation derived from human activities includes alterations in water sources and hydrodynamics, changes in wetland shape through filling. These are the types of changes that HGM is designed to detect and measure.

A downside in the time commitment—the investment in method development is necessary and substantial, but the benefits of the initial development work can be realized each time a rapid assessment is conducted. "For a single project in a specific wetland subclass, a minimum of four assessments may be necessary."

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This article is relevant in that it addresses the initial support to develop this approach and recognizes that here has been little follow-up to encourage its continued use as a mitigation tool. It appears to be a useful tool, but one that will require financial support and enforcement from the Corps.

Brinson M and Rheinhardt R. 1996. The role of reference wetlands in functional assessment and mitigation. Ecological Applications Vol. 6(1):69–76.

The establishment of reference wetland standards, representing a range from worst to highest wetland functional capacity, within each wetland class within similar geomorphic settings and regions, represents a useful tool for wetland mitigation. The authors state that compensatory mitigation in the United States occurs largely without analysis of the replacement of wetland functions. The authors propose the advantages of the reference wetland approach: (1) State clear goals for compensatory mitigation through the identification of reference standards from data that typify sustainable conditions in a given region. (2) Provide templates for the design of restored and created wetlands. (3) Establish a framework to measure wetland function decline or gain resulting from adverse impacts or restoration efforts. They acknowledge that some wetlands cannot be replaced such as river floodplain and peat-based wetlands cannot be replaced.

The authors argue that "reference wetlands should be central to the development of standards against which impacts to wetlands and restoration efforts are evaluated." The authors describe how reference wetlands and functional assessments are related. First wetlands are classified according to their similarities in their landscape setting, water source, and hydrodynamics. Personal judgement is used to create subclassifications. Next, wetland functions in each wetland class are identified. Finally, information on ecosystem function is collected from a number of wetlands in each classification. A reference data set is created for each wetland class that ranks sites from highly degraded to highly functioning and from early successional to mature. Finally, reference standards are developed using the least degraded wetlands as a model. This can be a time consuming process as sites selected to represent variation in function is based on the "best professional judgement" of a team of scientists representing a variety of expertise. An assumption is that wetland structure (e.g., biomass, species composition, soil/sediment type) is a good measure of corresponding function.

Ecosystem function (hydrologic, biogeochemical, plant community maintenance, and animal community maintenance) is defined as the activities or processes that characterize an ecosystem. Other functions include site water balance, facilitating energy flow, supporting nutrient cycling, and maintaining species diversity. Replacement ratios for individual functions are decided. The authors mention "giving priority to hydrologic variables because they are fundamental to overall wetland functioning or to base ratios on functions most critical to a region." They mention the potential to abuse the use of reference wetlands. For example, substandard reference wetlands could be selected. Reference wetlands may not work in all settings. For example, meeting reference standards in urban wetlands may not be possible without adaptive management.

This paper is relevant because it makes a strong case for the use of reference wetlands as a mitigation technique to establish standards to measure those wetlands created or restored through mitigation. It also mentions that this is a time consuming process despite the fact that HGM was intended to reduce the time needed to conduct an assessment.

Cole CA, Brooks RP. 2000. Patterns of wetland hydrology in the Ridge and Valley province, Pennsylvania, USA. Wetlands 20(3):438–447.

The authors looked at 30 wetlands in central Pennsylvania for an in-depth hydrologic assessment. The wetlands were classified using hydrogeomorphic subclasses. The surrounding landscape represented a range of human disturbance levels from pristine to highly disturbed. Automatic water-level recorders were installed at random locations in each wetland, with larger wetlands having more recorders than small wetlands.

This study expands on previous research that looked at the hydrology of several wetlands based on monthly sampling during the growing season in an earlier statewide wetland assessment effort. To augment the hydrologic study, they added data on moisture regimes and year-round hydrodynamics. Their objective was to extend their hydrologic analyses to a larger portion of their reference wetlands over a longer period of time.

The results of this extended study confirmed the author's earlier findings that there is a clear distinction in median depth of water by HGM subclass. The authors found that disturbance played a large role in determining hydrologic behavior. They conclude that knowledge HGM subclass is a reasonable and much less expensive technique for assessing hydrology than extensive site-specific sampling. Because their intensive hydrologic sampling yielded similar results to their earlier method of monthly sampling during the growing season, they argue that time and cost involved in intensive hydrologic sampling is not required.

The authors conclude that while the development of a water-budget for a single-site investigation is necessary, it is not required to provide hydrologic information on a larger scale. Their approach of assessing general hydrologic characteristic across a broad region and developing a median hydrologic qualities by HGM subclass is initially time- and labor-intensive but does eventually allow for the prediction of site hydrology using the HGM classification system and appropriate HGM subclass.

Cole CA, Kooser JG. 2002. HGM: hidden, gone, missing? National Wetlands Newsletter 24(2):1–18.

The authors look at the status of HGM in the regulation world—"seems to have faded from active view." Pining down the exact extent of the methodology's use is difficult, they state, partly because HGM involves three components (wetland classification, the use of reference wetlands, and wetland functional assessment), and each play a different role in the overall method.

Functional assessments using the HGM method requires the development of regional models using reference wetlands. The authors state that agency personnel, consultants, and academics have expressed concern that the "intensive data collection needed to develop and verify functional models frequently paralyzes the process." Further, they state that some inherent problems that make it time consuming and may limit its utility in helping regulators make permit decisions is that HGM categories exhibit different functions and it is difficult or impossible to compare impacts to wetlands of different HGM classification. However, alternative assessment methods to the HGM method do not truly measure wetland functions.

In their analysis, they found that the two most often listed reason for not using the HGM method were (1) that the state or Corps district in which the work was performed required another method, and (2) regulators did not require HGM. Other reasons included that the client did not request the HGM method, that it is too time consuming to apply, and the its use required training that the respondent did not have. The authors found that the most frequently used methods were those developed by a state agency, WET II, the Evaluation for Planned Wetlands, the New England Corps of Engineers method, the Federal Highway Administration method, professional judgement.

The authors encourage various Corps districts to begin using HGM classification schemes even if functional models are not readily available. They argue that a regional classification system is not difficult to develop and that it would be in place if a functional assessment were to occur at a later date. The authors describe the chicken and egg problem—"few people use HGM because no one requires it, therefore no one works on its development, Yet no one will require it until it is more fully developed."

This article highlights the need for increased financial commitments and institutional support for programs like HGM that appear to be useful tools for the management of wetland resources.

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A.) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265–278.

The authors compared the hydrology characteristics of three HGM subclasses using comparable long-term data sets from two different regions in the U.S. (Pennsylvania and Oregon). The study was to determine if hydrology was similar between two different geographic regions, if some aspects of developing models could be transferred between regions in an effort to shorten the time required to develop appropriate data sets and functional assessment models.

It didn't work! The study found strong differences between OR and PA in each of the 3 HGM subclasses. Although the 2 regions were similar in climate, there were very different water regimes. Fundamental hydrology was similar, but precipitation patterns were very different. Testing functions (nutrient cycling and export of organic matter) found a difference between sites. The most successful comparisons were with slope wetlands, and big difference between the forested and mainstem floodplain.

The results of this study were disappointing because "sharing models could lower costs and greatly improve implementation of HGM classification and assessments nationwide.

The study demonstrated that using a regionally developed HGM in another region could lead to serious errors in the interpretation of wetland functions between sites or among a group of sites. They agree that the "regional modification of national models was designed into the HGM process for good reason." This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models—up to 4 years in Pennsylvania but estimated to take one to two years for each subclass in each region (Ainslie and Sparks).

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423–428.

A set of 24 reference wetlands were categorized from 1993 to 1994 using the hydrogeomorphic (HGM) subclass using data collected from monitoring wells, piezometers, local water-table level assessments, pH, and specific conductance by month. Four subclasses were identified (riparian depression, slope, mainstem floodplain and headwater floodplain). Each of the subclasses identified showed different hydrologic behavior.

The authors found hydrogeomorphic subclass to be a significant organizing variable for characterizing the hydrology in reference wetlands and an improvement over earlier assessments based on geology or geomorphology. The authors found that the hydrogeomorphic characteristics of each subclass was predictable and consistent. Position in the landscape was determined to be the prime determinant in characterizing hydrology.

This study is very supportive of the hydrogeomorphic approach to classifying wetlands.

Findlay SEG, Kiviat E, Nieder WC, Blair EA. 2002. Functional assessment of a reference wetland set as a tool for science, management and restoration. Aquatic Sciences 64(2):107–117.

The authors looked at 12 wetland functions within three hydrogeomorphic subclasses (enclosed, sheltered and fringe marshes). They sampled five marshes within each subclass for 12 wetland functions and documented differences among the wetland classes.

Significant differences were documented among their HGM classes for 10 of 12 functions. Of the seven directly measured functions they confirmed independent measures. Denitrification was thought to be an important process of nitrate removal, but was fairly labor intensive to measure and required specialized instrumentation. Functions were found to vary greatly among wetland sites with scores ranging form 16 to 70 percent of the total possible. From the seven directly measured functions they validated simpler indicators that could account for ~ 40–90 percent of the variation in the function.

This study is relevant because it supports the usefulness of validated indicators of functions from reference sites. The authors list several strengths of the reference data set including (1) providing a reasonable coverage of local spatial variability for purposes of comparing variation in time and space, (2) providing a measure of how a particular marsh compares to others in the reference domain. The authors felt that this study supported the goal of the HGM approach to functional assessment to provide relatively rapid descriptions of particular sites. Further, the reference data set was useful as a wetland protection decision making tool for managers as it provided information on the best and worst functioning sites that could be targeted for restoration or protection. The authors identify problems with functional assessment on a set of reference wetlands. These include subjectivity in the choice of reference wetlands, the potential for bias in site selection due to logistical and financial constraints, how to deal with actual wetland size in assessing functions, and the risk of misapplication of models to sites outside of the region for which it was developed.

Gwin SE, Kentula ME, Shaffer PW. 1999. Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles. Wetlands 19(3):477–489.

The authors used HGM classification to generate a landscape profile to evaluate the effects of mitigation in

Portland, Oregon. They classified 45 naturally occurring wetlands into regional HGM classes (depression, riverine, slope, and lacustrine fringe). Fifty-one mitigated wetlands were classified into atypical HGM classes that described their unique combinations of site morphology and landscape setting (depression-in-riverine-setting, in-stream-depression, and depression-in-slope-setting). Most of the natural wetlands fell into regional HGM classes (91 percent), but most of the mitigated wetlands (MW) fell into atypical HGM classes. HGM revealed that the cumulative effects of wetland management decisions over time had altered wetland function. This landscape perspective was found to be useful for assessing the cumulative effects of wetland loss in a region.

The authors evaluated small (< 2 ha) palustrine wetlands ranged from emergent marsh to those dominated by open water. Some were natural and others mitigated wetlands. The study showed that there had been a shift in relative wetland types as a result of mitigation projects that converted wet prairies with braided stream channel wetlands into palustrine open water wetlands—a type of wetland that does not exist naturally in that region. Shifts to palustrine open water appear to be nationwide. Creation of open water is a problem as it may encourage invasive species such as the bull frog which has eliminated some native frogs from areas in the pacific northwest. Also, regional biodiversity is likely to be altered as drier-end wetlands are replaced with open and deep water wetlands.

The authors also point out that "when exchange is used for mitigation, a single Section 404 decision results in the destruction of the wetland for which the permit was issued, along with the conversion of a second wetland to a different, often atypical, HGM type. This double whammy means that exchange explicitly does not fulfill the objective of no net loss of wetlands but, instead, ensures loss of wetland area, additional wetland disturbance, and changes in overall ecological function."

Hauer FR, Smith RD. 1998. The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A. Freshwater Biol 40(3):517–530.

This paper discusses the values of the HGM approach to measuring wetland functions in riparian wetlands. The authors found that the HGM approach to the functional assessment of wetlands "was a robust and easy method for protecting riparian wetlands."

An important component of the HGM classification of wetlands is defining subclasses within distinct regional setting. These subclasses are similar in their structural and functional components. In the HGM approach, "functional capacity of a wetland is defined as the ability of the wetland to perform a single, specific function." Functions of a modified wetland are compared to reference wetlands that represent a range of functional capacities from worst to best. The authors argue that the complexity of assessing all aspects of a wetland's functions (e.g., biogeochemical cycling, which includes nitrogen cycling and within nitrogen cycling is the reduction of nitrate to gaseous nitrogen by denitrifying bacteria) is not feasible given the thousands of wetland permits submitted each year. To simplify the process another study identified four general functional categories.

The authors explain that the HGM approach can be used to determine functional capacity of a wetland before a project, to predict likely functional performance after impact, aid in mitigation or restoration efforts, and monitor future success of mitigation and restoration.

This article is relevant to performance issues. The authors found that there were many similarities between the HGM approach and IBI bioassessments. The similarities include combining biological and/or physical variable measurements in an index as a measure of ecosystem integrity, and both use data from reference sites for calibrating metrics against a standard. The HGM approach expands on the reference site approach by providing a range of sites from least to most degraded.

Hruby T. 1999. Assessment of wetland functions: what they are and what they are not. Environ. Manage. 23:75–85.

This study analyzed methods providing information about wetland function to understand their similarities, differences, and the type of information they provide. The author found that most methods generated a numeric assessment of performance or value of a wetland function that relied on a mechanistic approach to model construction. Rapid assessment methods were found to "provide a clear and concise way of organizing our current, and often subjective, knowledge about wetland functions." A criticism of current methods is that they are "often misunderstood by both wetland managers and the scientific community."

The author states that wetland managers are confused about what information the various methods provide. Specifically they have trouble differentiating among the "(1) levels at which wetlands perform functions and the values given those functions, (2) the meaning of indices generated by different methods, and (3) the potential that a wetland has to perform a function versus the actual level of performance." These misconceptions do nothing to help protect wetlands.

There are two types of models, logical and mechanistic. An example of a logical model is WET and mechanistic models include the U.S. Fish and Wildlife Service HEP models, the Connecticut method, the indicator value assessment (IVA) and HGM. The author asserts that we are making advances in assessing the performance of functions in wetlands, regardless that these methods are based on judgement. HGM and the IVA are an improvement over earlier methods because they are based on a structured process for quantifying the judgement of a group of local experts.

Hruby T. 2001. Environmental auditing testing the basic assumption of the hydrogeomorphic approach to assessing wetland functions. Environ. Manage. 27(5):749–761.

The author discusses a study of 44 wetlands in which four hydrogeomorphic subclasses (two depressional subclasses and two riverine subclasses) were rated to assess the level of severity of human alterations on the level of the performance of 15 wetland functions. Alterations in water regime, soils, vegetation, buffers, and contributing basis were measured on a scale of 1 to 5. Study results demonstrated that the ratings of performance did not differ between altered and unaltered sites. This suggested that HGM assumption that the least altered sites are characteristic for the subclass and sustainable might not work for wetlands in the lowlands of western Washington. Because of time and money constraints, this study was limited to quantifying the judgement of the group of experts rather than actual measurements of functions. The A teams in this study developed another assumption to provide relative estimates of wetland function: that "the highest level of performance of a wetland function will occur when a specific set of environmental conditions are met" rather than when a wetlands was the least altered. In this fashion, a set of the highest performing wetlands was identified for each function.

This study in interesting in that the HGM approach was not appropriate for this particular region. The levels of function in the more altered wetlands were not significantly different from those that were the least altered. As a result, Washington state does not assess the ecological integrity of the wetland ecosystem, rather it assesses the performance of the functions relative to the highest levels found in the regional subclass.

Shaffer PW, Kentula ME, Gwin SE. 1999. Characterization of wetland hydrology using hydrogeomorphic classification. Wetlands 19(3):490–504.

The authors monitored water levels in 45 wetlands for three years to characterize the hydrology of wetlands near Portland, Oregon. They classified wetlands using the HGM system of classification to determine if hydrologic regimes differed in wetlands in different HGM classes or between natural and created wetlands.

The study found that there was no relationship between hydrologic attributes and land use, soil associations, or wetland area. They did find highly significant differences in wetlands with or without a water-retention structure and wetland type (natural or created). In addition, they found significant differences in hydrologic variables for wetlands in different HGM classes. Human modification on wetland hydrology supported the development of regional wetland subclasses.

This paper focuses on the HGM classification process and comparisons of hydrology among the various wetland classes and subclasses. The results of this and similar studies can be used to evaluate changes in historic wetland function of created wetlands due to changes in wetland hydrology of mitigated sites. HGM could be used to re-establish natural wetland functions in areas that are not highly altered by human activity.

DEVELOPMENTAL TRAJECTORY ARTICLES

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2): 248–258.

The authors studied a created marsh and a nearby natural marsh located in North Carolina's Pamlico River estuary, sampling relevant variables via soil coring between 1983 and 1998. They assessed the development and maintenance of above-ground and below-ground biomass, soil characteristics, macroorganic matter, and benthic invertebrate density.

The study found that 15 years after creation the created marsh still had significantly greater bulk density, higher soil acidity and extractable Fe and Mn, and lower porosity, organic C and N, and macroorganic matter relative to the natural marsh. The created marsh exhibited strong gradients in wetland soil characteristics that the natural marsh did not. Though above-ground biomass of some marsh grasses increased over time, others did not change in a predictable manner.

The authors concluded above-ground biomass and macro-organic matter associated with *Spartina* increased predictably over time before achieving equivalence with the reference marsh. Soil organic C also increased predictably over time. However, the nature of the study—it involved only two sampling events—made it impossible for the authors to specify whether the trajectories of these variables were linear. They note that "fifteen years of data…support the idea that trajectories exist for some ecological attributes and that, for attributes of biomass, the trajectories are not linear."

LaSalle M, Landin MC, and Sims JG. 1991. Evaluation of the flora and fauna of a *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191–209.

The authors studied two created saltwater wetlands, aged four and eight years, located on the South Carolina Atlantic coast. They sampled the wetlands twice in September of 1988 and compared findings to descriptions in scientific literature of similarly located and constructed natural marshes.

The study found that the proportions of sand, silt, clay, and organic compounds in the created marshes were similar to the proportions observed in a nearby natural marsh, and the values of above and below-ground biomass and species composition metrics compared well with those reported for natural *Spartina alterniflora* marshes on the Atlantic and Gulf coasts. Dominance and density of oligochaetes and polychaetes, fish and shellfish assemblages, and gut contents of dominant fish species were all within the range observed in nearby marshes. The authors concluded that any observed differences in density or distribution of macrofauna species probably "are largely related to age or perhaps the distance to open water."

The article supports claims that it is possible to establish a functionally similar marsh in a short time frame. However, this support is less substantial than might be provided, given that the article bases conclusions on a small number of sampling events over a short time period, and only two created wetlands were compared to non-specific reference sites.

Morgan PA, Short FT. 2002. Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restoration Ecology 10(3):461–473.

This study supports functional trajectory development and has created some curves for constructed fringing salt marshes. The authors compared reference wetlands to constructed wetlands of varying ages to develop functional trajectories for wetland development using "space-for-time substitution" (comparing marshes of different ages rather than one marsh over many years). Although this sort of substitution may increase variance, the study found that overall, mean values for constructed wetlands were significantly lower than natural reference values for primary production (aboveground biomass), soil organic matter content, and plant species richness. This study supports space-for-time substitution as a means for developing trajectories, as it found that some functions (primary production, sediment deposition, plant species richness) "may reach natural site values relatively quickly (<10 years)," while other functions (soil organic matter content) "will take longer." The study also notes "whether development of functions in restored marshes follow predictable trends is still being debated, as is the potential value of trajectory models in assessing restoration projects."

The high variability in number of plant species and diversity index for reference wetlands found in this study supports other researcher claims that a population of wetlands should be used for comparison, rather than one reference wetland. This study specifically cautions against using just one wetland for these two indicators of plant diversity. For example, while the study found that the mean number of species was significantly less for constructed wetlands, it also found "considerable overlap between individual constructed and reference sites."

The study also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the "results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction."

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38–56.

This article emphasizes that landscape pattern determines function, and that it ultimately may be necessary to supplant our descriptive means of assessing functional equivalency with simple, controlled manipulative experiments. The study looked at wetlands in heavily urbanized landscapes, for which the authors mentioned that it was difficult to find reference wetlands there, particularly "where undisturbed wetlands are rare, small, and under stress."

The authors cite several papers that found that even well-established created wetlands differ in plant and animal species composition over natural wetlands, They cite another article to emphasize the difficulty in determining, even over long monitoring periods, whether these differences are the result of immature wetlands following developmental trajectories, different environmental conditions dictating different results, or different successional endpoints. In their own study, the authors found that "taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3–5 years," and that three indicators for bird usage showed a very rapid response (the site was a "haven" that attracted birds because there was limited alternative habitat in the nearby landscape). On the other hand, "sediment organic content…infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed…" The study cautions that extensive sediment accretion will likely inhibit development of a stable ecosystem.

Streever WJ. 2000. *Spartina alterniflora* marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecology and Management 8: 295–316.

The author reviewed literature concerning functionality of dredged material wetlands, discussing dredged marshes as habitat for fish, birds, and macroinvertebrates, as well as soil, vegetative, and hydrologic characteristics of dredged marshes relative to natural marshes.

His basic conclusion: "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time as a general rule." The review found that dredged material marshes seem to provide habitat for a different community of birds than natural marshes. Polychaetes and crustaceans seemed more abundant in natural marshes, though there seemed to be no general difference in mean total fish abundance. Available data did not suggest that below-ground biomass values in constructed and natural marshes converge over time (dredged marshes generally have lower levels), nor that nutrient reservoir sizes converge over time (dredged marshes generally have smaller reservoirs), nor that organic carbon levels converge (carbon levels generally are lower in dredged marshes).

This review is relevant because it strongly questions the validity of performance standards that assume created or mitigated marshes follow a maturation trajectory (linear or otherwise) toward comparability with natural marshes. It also questions the validity of single-season sampling for marsh assessment; also note that some studies reviewed here that found natural and created marsh comparability in a short time frame based their findings on single-season sampling.

Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restor Ecol 7:69–73.

This article is a good review article on the status of peer-reviewed research for engineered tidal wetlands in North America. No actual new data were reported. Overall, the authors are skeptical about the use of functional trajectories, and that most lack supportive data, few are based on long-term studies, and others "fail to predict functional equivalency within the prescribed monitoring periods."

Some of the points the article brings up include a discussion of the contextual shift in how compliance should be evaluated. For example, the focus of (non-mitigation) assessments should shift from a "yes/no" framework of success or failure to an assessment of "progress towards ecological goals," with new terminology reflecting this change in viewpoint. Terminology for compensatory mitigation should also be shifted—the word "compliance" in achieving performance standard thresholds and targets should be used instead of the words "success/failure" of the wetland.

The authors discuss the limitations of the science due to in part the lack of data on constructed wetland success, and they warn that much of the peer-reviewed research literature of constructed wetlands has been short-term evaluations of certain parameters sampled from small, newly created wetlands "with little repeated sampling." They encourage future research to focus on particular sites and identify "cause-effect mechanisms." They recommend that future assessments should incorporate "experimentation and the evaluation of ecosystem resiliency to unplanned disturbances," which will help determine ecosystem function.

The paper contains a valuable table that lists "Monitoring characteristics for single-site evaluation of wetland restoration projects in the peer-reviewed literature," including location, size, age, sampling frequency, parameters evaluated (19 references). Another table looks at the same data from a multiple-site perspective (7 references). Studies monitoring wetland mitigation compliance often identify main themes that have made "assessing and documenting restoration progress" problematic: (1) "no clear goals were established to determine success, (2) no natural marsh site was used for reference, (3) data only covered a short term" (the majority were monitored for fewer than 4 years, many were one-time assessments or 2–5 sampling periods, and (4) high variability in both natural and mitigated system impaired clear comparison.

The authors cite "significant shortcomings" of restored North American engineered tidal wetlands: "may lack the appropriate topographic complexity,…have modified tidal regimes, experience unexpected erosion and/or sedimentation,…fail to support the desired vegetation, lack sufficient soil organic matter and nutrients supplies,…fail to support desired animal populations,…or contain contaminants uncovered during construction. Any of these problems can keep a site from achieving functional equivalency with reference wetlands."

The authors suggest the engineering goals of all wetlands should tie to objectives, which should tie to performance standards. They should support the region's biota, resist invasion by exotic species, and become "a low-maintenance, self-sustaining ecosystem." Parameters to examine include "assessing topographic, hydrologic, soil, vegetation, and animal components." Site-dependent parameters that may be valuable for performance standards include "soil TKN, soil organic matter, soil texture, soil salinity (all within the top 10 cm); canopy architecture (e.g., height histograms) for bird nesting; vegetation cover from low-elevation remote sensing imagery; abundances of invertebrates that are important foods (e.g., crabs for clapper rails); fish species richness and dominance; size distributions of fish within specific habitat types (different tidal creek orders); gut contents to document foods; nesting and production of fledgling by target bird species." These could all be measured for meeting a minimum target or range for a minimum set number of years.

LANDSCAPE PERSPECTIVE AND GENERAL RESTORATION ARTICLES

Bartoldus CC. 1999. A Comprehensive review of wetland assessment procedures: a guide for wetland practitioners. Enivron. Concern Inc.

An extensive introduction to 40 different wetland assessment procedures that provide a procedure for identifying, characterizing, or measuring wetland functions and/or social benefits. A very useful book for those involved with wetland assessment.

Breaux A, Serefiddin F. 1999. Validity of performance criteria and a tentative model for regulatory use in compensatory wetland mitigation permitting. Environ. Manage. 24(3):327–336.

The authors reviewed 116 mitigation projects and found that vegetation was the most commonly measured mitigation feature, with hydrology in second place (a distant second). Wildlife was measured, but usually as a qualitative assessment as "evidence of use," and target wildlife generally included or was restricted to endangered species. Other criteria, including water quality, soils, and invertebrates were the least cited.

Regarding vegetation, the authors cite a common practice for restoring perennial tidal wetland restoration was to use a performance standard of 70–90 percent vegetative cover by the end of five years, which they considered to be "scientifically sound." They consider the restoration of these wetlands to be relatively simple, stating that restoration in an area regularly influenced by tides depends only on proper grading and correct elevations. They cite that "marsh fauna is expected to be naturally recruited once plant species have been established."

The authors argue that vegetation and wildlife measures used in coordination is the most promising approach to evaluate performance standards. They provide an example in which percent cover was combined with a wildlife criteria—a case where the height of pickerelweed was measured based on the "reported preference" of the endangered salt marsh harvest mouse for pickerelweed stands of 30 cm tall.

They also point out that setting vegetative percent cover for riparian areas is difficult, because of the different layers present in a riparian system ("upperbank, overbank, canopy shading, shrub layer, herbaceous layer, and ground cover"). They mention that succession as well as "natural climatic variations" will affect vertical and horizontal structure over time. (e.g., as forest matures, there is generally less cover in the understory layers because of shading from a mature canopy). Therefore "percent survival is more practicable," although they don't further explain their reasoning for this percent survival criteria. They also note that riparian areas require a relatively long period to establish, and that monitoring should be conducted for up to 20 years.

Regarding hydrology, the authors found that it was the most cited criteria for evaluating seasonal wetlands. They caution that use of hydrology criteria should be specific, not just a statement such as "at least 5 percent of the growing season" (a common standard), but that there should also be agreement as to how long the growing season should be.

The authors point out that it would be a good idea to strive for "standardization of measurements and assessment techniques for delineation and monitoring." They particularly raise a concern with (inaccurate) sampling methodologies, and how these can affect the development of success criteria. They suggest that "given the likelihood that differences will be missed, a minimum of three fixed-interval or randomly selected transects per 0.4 ha (1 ac) is not an unreasonable starting point to assure that most vegetation types are sampled, with at least ten individual sampling points on each transect" (decrease subsequent sampling if results show little or no variation; increase if high variation is found).

The study also stresses the need for a standardized language, which was not available (or used) in the 116 projects they reviewed, nor was a standard habitat classification system used. In sum, they feel no net loss can't be realized until performance criteria are set (regional and adaptive management seem ok to them), and they acknowledge that certainty is "impossible given the present state of our scientific knowledge and the limitation of time and experience."

The study appendix gives a suggested three-tiered monitoring program framework for compensatory mitigation based on size categories (i.e., less than 2 acres or 500 feet, 2–5 acres or 500–1,000 ft, greater than 5 acres or greater than 1,000 ft). Suggestions include categories to monitor (e.g., percent cover, water quality, inventories of invertebrates) as well as timing of monitoring, and in some cases, planting ratios.

Cao Y, Bark AW, Williams WP. 1996. Measuring the response of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic and diversity indices. Hydrobiologia 341: 1–19.

The authors studied nine sites in the UK's Middle Trent River and two major tributaries in the lowland river system, sampling macroinvertebrates during May, August, and October of 1993 in order to compare the effectiveness of different statistical methods in revealing differences in water quality (as correlated with macroinvertebrate community characteristics) along a pollution gradient.

The authors analyzed 25 samples using the CY Dissimilarity Measure, DCA ordination, TWINSPAN classification (clustering), and four biotic indices—Chandler Score, Chandler-ASPT, BMWP, and BMWP-ASPT.

The study found that all three multivariate approaches—CY, DCA, and TWINSPAN—illustrated changes in community structure along the pollution gradient represented by the sites, and revealed similar spatial patterns. Some approaches worked better than others in distinguishing particular chemicals or between particular pollution levels. Overall, though all the biotic indices could detect major changes in water quality, neither the BMWP nor the Chandler Score could clearly differentiate between two particular groups of sites, whereas all the multivariate approaches revealed the differences between the groups.

The authors' description of criticism of multivariate assessments is relevant to the specification of performance standards: these approaches are explicitly or implicitly similarity based, and cannot directly show whether conditions are improving or deteriorating in a water body because they measure differences between samples on a relative scale. The authors' description of the weaknesses and strengths of biotic indices also is relevant to standard specification: the biotic indices tested showed varying sensitivity to different ranges of pollution, and the authors argue that the metrics need to be refined to be effective over a wide range of water quality.

Ehrenfeld JG. 2000. Evaluating wetlands within an urban context. Ecological Engineering. 15(3–4): 253–265.

The author addresses the fact that urbanization often alters wetland hydrology, geomorphology, and ecology, and wetlands in these settings often function differently than those in non-urban lands. Therefore, evaluation of restoration success in urban settings will be on a different scale than those in non-urban settings. For example, there may not be highly functioning reference wetlands available. The author states that "appraisal of functional capacity and replacement is a necessary facet of evaluation, but should take place within a framework of social expectations, wetland capacities, needs for active management, and values unique to the particular urban context."

This paper discusses two levels of assessment for wetland restoration in urban settings: (1) An assessment of the extent of urban influence that restricts the potential for performance of the conventionally defined functions and takes into consideration social valuation, and (2) The development of a modified assessment for functional capacity within the urban context.

This paper offers thoughtful insight for wetland managers in an urban setting.

Fore LS, Karr JR, Conquest LL. 1994. Statistical properties of an index of biological integrity used to evaluate water resources. Canadian J. Fish. Aquat. Sci. 51: 1077–1087.

The authors studied the statistical properties of an IBI constructed from fish data collected from 67 Ohio stream sites in three river basins in late summer and early fall, 1980–1990.

The article describes statistical properties of the IBI and possible variations on the IBI in great detail, though this very specific information might be useful only in the later stages of performance standard specification. The more general yet relevant observations concerning IBI usage include:

IBIs may become unreliable at the low and high ends of the ranges they assess; bootstrap IBI (a common statistical approach) scores tend to be higher than true values for sites with low original scores and lower for sites with high original scores—that is, the bootstrap approach overestimates biotic integrity for degraded sites and underestimates it at pristine sites. The tendency of bootstrap scores to group sites closer to the middle of the possible range than actual fact may lead to an underestimation of the differences among sites. Also, when the IBI is constructed based on a small sample of fish, higher measurement error results; and, as noted in other articles, wetlands tend to have relatively small fish populations. Finally, the article notes that IBI scores from degraded sites generally are highly variable. However, this flaw, if tracked and observed, could be an effective indicator in itself—increasing variability as an indicator of increasing disturbance.

Galatowitsch SM, DC Whited, JR Tester. 1999. Development of community metrics to evaluate recovery in Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6: 217–234.

The authors studied 116 sites in eight wetland types classified as riverine, littoral, or depressional, located in three ecoregions in Minnesota. The authors sampled plant, amphibian, fish, and bird community attributes and assessed land use characteristics at different times and over different periods in 1995 and 1996, and attempted to correlate indicators of land use with community attributes.

The study found that only five metrics considered were consistently related to specific land use across several sites: proportion wetland birds, wetland bird richness, proportion of insectivorous species, importance of *Carex,* and importance of invasive perennials. It also identifies the specific land use characteristics that correlated, at varying degrees of strength, with each taxa. Its analysis concluded that "birds appear to be the most universally useful organismal group for monitoring changes in wetlands related to land use, and amphibians the least useful."

The authors also note that changes in species composition are not affected only by changes in the wetland itself, but also are influenced by upland changes, matrix conditions, barriers to animal movement, and other factors. They warn against applying metrics relevant to one wetland type to another without careful study.

The article is relevant to the development of performance standards because it suggests five indicators whose sensitivity to disturbance have been documented in wetland environments, and because it comments on the advantages and disadvantage of each taxa mentioned above as a metric for wetland health.

Grayson JE, Chapman MG, Underwood AJ. 1999. The assessment of restoration of habitat in urban wetlands. Landscape and Urban Planning 43(4):227–236.

This is a review paper focusing on the challenges of assessing wetland restoration projects in urban settings.

Urban restoration projects have generally been poorly assessed because (1) projects in urban areas have been given unrealistic goals that do not take into account the considerable level of anthropogenic disturbance (e.g., pollution, habitat fragmentation, recreational use); (2) goals often are not clearly defined, so it is difficult to then assess the "success" of the project; and (3) when an assessment has been made, the results are sometimes inconclusive because sampling design does not adequately compare control sites as well as reference sites. The authors recommend that studies and mitigation projects should start incorporating several "control sites" of unrestored degraded wetlands (not including the mitigation site itself) to use as references, in addition to natural reference sites. This will allow for a more realistic assessment of restoration in an urban context.

The authors point out that structure by itself is not a measure of function: "Wetlands in urban areas are often restored or created to fulfil a specific function (e.g., to provide habitat for wildlife). Despite these aims, measures of structure, instead of function, are often used to evaluate the success of such projects. This is done because structure is much easier to measure than is ecological function. It is assumed that if the pattern of structure looks right, the system will also function correctly. Structure and function are, however, not the same. Restoration of one does not necessarily mean restoration of the other. The structure, or pattern of an ecosystem describes the various physical and biological parts of that ecosystem, such as biomass and composition of species at any point in time. Function, on the other hand, includes the interactions of organisms with one another and with the physical environment. This requires examination of processes that occur through time, such as persistence of species, productivity, capacity to assimilate pollutants and recycling of nutrients."

Karr J. 1991. Biological integrity: a long-neglected aspect of water resource management. Ecological Applications 1(1): 66–84.

The author describes his original fish-based IBI in detail, and explores its advantages and disadvantages and ways it could be modified. He highlights the use of selected intolerant species in an IBI, noting that these can effectively reflect changes in oxygen-demanding wastes or sedimentation resulting in soil erosion. He also briefly discusses some metrics not explored in other articles reviewed here, the Invertebrate Community Index (ICI) and Rapid Bioassessment Protocol (RBP).

One salient point is that including greater numbers of metrics assessing multiple taxa in the IBI increases the probability that the IBI will be effective over a wide geographic area and relevant to different environmental conditions. He also emphasizes that careful and well thought-out metric construction is relatively more important than the inclusion of any one species or a very high level of precision concerning species attributes, noting, "I believe that just about any taxon could be selected and produce a reasonable level of insight about the water resource if appropriate wisdom is brought to bear on development of robust and general metrics."

Kentula ME. 2000. Perspectives on setting success criteria for wetland restoration Ecological Engineering 15(3–4):199–209.

The premise of this paper is that determining the success of wetland restoration projects is difficult because success means different things to different stake-holders in the restoration project. The author illustrates this by presenting three views of success. "(1) Compliance success: determined by evaluating whether the terms of the agreement were met (and again, by who is evaluating this success—or not). (2) Functional success: determined by evaluating whether the ecological functions of the system have been restored. (3) Landscape success (only now being considered), a measure of how the restoration, or management in general, has contributed to the ecological integrity of the region or landscape and to achievement of goals such as the maintenance of biodiversity."

The author states that definitions of success are limited by our current understanding of restoration ecology and our ability to use that information to make sound management decisions and establish measures of success. A key point she makes is that "particular characteristics of projects, such as vegetative cover and production, can resemble those in similar naturally occurring wetlands, when overall functional equivalency has not been demonstrated." The author describes the use of HGM classification as a useful approach for predicting landscape level effects based on hydrology equivalence, because "HGM is built on the premise that wetland structure and function are a reflection of geomorphic setting, water source, and hydrodynamics." This approach goes beyond measures of success such as percent vegetation cover and addresses system function.

The author supports the use of reference wetlands to "define a suite of wetlands from highly degraded to highly functional and early successional to mature." However, she acknowledges that there are situations where a reference system may not be appropriate or realistic. In addition, she addresses the potential use of developmental patterns or trajectories to measure performance curves. For example, she mentions a restoration project on the coast of Oregon with an estimated restoration time of at least 50 years. Many restoration projects are still too ecologically young at the end of the required 3–5 years of monitoring to be deemed a success or failure. Adaptive management is presented as realistic monitoring approach that allows for the flexibility to modify programs to adapt to changes in conditions or to incorporate new information.

Kentula M, Sifneos J, Good J, Rylko M, Kunz K. 1992. Trends and patterns in section 404 permitting requiring compensatory mitigation in Oregon and Washington. U.S.A. Environ Manage 16(1):109–119.

The authors recommend comparing samples of populations of naturally occurring wetlands and restoration projects to assess the entire range of conditions and factors important to ecological function of the wetland in a landscape context and within the natural variability of naturally occurring wetlands. They cite another study in which the authors also suggest that a population of wetlands should be used to develop a range of target values for wetland function. They assessed wetlands that ranged from highly degraded to pristine as well as from early successional to mature.

LaSalle M, Landin MC, and Sims JG. 1991. Evaluation of the flora and fauna of a *Spartina alterniflora* marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191–209.

[Note: This article was reviewed in another section, but it is included here because the summaries are substantively different, although not contradictory.]

The authors studied two sites, aged four and eight years, in a 14 year old marsh that naturally developed on unconfined dredge material in South Carolina's Winyah Bay. The authors sampled and evaluated the marsh over two days in September 1988 and compared their observations to data available in scientific literature on the typical functioning of natural *Spartina alterniflora* marshes in order to assess the performance of the artificial wetland.

The study found that vegetative structures at both sites were within the range reported for natural sites, with a trend toward greater below-ground biomass development with age, macrofaunal assemblages at both sites were similar to natural assemblages in terms of species composition, number, presence/absence, and equitability and degree of dominance by a similar group of annelids, proportions of sand, silt, clay, and organic content were similar between the sites and the reference conditions, and fish and shellfish assemblages also were typical of natural marshes. Similarity of macrofaunal assemblages was relatively low based on relative abundance of common species.

The article implies that developmental trajectories do exist (though does not comment on whether these vectors are linear), and that restoration targets can be achieved within a short time span. However, note that the findings were based on single season, highly limited sampling.

Morgan KL, Roberts TH. 2003. Characterization of wetland mitigation projects in Tennessee, U.S.A. Wetlands 23(1):65–69.

This study evaluated whether wetland mitigation projects resulted in jurisdictional wetlands. The study identified design problems "that resulted in inappropriate hydrology and poor vegetation establishment." The most significant problem noted was the failure of mitigation projects to create a water budget to support the assertion that the design would result in a jurisdictional wetland. Other problems included excavation depths (1–2 m over entire site) that would preclude "growth of all moist-soil and many emergent species," excavations that lacked bottom contours (whereas variable depths present in natural wetlands promote the development of a diverse plant community), very steep upland boarders, vegetation planted at inappropriate elevations, failure to properly follow the approved mitigation plan such as planting in midsummer rather than during the permit-stipulated dormant season, failure "to create canopy gaps for shade-intolerant species" and "planting species other than those listed in the permit." The majority (72 percent) of the wetlands "contained less wetland area than specified in the permit." Results of this study were similar to mitigation studies in other states.

The authors identifies early studies that showed that mitigation projects "frequently did not succeed and, in many cases, were not even attempted". "Later studies…indicated some improvement over earlier attempts…but site visits by agency personnel in Tennessee indicated that, in the mid-1990s, problems still were occurring." The authors suggest that a "shift of focus to a site's fundamental geomorphology and hydrodynamics, instead of vegetation survival (as it has been), should greatly enhance success of future mitigation efforts." "Improvements in mitigation projects likely can be accomplished by emphasizing site-specific factors such as landscape position and hydrology, rather than vegetation survival and coverage."

Zedler JB. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Front. Ecol. Environ. 1(2):65–72.

This study looked at a region were large areas of wetlands, and their functions, were lost when drained for agriculture. These losses included flood abatement, improved water quality, and support for biodiversity. The author states that these services could be restored through careful planning, by adapting existing landscape-design models, and using adaptive management. She stresses the importance of using a science-based process, such as adaptive management, to increase the success of restoration efforts.

This paper supports adaptive management and a landscape approach for the restoration of biodiversity, the benefit of which is that lager areas typically support more species. In addition, it confirms the importance of restoring the correct hydrology, because when water levels are too high or low, plantings may die, and animals may fail to use the site, supporting the idea that wetland structure and function are driven by the correct hydrology. In areas of high human disturbance, the best approach to restoration may be to aim for modified structural and functional equivalence, recognizing that the wetland system may no longer be able to function at historic levels due to alterations in the surrounding uplands and watershed.

APPENDIX D.
SUMMARY TABLES OF REVIEWED LITERATURE

Amphibian Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Chovanec A. 1994. Man-made wetlands in urban recreational areas: A habitat for endangered species? Landscape and Urban Planning 29(1): 43-54.	International - Austria, Vienna	Urban wetlands	Amphibians	The author describes a man-made pond. The pond was designed according to the ecological requirements of amphibians and dragonflies. Special measures were taken to control of visitors to minimize disturbance and human impacts from recreational activities. Based on the colonization by amphibians and dragonflies in the three years following construction, the author concluded that constructing and successfully managing artificial wetlands can offer refugia for endangered species in high density urban areas. This article is relevant from a wildlife habitat performance standard perspective. This represents a success for an urban setting, although there is no comparison with a natural wetland in the same setting.
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh	Amphibians -- reviews literature concerning fish colonization in artificial marshes; 22 fish morphotypes	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.

Amphibian Articles Reviewed

Hecnar SJ, McLoskey RT. 1996. Regional dynamics and the status of amphibians. Ecology 77:2091-2097.	International - Canada	Ponds -- 97 ponds in southwestern Ontario	Amphibians -- 11 species	The authors explain that the HGM approach can be used to determine functional capacity of a wetland before a project, to predict likely functional performance after impact, aid in mitigation or restoration efforts, and monitor future success of mitigation and restoration.
Babbitt KJ, Tanner GW. 2000. Use of temporary wetlands by anurans in a hydrologically modified landscape. Wetlands 20(2):313-322.	State - Florida	Temporary wetlands	Amphibians -- 11 species	12 temporary wetlands created by ditching. Hydroperiod was positively correlated with species richness and the abundance of metamorphosing amphibians but not that of tadpoles. However, researchers in this study found that species richness of amphibians is highly endemic to the wetland the species inhabits. In terms of performance standards this information is useful because it let's us know how useful these species are.
Swihart RK, Kolozsvary MB. 1999. Habitat fragmentation and the distribution of amphibians: patch and landscape correlates in farmland, Indiana, US. Can J. Zool. 77(8):1288-1299.	State - Indiana	Breeding pools	Amphibians	Article discusses the effects of agriculturally induced fragmentation of forests and wetlands on amphibians assemblages and distribution at the landscape level. Results found anuran and salamander assemblages were non-randomly distributed across the landscape. Two species were ubiquitous, one was positively associated with patch size, several ranid frogs were positively associated with proximity of wetlands; degree of wetland permanency was positively correlated with three other species. The nonrandom distribution suggests the species' responses to landscape-level attributes and to fragmentation was consistent with their differences in life history and ecology; these factors must be considered when standards are specified.

Amphibian Articles Reviewed

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.	State - Maine	Isolated vernal pools	Amphibians -- bullfrogs and green frogs, red-spotted newts, spotted salamanders	Following loss of small wetlands, elevated extinction risk response for 3 of the 5 taxa. The most dispersive taxa studied, turtles and birds, were most prone to extinction. Small wetlands are likely critical for the maintenance of taxa endemic to those habitats.
Gibbs JP. 2000. Wetland loss and biodiversity conservation. Conservation Biology 14(1):314-317.	State - Maine and New York	Palustrine wetlands	Amphibians	Transects along the urban-rural gradient surrounding NY City and through rural southern ME. Article addresses the importance of an amphibian IBI monitoring to sample at the landscape level. Gibbs points out that adaptation to an aquatic existence has imposed severe constraints on the ability of many wetland animals to disperse across the uplands separating wetlands. Also that this dispersal of aquatic plants is highly dependent on transport by wetland animals and that reduced wetland density and proximity has important energetic implications for larger-bodied animals such as waterfowl, that must move daily among multiple wetlands to forage.
Simon TP. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3):407-418.	State - Michigan	Palustrine and vernal ponds	Amphibians -- 7 species	Authors construct an IBI to measure anthropogenic impact. Article observed that for small wetlands and vernal ponds, and IBI that includes a mix of taxonic groups is most appropriate. Crayfish are a little-used indicator taxon, but exhibit well-structure assemblage differences between degraded and non-habitats and could be valuable components of an IBI. Also, the article found higher numbers amphibians, crayfish in higher quality wetlands and vernal ponds.

Amphibian Articles Reviewed

Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites chosen to represent a land use gradient (18 categories)	Amphibians	The article notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.
Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressonal wetlands	Amphibians	10 amphibian taxa studied. Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.

Amphibian Articles Reviewed

Petranka JW, Murray SS, Kennedy CA. 2003. Responses of amphibians to restoration of a southern Appalachian wetland: Perturbations confound post-restoration assessment. Wetlands 23(2):278-290.	State - North Carolina	Isolated wetland and vernal pools	Amphibians -- R. sylvatica, A. maculatum	The authors note that monitoring for longer than five years may be required to monitor amphibian population dynamics in mitigation sites, due to significant amphibian population lags and sensitivity to site perturbations.
Paton PWC, Crouch WB. 2002. Using the phenology of pond-breeding amphibians to develop conservation strategies. Conservation Biology 16(1):194-204.	State - Rhode Island	Vernal pools	Amphibians -- anurans and caudates	This study supports the importance of multi-year of monitoring when amphibians are included in a metric. The authors note that generally, the majority of pond-beeding amphibians require pools flooded for four to nine months (March through August) for successful reproduction, indicating a possible design standard. They also stress that an understanding of amphibian movement phenology needs to inform performance standards and wetland regulations.
Snodgrass JW, Komoroski MJ, Bryan AL, Burger J. 2000. Relationship among isolated wetland size, hydroperiod, and amphibian species richness: Implications for wetland regulations. Conserv. Biol. 14(2):414-419.	State - South Carolina	Depressional wetlands	Amphibians -- larval assemblages	The authors examined relationships among hydroperiod length, fish presence/absence and larval amphibian assemblage structure in relatively pristine depression wetlands. "Most species occurred along a restricted portion of the hydroperiod gradient, and some species were found almost exclusively in wetlands with fish." Their results identified 4 groups of wetlands with similar assemblage structure (1) short (drying in spring) (2) medium (drying in summer) (3) long (drying in fall or semi-annually) hydroperiods wetlands without fish, and (4) long hydroperiod wetlands with fish. This paper is relevant if amphibians are to be used in an IBI; managers would strive to create a diversity of wetland types with varying hydroperiods for highest amphibian diversity.

Amphibian Articles Reviewed

Olson DH, Leonard WP, Bury RB (eds). 1997. Sampling Amphibians in Lentic Habitats. Northwest Fauna 4, Olympia, WA, USA.	State - Washington	Freshwater	Amphibians	This book is presents standardized survey methods for pond-breeding amphibians in the Pacific Northwest. Because surveys for amphibian assemblages are complicated by great diversity of lentic habitat types and species-specific factors, this book gives a toolbox of methods and guidance. The authors stress that developing a standardized survey design and methodologies at the regional scale is critical to effective species management and conservation; presumably, standardized methodology also is critical to effective management of species in restored or mitigated wetlands.
Semlitsch RD. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12(5):1113-1119	U.S.	Freshwater ponds	Amphibians -- literature review of 8 salamander studies	Some salamander species use aquatic habitats for only a few weeks per year, usually for reproduction, and then return to wetland habitats. In this study, adult salamanders were found an average of 125.3 m from the edge of wetlands. Thus, an IBI for amphibians would have to assess variables at the landscape level. The article also emphasizes the importance of small wetlands within close proximity of one another to maintain viable populations and communities of amphibians.
U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Amphibians in Bioassessments of Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-022.	U.S.	Freshwater wetlands	Amphibians	Significant gaps in our knowledge of amphibian ecology and distribution, complicated population structure change over time in response to environmental conditions, and high costs of research or lab time suggest that amphibians may not be useful components of an IBI. Notes that attempts to use amphibians as indicators of wetland health are still in early stages.

Amphibian Articles Reviewed

Semlitsch RD, Bodie JR. 1998. Are small, isolated wetlands expendable? Conservation Biology 12(5):1129-1133.	U.S.	Isolated wetland and vernal pools	Amphibians -- pond breeding	The authors express concern that regulations drafted by the U.S. Army Corps of Engineers reduce protection for “headwater” or “isolated” wetlands, which are critical breeding habitat for many amphibian species and are important for maintaining wetland flora and fauna. They argue that loss of small wetlands will limit amphibian dispersal, and that a reduction in wetland density could decrease the probability that a population could be rescued by a different source population. The article's discussion of amphibian population behavior implies that an amphibian-based IBI would require a landscape approach.
Semlitch RD. 2000. Management of aquatic-breeding amphibians. J. Wild. Mange. 64(3):615-631.	U.S.	Palustrine and vernal pools	Amphibians -- salamanders and frogs	Two tables in the paper present excellent summaries: (1) a checklist of what managers should look for to determine management goals and create effective management plans, and (2) Critical elements of effective and biologically based management plans for amphibians that consider both population and landscape processes. This paper stresses that when using amphibians as indicators, managers will also have to spend considerable time in the uplands monitoring. The paper also stresses the importance of hydroperiod and some abiotic and biotic challenges amphibian-based IBIs pose to managers.
Heyer WR, Donnelly MA, McDiarmid RW, Hayek LC, Foster MS. 1994. Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution Press. Washington and London.	U.S.		Amphibians	This article is an excellent resource for developing amphibian IBIs. It covers sampling methods, data collection, data analysis, etc.

Amphibian Articles Reviewed

Paton PWC and Crouch WB. 2000. Using egg mass counts to monitor wood frog populations. Wildl Soc Bul 28:895-901.	U.S. region - Eastern	Vernal pools	Amphibians -- wood frog	The authors describe a metric for measuring population size based on egg mass counting. The methodology could be useful in the specification of a performance standard.
Brooks RP, O'Connell TJ, Wardrop DH, Jackson LE. 1998. Towards a Regional Index of Biological Integrity: The example of forested riparian ecosystems. Environ. Monitoring and Assessment 51(1-2):131-143.	U.S. region - Mid-Atlantic	Forested riparian ecosystems	Amphibians	State that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrates communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.
Brooks RP, Cole CA, Wardrop DH, Bishel-Machung L, Prosser DJ, Campbell DA, Gaudette MT. 1996. Wetlands, wildlife, and watershed assessment techniques for evaluation and restoration (W3ATER). Vol. 1, 2A, and 2B, , Penn State Coop. Wetlands Ctr. Rep. No. 96-2, University Park. http://www.cas.psu.edu/docs/CASDEPT/FOREST/wetlands/Research/Publist.htm#1999	U.S. region - Mid-Atlantic	Forested	Amphibians	The authors state that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrate communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.

Amphibian Articles Reviewed

Richter KO, Azous AL. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound Basin. Wetlands 15(3):305-312.	U.S. region - Pacific Northwest	Palustrine wetlands -- 19 wetlands representing a range of conditions	Amphibians -- 10 species of lentic, lotic, and 2 terrestrial	The authors assessed amphibian species richness in the context of wetland size, vegetation class, presence of bullfrog and fish predators, hydrologic characteristics of water flow, fluctuation, and permanence, and land use. Low velocity flow and low fluctuation were correlated with high amphibian species richness, and increasing mean water-level fluctuation and percent watershed urbanization were correlated with low species richness. The authors recommend that flow velocity be minimized in developing wetland watersheds -- this recommendation could be relevant both to design and performance standards.
Pechmann JHK, Estes RA, Scott DE, Gibbons JW. 2001. Amphibian colonization and use of ponds created for trial mitigation of wetland loss. Wetlands 21(1):93-111.	U.S. region - Southern	Ponds	Amphibians in created ponds	The study monitored amphibian population sizes and juvenile recruitment from created ponds and compared these results with populations observed at natural wetlands. Near the end of the study five-year study, breeding populations differed amount the created ponds and among the group of original ponds and the reference wetlands (natural wetlands group). The authors concluded that "the created ponds provided partial mitigation for the loss of the natural amphibian breeding habitat. Differences between the created ponds and the natural wetlands were likely related to differences in their hydrologic regimes, size, substrates, vegetation, and surrounding terrestrial habitats and the limited availability of colonists of some species." The article is a good example of how amphibian-based metrics can provide information about a variety of wetland components.

Fish Articles Reviewed

Title / Reference information	**Region**	**Wetland type**	**Parameter**	**Comments**
Lyons et al. 1995. Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in West-Central Mexico. Conservation Biology 9(3): 569-584.	International - West-central Mexico	Streams and small rivers	Fish	Authors create and apply an IBI to assess water degradation. The article is valuable mainly for its detailed description of the process and considerations associated with construction of a modified IBI. The authors successfully constructed and applied a fish-based IBI that included ten metrics in three categories: compositional, structural, and functional. Specifically relevant to wetlands is the authors' observation that "Versions of the index of biotic integrity also could be developed for. . .estuaries and nearshore marine environments. . .The use of a wider range of species-composition and trophic function metrics, including at least one for plankton or filter-feeding species, would probably be warranted in these waters."
Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.	State - California	Salt marshes	Fish -- 31 species	The intertidal area of the mitigated (created) marsh was dominated by eurhaline sticklebacks and topsmelts. This area did not replace the intertidal and subtidal habitat of the natural marsh, which had more stable salinity and water temperatures and was used extensively by juvenile English sole. Possible performance indicators include (1) stability of salinity and water temperatures relative to a reference/control site, and (2) fish composition -- numbers of juvenile sole vs. other species.

Fish Articles Reviewed

Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.	State - California	Intertidal wetlands	Fish	Measures of individual species abundance and relative assemblage structure (fish) in constructed channels were not equivalent to those in natural wetlands. Soil salinity and nitrogen concentration (lack of) were linked to failure to replicate habitats of certain fish species. The proportion of two fish species differed significantly.
Williams GD, Zedler JB. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: Relative influence of channel morphology and restoration history. Estuaries 22(3A):702-716.	State - California	Tidal wetlands	Fish	Fish species richness and density did not vary significantly between constructed and natural channels, though California killifish was in higher densities in the constructed channels. Focus of article: assemblage and composition is related to channel physical properties/characteristics, so it is important to design projects with natural hydrologic features and use assessment tools that measure fish habitat function.
Zedler JB. 1990. A Manual for Assessing Restored and Natural Coastal Wetlands with Examples from Southern California. Report. No. T-CSGCP-021. La Jolla: California Sea Grant College.	State - California (southern)	Salt marshes	Fish	Low available nitrogen and soil organic matter in constructed tidal marshes may be a key factor in poor performance outcomes.
Brawley AH, Warren RS, Askins RA. 1998. Bird use of restoration and reference marshes within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. Environ. Manage. 22(4):625-633.	State - Connecticut	Estuarine, tidal marsh	Fish	This study compared restored tidal marshes to control site. Study found that reintroduction of tidal flooding can effectively restore important ecological functions to previously impounded tidal marshes based on vegetation, macroinvertebrate, and fish species richness and frequency.

Fish Articles Reviewed

Langston MA, Kent DM. 1997. Fish recruitment to a constructed wetland. Journal of Freshwater Ecology 12(1): 123-129.	State - Florida	Marsh	Fish	Fish assemblages at the constructed wetlands were compared to species lists from several natural and constructed waterbodies in the area. A rich and abundant fish community rapidly developed within the constructed wetland. Representative richness was achieved within one year and the constructed wetland's fish species richness compared favorably with richness of the constructed and natural marshes in the reference group. Overall, the article was not particularly useful the discussion of performance standards.
Lewis RR. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. Ecological Engineering 15(3-4):191-198.	State - Florida	Mangrove forest and tidal marshes	Fish	This review paper focused on goals of marsh and mangrove restoration projects in southern Florida and claims that though these goals now typically seek functional equivalency and ecological restoration, rather than more simplistic aims (such as establishment of persistent vegetative cover), political will does not exist to properly fund wetland compensatory mitigation programs; thus, programs are unlikely to effectively meet new goals. The authors comment on multiple flaws of the Florida restoration projects, and their observations are highly relevant to improving design standards. They observe that because the science of functional analysis has lagged behind permitting for construction of mitigation wetlands, goal setting and success criteria based on functionality have been set in ad hoc and inconsistent manners -- and recommend that generally accepted criteria based on functionality be set and applied by managers who have been given effective training and understand principles of adaptive management.

Fish Articles Reviewed

Streever WJ, Crisman TL. 1993. A comparison of fish populations from natural and constructed marshes in Central Florida. Journal of Freshwater Ecology 8(2): 149-153.	State - Florida	Freshwater wetlands	Fish -- 8 species plus some unidentified	If fish communities differ but species pools are similar, differential conditions must be present. The fish E. Evergladei was present in high numbers in 7 of the 8 natural marshes, but in very low numbers in only 2 of the constructed marshes. Overall, not a highly useful article.
Vose FE, Bell SS. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: evaluation of habitat restoration by hydrologic modification. Estuaries 17(3):585-596.	State - Florida	Salt marshes	Fish	Fish abundance, biomass, and mean monthly number of species decreased after tidal flow was established. Pre and post-breach community similarity of fish, amphipod, and polychaete assemblages increased during last year of sampling but remained generally low. Suggests that differences between a natural and modified wetland can be observed in a short time frame.
Schwartz JS. 2002. Stream Habitat Characterized by Stage-Specific Flows and Three-Dimensional Geomorphological Complexity: Development of Ecological Criteria for Stream Restoration Design. PhD Dissertation	State - Illinois	Third-order streams	Fish	The ecological relationship discussed in this dissertation illustrate the importance of the pool-riffle sequence in maintaining fish community diversity, and the importance of bed and bank morphology during high-flow stages for hydrodynamic conditions necessary for fish refugia. This discussion implies that HGM factors clearly are important to both wetland design and performance.
Dionne M, Short FT, Burdick DM. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.	State - Maine and New Hampshire	Salt marsh	Fish -- 15 fish species, 3,275 fish from 62 samples	The study notes the importance of biannual sampling, at least. There is also a discussion of the importance of tidal inundation patterns and elevation. From the results of the study, determinations cannot be made about fish growth/survival in disturbed marshes and compare them to natural marshes.

Fish Articles Reviewed

Simon TP. 1998. Modification of an index of biotic integrity and development of reference condition expectations or dunal, palustrine wetland fish communities along the southern shore of Lake Michigan. Aquatic Ecosystem Health and Management 1(1):49-62.	State - Michigan	Dunal, palustrine wetlands	Fish -- 32 species	The article discusses specific ways to modify the Karr fish IBI for palustrine wetlands, including replacing sucker species with minnows, replacing percentage carnivore and percentage hybrids with percentage pioneers and percentage lake obligates, and including black bass numbers. Sites were sampled to develop reference expectations for dunal wetlands less than 35 ha in surface area. The article warns that low catches may cause IBI scoring problems, and also that fish communities not be used to assess ecosystem health unless the wetland is over 3 ha (smaller often have two or fewer fish species).
Simon TP. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3):407-418.	State - Michigan	Palustrine and vernal ponds	Fish -- 12 species	Authors constructed an IBI to measure anthropogenic impact. Article observed that for small wetlands and vernal ponds, and IBI that includes a mix of taxonic groups is most appropriate. Crayfish are a little-used indicator taxon, but exhibit well-structure assemblage differences between degraded and non-habitats and could be valuable components of an IBI. Also, the article found higher numbers amphibians, crayfish in higher quality wetlands and vernal ponds.

Fish Articles Reviewed

Drake MT, Pereira DL. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. N. AM. J. of Fisheries Management 22(4):1105-1123.	State - Minnesota	Lakes	Fish	The study found that species richness and community composition metrics describing intolerant or habitat specialist species were the most sensitive to differences in human-induced stress in the lakes studied, and that the IBI scores reflected differences in land-use patterns, trophic state, and aquatic vegetation. Relative biomass metrics showed a stronger response than relative abundance metrics in measuring integrity. The article emphasizes that effective IBIs should be subject to independent measures of lake ecosystem integrity.
Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites chosen to represent a land use gradient (18 categories)	Fish -- 18 species	The article notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.

Fish Articles Reviewed

Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressional wetlands	Fish -- 44 fish taxa	Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.

Fish Articles Reviewed

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606-627.	State - Minnesota and Wisconsin	Streams	Fish -- 106 species	Fish data from a large set of streams were collected and analysis sought correlation between assemblages and stream HGM; data from databases. The authors assessed fish assemblages in streams along a gradient of hydrologic variability, and found that fish attributes were correlated with nature of the hydrologic environment. Variable aquatic habitats were characterized by resource generalists, more silt-associated fish, slower fish, more small stream and wide-ranging fish species, weakly interactive opportunists, substratum generalists, more planktivores, omnivores, and generalist invertebrates, and fewer parasitic fish. Stable aquatic environments were characterized by a higher proportion of specialist species, highly interactive and limited by stable resources, more benthic invertebrates and parasitic fish, fewer omnivores, generalist invertebrates and planktivores, faster fish, and more rubble-associated fish. The results demonstrate that fish attributes can serve as indicators of environmental conditions.
Zampell, Robert and Bunnell, John. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645-658.	State - New Jersey (Mullica River Basin)	Streams	Fish -- 19 species	Authors use natural stream set to construct and apply an IBI measuring degradation. The main purpose of article is to highlight use of PCA and DCA statistical tools in constructing IBIs based on fish assemblages. The article found that fish assemblage may change subtly with watershed disturbance gradients; the major difference associated with declining water quality concerned the occurrence of nonnative. Presence/absence of species was equally valid measure as relative abundance.

Fish Articles Reviewed

Harig A, Bain M. 1998. Defining and Restoring Biological Integrity in Wilderness Lakes. Biological Applications 8(1): 71-87.	State - New York (Adirondacks)	Small lakes	Fish -- 24 species from 10 families	Lake communities with high biological integrity were characterized by native fish communities, zooplankton communities, biomass, larger species, and phytoplankton communities. Authors constructed an IBI with six indicators. The species composition of these communities gave the earliest sign of disturbance. Like other articles on small water bodies, there was an indication that they need to rely on multiple taxa to produce sensitive indices.
Fonseca MS, Kenworthy WJ, Colby DR, Rittmaster KA, Thayer GW. 1990. Comparisons of fauna among natural and transplanted eelgrass Zostera marina meadows: criteria for mitigation. Marine Ecology Progress Series 65: 251-264.	State - North Carolina	Eelgrass meadow	Fish -- 1109 individuals from 32 species	Article is innovative in that it applies vector-graphical analysis as an alternative method of quantifying marsh maturation. Functional equivalence is measured by the faunal/eelgrass shoot abundance ratio of the natural and mitigated sites. The diagnostic parameter is percentage similarity/species shared. Hypothesis (mostly confirmed) was: faunal population stabilizes when a given eelgrass population stabilizes. "Fish abundance and composition in a 1.9-year-old transplanted bed and a 6-month-old seed-developed bed were indistinguishable from natural eelgrass beds."

Fish Articles Reviewed

Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.	State - North Carolina	Salt marshes	Fish -- Fundulus heteroclitus	The study also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the “results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction.”
Rulifson RA. 1991. Finfish utilization of man-initiated and adjacent natural creeks of South Creek Estuary, North Carolina using multiple gear types. Estuaries 14(4):447-464.	State - North Carolina	Salt marshes	Fish -- many types; finfish, spot, and Atlantic croaker most significant	The authors compared fish catches in natural and artificial marshes based on gear type: with ring analysis, finfish catches were greater in constructed marsh; with trawl sampling, spot was more abundant in the constructed marsh; using ring analysis, spot was more abundant in the constructed marsh than in one of the two natural. Atlantic croaker was lower in the constructed marsh relative to natural. The article highlights gear considerations important when collecting data to inform a performance standard.

Fish Articles Reviewed

Tangen BA, Butler MG, Michael JE. 2003. Weak correspondence between macroinvertebrate assemblages and land use in Prairie Pothole Region wetlands, USA. Wetlands 23(1):104-115.	State - North Dakota	Prairie wetlands	Fish	Results showed that fish strongly impacted macroinvertebrate abundance, but there was not a strong relationship between macroinvertebrate community structure and land use. Temporal and seasonal patterns (which must be addressed in sampling design) and among-wetland variation accounted for 62% of the total variation in the invertebrate community. Biotic and abiotic conditions heavily outweighed land use practices in their influence on the studied invertebrate communities. Though the authors "identified numerous potential limitations to biological assessment in the Prairie Pothole wetlands," they recommend that metrics for amphibians or birds could be used as functional assessment tools.
Fore LS, Karr JR, Conquest LL. 1994. Statistical properties of an index of biological integrity used to evaluate water resources. Canadian J. Fish. Aquat. Sci. 51: 1077-1087.	State - Ohio	Stream	Fish	Statistical properties of IBI supported the use of standard analysis techniques such as ANOVA for hypothesis testing. IBI is an effective monitoring tool that can be used to communicate qualitative assessments. The article also notes IBI problems -- cannot provide independent, replicate measurements. The author states uncertainties about the IBI's ability to measure changes (over time and location). There is a tendency of the IBI's to overestimate quality at degraded sites and underestimate it for pristine sites.

Fish Articles Reviewed

LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	Fish	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.
Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.	State - Texas (Galveston Bay)	Salt marshes	Fish	The study's results showed that the size of daggerblade shrimp in created marshes was smaller than in natural marshes, and densities of four other shrimp types were lower in created vs. natural marshes. Globe and pinfish densities, sediment macro-organic matter and density and species richness of macroinfauna all were lower in created marshes. The authors concluded that differences in nekton densities primarily were related to tidal flooding -- created marshes had wider flooding duration ranges than natural marshes, and ranged to a much lower level. This hypothesis suggests that performance standards based on range of tidal inundation, or on hydrologic factors generally, might be appropriate.
Contreras-Balderas S, Edwards RJ, Lozano-Vilano MD, Garcia-Ramirez ME. 2002. Fish biodiversity changes in the Lower Rio Grande/RioBravo, 1953-1996 - A review. Reviews in Fish Biology and Fisheries. 12(2):219-240.	State - Texas and Mexico	River -- Altered system: shifts over time in pollution, temp, salinity, turbidity	Fish -- 142 species	Survey results are being incorporated into a fish IBI. Changes over 43 years demonstrated change in fish fauna with a loss of the majority of freshwater species replaced by marine invaders due to shifts in whole-basin ecology including higher water temp, salinity, turbidity, and lower runoff levels and maybe pollution.

Fish Articles Reviewed

Layman CA, Smith DC. 2001. Sampling bias of minnow traps in shallow aquatic habitats on the eastern shore of Virginia. Wetlands 2(1): 145-154.	State - Virginia	Estuary	Fish	Study compares sampling methods -- seines vs. minnow traps. Authors comment that minnow traps are often-used passive sampling devices. However, they can be species-selective, have low and variable catch efficiency, and cannot make quantitative density estimates. In wetlands they bias toward the collection of Fundulus heteroclitus and against some resident species and juveniles of estuarine transients. They are not appropriate when sampling, as opposed to "collection," is action required by an assessment tool.
Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Fish -- occurrence and density	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.

Fish Articles Reviewed

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf.	U.S.	Freshwater wetlands	Fish	Reviewed section of this document is a literature review of attempts to construct IBIs for wetland fish assemblages and studies on fish response to variance stressors. Adamus and co-authors comment on a wetland IBI proposed by Galatowitsch and co-authors, noting that the following variables are strong indicators of wetland health in the noted wetland type: small river floodplain -- species richness and proportion Cyprinids; medium river floodplain - species richness; large river floodplain -- proportion piscivores, fish abundance, proportion Catostomids; non-calcareous littoral wetlands -- total fish abundance; calcareous wetlands -- species richness, abundance, proportion Cyprinids, and number sunfish; forest and prairie glacial marshes -- total richness and abundance. The authors also discusses an IBI proposed by Schultz and co-authors.

Fish Articles Reviewed

Karr J. 1991. Biological integrity: A long-neglected aspect of water resources management. Ecological Applications 1(1): 66-84.	U.S.	Water resources generally	Fish	The article describes in detail the original Karr IBI, its advantages and disadvantages. It also discusses techniques for modification. Karr observes that an IBI that includes greater numbers of metrics assessing multiple taxa will be relatively more likely to be widely applicable and relevant to different environmental conditions. He also notes that the intelligent development of an IBI and its component metrics is relatively more important than the choice of any one (relatively reasonable) component, noting that "I believe that just about any taxon could be selected and produce a reasonable level of insight about the water resource if appropriate wisdom is brought to bear on development of robust and general metrics." This article is not study specific, but does provide support for effectiveness of ambient biological monitoring for water quality assessment.
Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.	U.S.	Streams and rivers generally	Fish	This is one of Karr's earliest articles, in which he first proposes the fish-based IBI. He argues for the evaluation of several major taxa in any IBI, and proposes an IBI that uses 12 fish community parameters, in two categories: species composition and richness and ecological factors. He observes that IBI descriptive accuracy requires an accurate baseline, a representative sample of the fish (or other target species) at the sample site and the larger geographic area of interest, and a scientist’s ability to adjust the IBI to local conditions.

Fish Articles Reviewed

Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.	U.S.	Constructed wetlands	Fish	The article finds that "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time." Limited data indicates that dredged marshes may support a different community of birds, and have lower or smaller values associated with belowground biomass, organic carbon levels, soil nutrient reservoirs, and abundance of polychaetes and crustaceans. Streever also warns against single-season sampling as a way of characterizing wetlands -- though this method is often employed in the literature. Article is particularly relevant because it questions the trajectory model for wetland development.
Beck MW, Heck KL, Able KW, Childers DL, Eggleson DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. Issues in Ecology 11 (Spring): 1-12.	U.S. region	Salt marshes, mangroves, seagrass meadows	Fish	Article is a review of literature (more than 200 relevant papers) on wetlands as fish nurseries, but much is generally applicable. Discusses predation, structural complexity, food availability and competition for food -- discusses all, but no new information. Emphasizes the need for assessment that accounts for growth and juvenile migration to adult habitats. Wetland characteristics must be assessed on a unit-area basis.

Fish Articles Reviewed

Wilcox DA, Meeker JE, Hudson PL, Armitage BJ, Black MG, Uzarski DG. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. Wetlands 22(3):588-615.	U.S. region - Great Lakes, Midwest	Lake coastal wetlands	Fish	This study compared natural and constructed wetlands, examining nesting by the endangered light-footed clapper rail and associated trends in intertidal cordgrass (Spartina foliosa) growth. The author found that a marsh's failure to foster nesting primarily was caused by tidal inundation related insufficient cordgrass height and density, and predation. When evaluating marsh vegetation, the author recommends using cordgrass height distributions and density parameters, rather than canopy structure measures; grouping density and height distribution data together in a single indicator; and monitoring for an extended time period in order to account for interannual and spatial variability and lag effects. The author also points out that sampling methodology is critical for accurate assessment, and makes many suggestions concerning research design components.
Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.	U.S. region - Pacific Northwest	Saltwater marshes -- restoration of multiple wetlands in multiple river sites	Fish -- salmon	The authors argue that fish occurrence and abundance are not sufficient to measure mitigation success. Habitat assessment must be functional, not focused on structure. They suggest three types of metrics to assess wetlands -- capacity, opportunity, and realized function metrics. Also, assessment must address landscape and system attributes.

Fish Articles Reviewed

Minello TJ, Able KW, Weinstein MP, Hays CG. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progression Series 246: 39-59.	U.S. region - various, but mainly Gulf and Atlantic Coast	Seagrass meadow, salt marsh, non-vegetated marsh, and open sea	Fish	Review of data from 32 studies (world-wide, but mainly in US) to evaluate hypotheses about density, growth, and survival. The article mainly compares the value of salt marshes, seagrass meadows, and open water for the fostering (that is, the nursery capacity of each habitat) of nekton. It is not particularly useful for study of performance standards. It does emphasize the need to include metrics assessing growth rates of transient nekton in any performance standard, but discusses the problems associated with this inclusion -- no single good technique for measuring growth rates, problematic tidal dynamics, and others.

Invertebrate Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Chovanec A. 1994. Man-made wetlands in urban recreational areas: A habitat for endangered species? Landscape and Urban Planning 29(1): 43-54.	International-Austria, Vienna	Urban wetlands	Dragonflies	The author describes a man-made pond. The pond was designed according to the ecological requirements of amphibians and dragonflies. Special measures were taken to control of visitors to minimize disturbance and human impacts from recreational activities. Based on the colonization by amphibians and dragonflies in the three years following construction, the author concluded that constructing and successfully managing artificial wetlands can offer refugia for endangered species in high density urban areas. This article is relevant from a wildlife habitat performance standard perspective. This represents a success for an urban setting, although there is no comparison with a natural wetland in the same setting.
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh	Macroinvertebrates -- amphipod, decapod, mysid, polychaete, jellyfish, cladoceran	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.

Invertebrate Articles Reviewed

Muzaffar SB, Colbo MH. 2002. The effects of sampling technique on the ecological characterization of shallow, benthic macroinvertebrate communities in two Newfoundland ponds. Hydrobiologia 477(1):31-39.	International - Canada (Newfoundland)	Freshwater ponds	Macroinvertebrates	Sweep-net and rock-bag sampling techniques were used to collect macroinvertebrates from two similar ponds. The sampling techniques provided different estimates of diversity and density, neither was highly representative, neither collected all taxa, and both typically over- or under-estimated the abundance of taxa. Though the authors comment that natural pond characteristics are an important factor, and the different depths of the ponds as well as other unique attributes may have accounted for some of the variance in sampling results, their results also highlight the significance of sampling method on the data that inform performance standards or regulations.
Cao Y, Bark AW, Williams WP. 1996. Measuring the response of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic and diversity indices. Hydrobiologia 341: 1-19.	International - United Kingdom	Lowland river	Macroinvertebrates -- samples collected from all sites, using artificial substrate; 77 total samples and 25 composite samples; 63 species	Study compared the effectiveness of different statistical methods in revealing differences along a pollution gradient. Authors report that species abundance patterns in their study were sig. different among sites of varying water quality with more rare species in the least impacted site. Further, they stress that species abundance patterns are most likely to vary among sites and samples in any study and some sample methods delete rare spp. or spp that occur infrequently (as is often the case with rare species) and that this results in an inadequate or flat out wrong interpretation of the biological condition of the site. The authors provide results that demonstrate that sample size can greatly affect the comparison of species richness and may underestimate differences among sites.

Invertebrate Articles Reviewed

Chessman BC, Trayler KM, Davis JA. 2002. Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research 53(5):919-930.	International - Western Australia	Coastal wetlands	Macroinvertebrates	The authors developed a macroinvertebrate pollution sensitivity biotic index for wetlands. Grades between 1 and 100 were assigned to macroinvertebrates at the family and species levels to reflect the sensitivities of these taxa to human impacts. Scores for both family and species levels detected strong correlation with cultural eutrophication and other human disturbances, but the correlation was generally higher for species level scores. The species level index was also better at distinguishing between individual wetlands. The authors feel this method would work well in routine and rapid wetland assessment and monitoring. This study offers support for the use of macroinvertebrates as rapid wetland assessment tools and for use in biomonitoring.
Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.	State - California	Salt marshes	Macroinvertebrates -- 2 crab species	The intertidal area of the mitigated (created) marsh was dominated by eurhaline sticklebacks and topsmelts. This area did not replace the intertidal and subtidal habitat of the natural marsh, which had more stable salinity and water temperatures and was used extensively by juvenile English sole. Possible performance indicators include (1) stability of salinity and water temperatures relative to a reference/control site, and (2) fish composition -- numbers of juvenile sole vs. other species.

Invertebrate Articles Reviewed

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.	State - California	Salt marsh	Macroinvertebrates -- type of oligochaete and connection to level of soil organic matter	A constructed marsh had significantly lower levels of nitrogen and organic matter than an adjacent natural marsh. Article sites others which say that constructed marshes may take 15-30 years to develop nitrogen and organic carbon pools equal to those of natural salt marshes. Organic amendments did not increase soil organic content. Soil nitrogen showed few differences that were related to soil amendments. It is unclear whether these marshes need more time or if the amendments are not sufficient.
Griffith MB, Husby P, Hall RK, Kaufmann PR, Hill BH. 2003. Analysis of macroinvertebrate assemblages in relation to environmental gradients among lotic habitats of California's Central Valley. Environ. Monitoring and Assessment 82(3):281-309.	State - California	Streams	Macroinvertebrates	This study aimed to identify taxa or metric diagnostics of lotic environments and compare the approaches to see if they could be used to diagnose stressors. The authors discovered that the approaches measured different aspects of macroinvertebrate assemblages and differed in their ability to detect environmental stressors. A combination of metrics would be more useful but expensive.

Invertebrate Articles Reviewed

Scataloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16(1): 24-37.	State - California (San Diego Bay)	Salt marshes	epibenthic invertebrates -- 45 species, majority polychaetes and crustaceans (more crabs than typical)	The natural, fully-vegetated marsh studied by the authors had two to three times as many individuals (epibenthics) as the four-year-old constructed marsh. The articles hypothesize that coarser sediment, lower organic matter, and relatively more sparse vegetative cover were potential causes of the significantly lower abundance in constructed marshes. The article suggests that epibenthic populations can serve as indicators for soil and vegetative wetland components, and also emphasizes the influence of these components on wetland development generally.
Brawley AH, Warren RS, Askins RA. 1998. Bird use of restoration and reference marshes within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. Environ. Manage. 22(4):625-633.	State - Connecticut	Estuarine, tidal marsh	Macroinvertebrates	This study compared restored tidal marshes to control site. Study found that reintroduction of tidal flooding can effectively restore important ecological functions to previously impounded tidal marshes based on vegetation, macroinvertebrate, and fish species richness and frequency.
Streever WJ, Crisman TL. 1993. A preliminary comparison of meiobenthic cladoceran assemblages in natural and constructed wetlands in Central Florida. Wetlands 13(4): 229-236.	State - Florida	Freshwater wetlands	Meiobenthic cladocerans, chydorid cladocerans and allied taxa	Rare species seemed to occur more frequently in natural wetlands than in constructed wetlands. Meiobenthic cladoceran assemblages were more variable in natural wetlands -- article hypothesizes that the environmental and ecological attributes that control assemblages may be more variable in natural areas. Also notes the need for a broad range of biotic assemblages and driving conditions to be considered in an effective IBI.

Invertebrate Articles Reviewed

Vose FE, Bell SS. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: evaluation of habitat restoration by hydrologic modification. Estuaries 17(3):585-596.	State - Florida	Salt marshes	Amphipod and polychaete abundance increased after berm removal	Fish abundance, biomass, and mean monthly number of species decreased after tidal flow was established. Pre and post-breach community similarity of fish, amphipod, and polychaete assemblages increased during last year of sampling but remained generally low. Suggests that differences between a natural and modified wetland can be observed in a short time frame.
Delaune RD, Buresh RJ, Patrick Jr WH. 1979. Relationship of soil properties to standing crop biomass of Spartina alterniflora in a Louisiana marsh. Estuarine Coastal Marine Sci. 8:477–487.	State - Louisiana	Marsh (saltwater)	Vegetation	There was a strong positive correlation between soil nutrient density (g/cm3 wet soil) and plant biomass. Thus, it is important for soil and substrates to be healthy in a wetland for the success of plant growth and the health of the wetland.
Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.	State - Maine	Isolated vernal pools	Macroinvertebrates	Following loss of small wetlands, elevated extinction risk response for 3 of the 5 taxa. The most dispersive taxa studied, turtles and birds, were most prone to extinction. Small wetlands are likely critical for the maintenance of taxa endemic to those habitats.
Dionne M, Short FT, Burdick DM. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.	State - Maine and New Hampshire	Salt marsh	Macroinvertebrates -- 4 crustacean species	The study notes the importance of biannual sampling, at least. There is also a discussion of the importance of tidal inundation patterns and elevation. From the results of the study, determinations cannot be made about fish growth/survival in disturbed marshes and compare them to natural marshes.

Invertebrate Articles Reviewed

Gibbs JP. 2000. Wetland loss and biodiversity conservation. Conservation Biology 14(1):314-317.	State - Maine and New York	Palustrine wetlands -- transects along the urban-rural gradient surrounding NY City and through rural southern ME	Macroinvertebrates -- general mention regarding low dispersal ability.	This article addresses the importance of an amphibian IBI monitoring to sample at the landscape level. Gibbs points out that adaptation to an aquatic existence has imposed severe constraints on the ability of many wetland animals to disperse across the uplands separating wetlands. Also that this dispersal of aquatic plants is highly dependent on transport by wetland animals and that reduced wetland density and proximity has important energetic implications for larger-bodied animals such as waterfowl, that must move daily among multiple wetlands to forage.
Ranasinghe JA, Frithsen JB, Kutz FW, Paul JF, Russell DE, Batiuk RA, Hyland JL, Scott J, Dauer DM. 2002. Application of two indices of benthic community condition in Chesapeake Bay. Environmentrics 13(5-6):499-511.	State - Maryland (Chesapeake Bay)	Estuaries	Macroinvertebrates	This study that compared the Chesapeake Bay Benthic Index of Biotic Integrity (B-IBI) with the Environmental Monitoring and Assessment Program's Virginian Province Benthic Index (EMAP-VP BI). Both indices are intended to identify benthic invertebrate assemblages in systems that have been degraded by low dissolved oxygen concentrations or high concentrations of chemical contaminants. The indices were applied to 294 sample events. The two indices yielded similar results, suggesting that either index is suitable for evaluating the benthic condition.

Invertebrate Articles Reviewed

Simon TP. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3):407-418.	State - Michigan	Palustrine and vernal ponds	Crayfish -- 3 species; also suggests that macroinvertebrates be included in a more complete IBI; does not measure	Authors construct an IBI to measure anthropogenic impact. Article observed that for small wetlands and vernal ponds, and IBI that includes a mix of taxonic groups is most appropriate. Crayfish are a little-used indicator taxon, but exhibit well-structure assemblage differences between degraded and non-habitats and could be valuable components of an IBI. Also, the article found higher numbers amphibians, crayfish in higher quality wetlands and vernal ponds.
Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites chosen to represent a land use gradient (18 categories)	Insects, crustaceans, mollusks	The article notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.

Invertebrate Articles Reviewed

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606-627.	State - Minnesota and Wisconsin	Streams	Benthic, omnivore, generalist, invertivore, planktivore invertebrates	Fish data from a large set of streams were collected and analysis sought correlation between assemblages and stream HGM; data from databases. The authors assessed fish assemblages in streams along a gradient of hydrologic variability, and found that fish attributes were correlated with nature of the hydrologic environment. Variable aquatic habitats were characterized by resource generalists, more silt-associated fish, slower fish, more small stream and wide-ranging fish species, weakly interactive opportunists, substratum generalists, more planktivores, omnivores, and generalist invertebrates, and fewer parasitic fish. Stable aquatic environments were characterized by a higher proportion of specialist species, highly interactive and limited by stable resources, more benthic invertebrates and parasitic fish, fewer omnivores, generalist invertebrates and planktivores, faster fish, and more rubble-associated fish. The results demonstrate that fish attributes can serve as indicators of environmental conditions.

Invertebrate Articles Reviewed

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh	Macroinvertebrates -- benthic invertebrate density	This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.
Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecol. Manage. 8(2/3):197-207.	State - North Carolina	Saltwater marshes	Macroinvertebrates -- benthic invertebrate densities	Development of a benthic invertebrate community depends on MOM and organic matter inputs; the quality of the organic matter, based on soil N content, also may be important. It make take more than 10-15 years for the organic-rich surface layer characteristic of natural marshes to develop in created ones. Necessary time depends on duration and frequency of inundation, NPP of emergent vegetation, tidal amplitude, and other factors.

Invertebrate Articles Reviewed

Fonseca MS, Kenworthy WJ, Colby DR, Rittmaster KA, Thayer GW. 1990. Comparisons of fauna among natural and transplanted eelgrass Zostera marina meadows: criteria for mitigation. Marine Ecology Progress Series 65: 251-264.	State - North Carolina	Eelgrass meadow	Macroinvertebrates - shrimp, 7563 individuals from 19 species	Article is innovative in that it applies vector-graphical analysis as an alternative method of quantifying marsh maturation. Functional equivalence is measured by the faunal/eelgrass shoot abundance ratio of the natural and mitigated sites. The diagnostic parameter is percentage similarity/species shared. Hypothesis (mostly confirmed) was: faunal population stabilizes when a given eelgrass population stabilizes. "Fish abundance and composition in a 1.9-year-old transplanted bed and a 6-month-old seed-developed bed were indistinguishable from natural eelgrass beds."
Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.	State - North Carolina	Salt marshes	Insects	The study also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the "results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction."

Sacco JN, Seneca ED, Wentworth TR. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17(2):489-500.	State - North Carolina	Salt marshes	Total infaunal density, density of dominant taxa, proportion of trophic groups; over 18,000 organisms from 41 taxa in 729 samples	The study found that though natural and artificial marshes showed nearly equal proportions of surface feeders and sub-surface deposit feeders, the absolute densities of infaunal organisms were significantly greater in the natural marshes. The authors concluded that though artificial marshes are capable of supporting infaunal structures similar to those of natural marshes, they are unable to support similar densities due to their lower organic matter content. Yet marsh age is not the dominant influence on soil organic matter accumulation -- the authors discuss other factors that influence accumulation. The article highlights the importance of soil characteristics in determining wetland function, suggesting the potential value of soil-based performance standards.

Invertebrate Articles Reviewed

Tangen BA, Butler MG, Michael JE. 2003. Weak correspondence between macroinvertebrate assemblages and land use in Prairie Pothole Region wetlands, USA. Wetlands 23(1):104-115.	State - North Dakota	Prairie wetlands	Macroinvertebrates	Results showed that fish strongly impacted macroinvertebrate abundance, but there was not a strong relationship between macroinvertebrate community structure and land use. Temporal and seasonal patterns (which must be addressed in sampling design) and among-wetland variation accounted for 62% of the total variation in the invertebrate community. Biotic and abiotic conditions heavily outweighed land use practices in their influence on the studied invertebrate communities. Though the authors "identified numerous potential limitations to biological assessment in the Prairie Pothole wetlands," they recommend that metrics for amphibians or birds could be used as functional assessment tools.

Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030	State - Ohio	Created and restored wetlands	Macroinvertebrates -- 42 taxa	The authors seeded one created wetland and left the other unseeded, hypothesizing (based on self-design and self-organization theory) that the two hydrologically similar wetlands would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. After three years, both sites had relatively similar numbers of species (65 versus 54), similar nutrient levels, and similar diversity indices, though the benthic taxon richness was higher in the planted wetland. The study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward functionality (though both experimental wetlands did receive a regulated water supply). The article is relevant to design standards and performance standards based on developmental trajectories.

Invertebrate Articles Reviewed

Spieles DJ, Mitsch WJ. 2000. Macroinvertebrate community structure in high-and low-nutrient constructed wetlands. Wetlands 20(4):716-729.	State - Ohio	Constructed wetlands	Macroinvertebrates	Macroinvertebrate community structure was related to physical, chemical, and biological gradients in flow-through constructed wetlands receiving secondarily treated domestic wastewater and lower-nutrient river water in Ohio. This study addresses a problem with macroinvertebrates as an IBI is that many of the indices were developed for stream analysis, and temperate freshwater marsh wetlands are generally highly productive, accumulate organic carbon, and generally have lower dissolved oxygen and higher temperatures during summer months than streams. Macroinvertebrates analyses used in this study was a valuable tool for demonstrating change in community structure along a complex pollution gradient in constructed wetlands and highlighted differences in water quality between sites and at the inflow.
Fore LS, Karr JR, Wisseman RW. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. J N Am Benthol Soc 15(2):212-231.	State - Oregon	Streams -- disturbed habitat (logging and assoc. roads)	Macroinvertebrates	Benthic IBI were used to compare disturbed from minimally disturbed sites and found that IBI scores were significantly lower for streams in watersheds with higher levels of human activity. Also tested were rapid bioassessment protocols but found these failed to detect differences among sites that IBI did detect.

Invertebrate Articles Reviewed

LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	Polychaetes, oligochaetes, others; also shellfish	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.
Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.	State - Texas (Galveston Bay)	Salt marshes	decapod crustaceans (shrimp, others), polychaete worms	The study's results showed that the size of daggerblade shrimp in created marshes was smaller than in natural marshes, and densities of four other shrimp types were lower in created vs. natural marshes. Globe and pinfish densities, sediment macro-organic matter and density and species richness of macroinfauna all were lower in created marshes. The authors concluded that differences in nekton densities primarily were related to tidal flooding -- created marshes had wider flooding duration ranges than natural marshes, and ranged to a much lower level. This hypothesis suggests that performance standards based on range of tidal inundation, or on hydrologic factors generally, might be appropriate.

Invertebrate Articles Reviewed

Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.	State - Virginia	Tidal marsh	Blue crabs, benthic infauna	The study examined various elements of constructed and natural wetlands. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush, and use by birds. A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.
Doberstein CP, Karr JR, Conquest LL. 2000. The effect of fixed-count subsampling on macroinvertebrate biomonitoring in small streams. Freshwater Bio. 44(2):355-371.	State - Washington	Small streams -- 5 streams that represented a gradient of human influence from urban to rural	Macroinvertebrates	Of 44 states using macroinvertebrate bioassessment in rivers and streams, more than 30 of these reported subsampling methods. Authors feel that it is necessary to analyze the effects of subsampling on the measures used in the assessments from these samples. Authors found that variance increased as sample size decreased. They caution that there is a problem of differentiating between true differences and sample variability differences when using subsampling as a method. They state that successful biological monitoring requires clear goals on what information is needed and the quality of that information to inform management decisions.

Invertebrate Articles Reviewed

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Benthic and planktonic invertebrates -- composition and stock	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.
Cooper CB, Anderson SH. 1996. Significance of invertebrate abundance to dabbling duck brood use of created wetlands. Wetlands 16(4): 557-563.	State - Wyoming	Emergent wetlands	Macroinvertebrates -- total macroinvertebrates, zooplankton, nekton	Much is known about creating habitat for waterfowl use and production. Dabblers use a variety of wetland types, favoring shallow, ephemeral wetlands with some emergent vegetation, but also using deep, permanent wetlands. Higher densities of macroinvertebrates increased brood use of created ponds, most or all of the macroinvertebrates were accessible to dabblers in the water column.
Barbour MT, Gerritsen J. 1996. Sub-sampling of benthic samples: A defense of the fixed-count method. J. North Am. Benthol. Soc. 15:386-391.	U.S.	Streams and wadeable rivers	Macroinvertebrates	The authors argue that subsamples, even a minimum of 100 individuals, does not compromise macroinvertebrate data quality. It is inconclusive whether this can relate to performance standards.

Invertebrate Articles Reviewed

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.	U.S.	Streams and rivers generally	Comments that use of invertebrates has major deficiencies, mostly relating to difficulty and expense	This is one of Karr's earliest articles, in which he first proposes the fish-based IBI. He argues for the evaluation of several major taxa in any IBI, and proposes an IBI that uses 12 fish community parameters, in two categories: species composition and richness and ecological factors. He observes that IBI descriptive accuracy requires an accurate baseline, a representative sample of the fish (or other target species) at the sample site and the larger geographic area of interest, and a scientist's ability to adjust the IBI to local conditions.
Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.	U.S.	Constructed wetlands	Polychaetes, crustaceans	The article finds that "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time." Limited data indicates that dredged marshes may support a different community of birds, and have lower or smaller values associated with belowground biomass, organic carbon levels, soil nutrient reservoirs, and abundance of polychaetes and crustaceans. Streever also warns against single-season sampling as a way of characterizing wetlands -- though this method is often employed in the literature. Article is particularly relevant because it questions the trajectory model for wetland development.

Invertebrate Articles Reviewed

Wilcox DA, Meeker JE, Hudson PL, Armitage BJ, Black MG, Uzarski DG. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. Wetlands 22(3):588-615.	U.S. region - Great Lakes, Midwest	Lake coastal wetlands	Macroinvertebrates	This study compared natural and constructed wetlands, examining nesting by the endangered light-footed clapper rail and associated trends in intertidal cordgrass (Spartina foliosa) growth. The author found that a marsh's failure to foster nesting primarily was caused by tidal inundation related insufficient cordgrass height and density, and predation. When evaluating marsh vegetation, the author recommends using cordgrass height distributions and density parameters, rather than canopy structure measures; grouping density and height distribution data together in a single indicator; and monitoring for an extended time period in order to account for interannual and spatial variability and lag effects. The author also points out that sampling methodology is critical for accurate assessment, and makes many suggestions concerning research design components.
Blocksom KA. 2003. A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic highlands streams. Environ. Manage. 31(5):670-682.	U.S. region - Mid-Atlantic	Streams	Macroinvertebrates	Study results found that the method for scoring metrics affects the outcome of the final index, particularly variablilty, and should be kept in mind when developing an index.

Invertebrate Articles Reviewed

Brooks RP, Cole CA, Wardrop DH, Bishel-Machung L, Prosser DJ, Campbell DA, Gaudette MT. 1996. Wetlands, wildlife, and watershed assessment techniques for evaluation and restoration (W3ATER). Vol. 1, 2A, and 2B, , Penn State Coop. Wetlands Ctr. Rep. No. 96-2, University Park. http://www.cas.psu.edu/docs/CASDEPT/FOREST/wetlands/Research/Publist.htm#1999	U.S. region - Mid-Atlantic		Macroinvertebrates	The authors state that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrate communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.
Brooks RP, O'Connell TJ, Wardrop DH, Jackson LE. 1998. Towards a Regional Index of Biological Integrity: The example of forested riparian ecosystems. Environ. Monitoring and Assessment 51(1-2):131-143.	U.S. region - Mid-Atlantic	Forested riparian ecosystems	Macroinvertebrates	State that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrates communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.

Invertebrate Articles Reviewed

Llanso RJ, Scott LC, Hyland JL, Dauer DM, Russell DE, Kutz FW. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the Untied States. II. Index Development. Estuaries 25(6A):1231-1242.	U.S. region - Mid-Atlantic (Delaware Bay estuary to Albemarle-Pamlico Sound)	Estuarine	Macroinvertebrates	This paper discusses the development of a benthic IBI to use in estuaries of the mid-Atlantic. Reference sites were selected and ranked as degraded or non-degraded based on dissolved oxygen, sediment contamination, and sediment toxicity criteria. The index correctly classified 82% of all sites. The authors caution that the application of the index to low salinity habitats require care, but overall, the index appeared to be quite reliable, with a high probability of correctly identifying both degraded and nondegraded systems and significant potential for use as a model for other regions and systems.
Lewis PA, Klemm DJ, Thoeny WT. 2001. Perspectives on use of a multimetric lake bioassessment integrity index using benthic macroinvertebrates. Northeastern Naturalist 8(2):233-246.	U.S. region - New England	Lakes -- impacted by anthropogenic disturbances	Macroinvertebrates	The authors developed a macroinvertebrate-based IBI to evaluate the biological integrity of 19 lakes in the Northeast. Lakes were classified according to size, temperature, and degree of anthropogenic disturbance. The bioassessment index successfully ranked the biological integrity for 17 or the 19 lakes, and this rate of success indicates that the index may be useful both in separating impacted from non-impacted lakes and, with modification, in assessing differences in wetland health.

Invertebrate Articles Reviewed

Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.	U.S. region - Pacific Northwest	Saltwater marshes -- restoration of multiple wetlands in multiple river sites	Insects	The authors argue that fish occurrence and abundance are not sufficient to measure mitigation success. Habitat assessment must be functional, not focused on structure. They suggest three types of metrics to assess wetlands -- capacity, opportunity, and realized function metrics. Also, assessment must address landscape and system attributes.
Morley SA, Karr JR. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Con. Bio. 16(6):1498-1509.	U.S. region - Pacific Northwest (Puget Sound basin)	Second- and third-order streams	Invertebrates compose the benthic index	The high variability in number of plant species and diversity index for reference wetlands found in this study supports other researcher claims that a population of wetlands should be used for comparison, rather than one reference wetland. This study specifically cautions against using just one wetland for these two indicators of plant diversity. For example, while the study found that the mean number of species was significantly less for constructed wetlands, it also found “considerable overlap between individual constructed and reference sites.”

Invertebrate Articles Reviewed

Davis S, Golladay SW, Vellidis G, Pringle CM. 2003. Macroinvertebrate biomonitoring in intermittent coastal plain streams impacted by animal agriculture. J. Environmental Quality 32(3):1036-1043	U.S. region - Southeast	Intermittent coastal plain streams -- impacted agricultural areas	Macroinvertebrates	Little data is available on the ecology of intermittent coastal plain streams in the southeastern United States. This study compared differences in biomonitoring metrics between reference and agricultural streams. The sites were physically and biologically similar during the intermittent period when natural stresses (i.e., stagnant water, high temperatures, and low dissolved oxygen) were high. The study compared biomonitoring metrics during the flow and intermittent flow periods.
Minello TJ, Able KW, Weinstein MP, Hays CG. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progression Series 246: 39-59.	U.S. region - various, but mainly Gulf and Atlantic Coast	Seagrass meadow, salt marsh, non-vegetated marsh, and open sea	7 decapods crustacean species	Review of data from 32 studies (world-wide, but mainly in US) to evaluate hypotheses about density, growth, and survival. The article mainly compares the value of salt marshes, seagrass meadows, and open water for the fostering (that is, the nursery capacity of each habitat) of nekton. It is not particularly useful for study of performance standards. It does emphasize the need to include metrics assessing growth rates of transient nekton in any performance standard, but discusses the problems associated with this inclusion -- no single good technique for measuring growth rates, problematic tidal dynamics, and others.

Bird Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Balian LV, Ghasabian MG, Adamian MS, Klem D Jr. 2002. Changes in the waterbird community of the Lake Sevan–Lake Gilli area, Republic of Armenia: a case for restoration. Biological Conservation. 106(2): 157-163.	International - Armenia	Lake	Birds	Authors of this article found loss of fish farming ponds is estimated to result in the loss of as much as 80% of the waterbird species breeding in Armenia. To address this problem, authors recommend the restoration of Lake Gilli and its extensive surrounding wetland area. Performance standards can benefit from this study because it addresses the importance of the relationship between wetlands and bird species and why it may be important to preserve wetlands or restore them to a healthy state.
Bolscher B. 1995. Niche requirements of birds in raised bogs: Habitat attributes in relation to bog restoration. In: Wheeler BD, Shaw SC, Fojt WJ, Robertson RA, eds. Restoration of Temperate Wetlands. John Wiley & Sons Ltd. Pp. 359-378.	International - Sweden	Bogs	Birds	The differences between the natural and rewetted bogs could result from geographic differences rather than rewetting effects. Study found that it is important to incorporate other aspects into a restoration project; rewetting is not the only necessity when restoring bogs. Soil restoration is also important.
Blair RB. 1996. Land use and avian species diversity along an urban gradient. Ecol. Appl. 6: 107-112.	State - California	Oak woodlands -- biological preserve, open-spaces, residential, office park, business district	Birds -- diversity, urban settings.	The bird community shifted in numbers from predominately native species to predominately non-native species as one moved closer to the urban areas. As sites became more urban the predevelopment bird would not appear as much. Location is very important when forming a wetland. From this study it seems that the more urban a region is then more invasive species are present.

Bird Articles Reviewed

Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.	State - California	Intertidal wetlands	Birds -- light-footed clapper rail and California least tern	Measures of individual species abundance and relative assemblage structure (fish) in constructed channels were not equivalent to those in natural wetlands. Soil salinity and nitrogen concentration (lack of) were linked to failure to replicate habitats of certain fish species. The proportion of two fish species differed significantly.
Rottonborn SC. 1999. Predicting the impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.	State - California	Riparian wetlands	Birds	The author concluded that urbanization is likely to cause a decline in neo-tropical species richness in riparian areas. The article is valuable for its discussion of the dynamics of bird community change.
Zedler JB. 1990. A Manual for Assessing Restored and Natural Coastal Wetlands with Examples from Southern California. Report. No. T-CSGCP-021. La Jolla: California Sea Grant College.	State - California (southern)	Salt marshes	Birds	Low available nitrogen and soil organic matter in constructed tidal marshes may be a key factor in poor performance outcomes.
Adamus PR. 1995. Validating a habitat evaluation method for predicting avian richness. Wildlife Soc. Bull. 23(4):743-749.	State - Colorado	Lowland and riparian wetlands	Birds -- avian richness	Study about the new avian richness evaluation method (AREM), which was tested at 76 wetlands and riparian areas for accuracy. Could be useful for performance standards to predict the viability of whether a constructed or restored wetland can sustain a livable habitat that would imitate that of the wetland it is replacing.

Bird Articles Reviewed

Cole CA. 1997. Study Raises Questions About Use of Restored Mangroves by Birds, Suggests Value of Organic Soil Amendments (Florida). Restoration and Management Notes 15(2):190 - 191.	State - Florida	Mangroves	Birds	Created wetlands did not have a well-developed substrate, a necessity for large, burrowing invertebrates. Without the proper habitat for invertebrates, the birds could not find food. Therefore, this wetland was not able to attract many species of birds. This paper implies the importance of providing a proper habitat for species within the entire food chain
Delphey PJ, Dinsmore JJ. 1993. Breeding bird communities of recently restored and natural prairie potholes. Wetlands 13: 200-206.	State - Iowa	Prairie potholes	Birds	Reference wetlands had the four types of vegetation normal for those wetlands. Restored wetlands were missing some of these types of vegetation. Restored wetlands may need more time for the other types of vegetation to emerge.
Fairbairn SE, Dinsmore JJ. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21(1):41-47	State - Iowa	Prairie potholes	Birds	EMERG% was the most important variable that was measured in this study when analyzing species richness; wetlands with much emergent vegetation typically have several veg zones and are more likely to support a diverse bird community. Migrating birds use general features of the landscape to decide whether to further investigate the land for nesting.

Bird Articles Reviewed

VanRees-Siewert KL, Dinsmore JL. 1996. Influence of wetland age on bird use of restored wetlands in Iowa. Wetlands 16:577-582.	State - Iowa	Prairie wetlands	Birds	The mean number of breeding bird species was significantly greater in older restored wetlands, although the mean number of all bird species (breeding and non-breeding) did not change with restored wetland age. If goal of wetland restoration is to simply provide breeding sites for waterfowl, then this target can be reached in a few years. However, the authors favor long-term restorations as these are more likely to create more diverse bird communities that resemble those in natural wetlands. Percent cover of vegetation, wetland age, and wetland area affected bird community composition.
Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.	State - Maine	Isolated vernal pools	Birds -- sparrows and song sparrows	Following loss of small wetlands, elevated extinction risk response for 3 of the 5 taxa. The most dispersive taxa studied, turtles and birds, were most prone to extinction. Small wetlands are likely critical for the maintenance of taxa endemic to those habitats.
Hotaling NEM, Kuenzel WJ, Douglass LW. 2002. Breeding season bird use of restored wetlands in eastern Maryland. Southeastern Naturalist 1(3):233-252.	State - Maryland	Restored emergent wetlands and associated adjacent habitats (woodlots, fields, hedgerows)	Birds	The study looked at breeding bird species richness, abundance, and diversity in 21 restored wetlands in woodlots, cultivated and uncultivated fields, and hedgerows, on Maryland's Eastern Shore for two years. Bird abundance, species richness and diversity were higher in restored wetlands at the end of second year of study. The authors caution that although resorted emergent wetlands provided habitat for wetland birds, the benefit of restored habitat must be weighed against the loss of habitats converted into wetlands.

Bird Articles Reviewed

Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.	State - Massachusetts	Forested wetlands	Birds -- breeding	Study concluded that deciduous wetlands provide healthy breeding grounds for a diverse, dense population of birds. Results also showed bird populations to be positively correlated with vegetation and surface hydrology. Bird community characteristics could serve as indicators for these latter wetland components.
Hanowski JM, Christian DP, Nelson MC. 1999. Response of breeding birds to shearing and burning in wetland brush ecosystems. Wetlands 19(3):584-593.	State - Minnesota	Shrub-scrub wetlands -- 58 managed wetlands; burned and sheared	Birds	Breeding birds were surveyed in managed and unmanaged shrub/scrub wetlands for 2 years to examine the bird responses to management and the time elapsed since management. There were more shrub/scrub birds in the unmanaged area and more emergent habitat species in managed areas.
Lechisin DA, Williams GL, Weler MW. 1992. Factors affecting waterfowl use of constructed wetlands in northwestern Minnesota. Wetlands 12:178-183.	State - Minnesota	Constructed wetland	Birds -- waterfowl	The authors found that wetlands with larger surface area and longer shoreline length had greater pair use by all the ducks recorded except gadwall. They conclude that "the importance of wetland size, spacing and density suggests that pair spacing behavior may influence which wetlands receive the most use." This article highlights the influence of HGM factors on the use of wetlands by wildfowl, and implies that HGM factors should be considered in both design and performance standards.

Bird Articles Reviewed

Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressional wetlands	Birds -- 171 bird taxa	Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.
Farley GH, Ellis LM, Stuart JN, Scott NJ Jr. 1994. Avian species richness in different-aged stands of riparian forest along the middle rio grande, new Mexico. Conservation Biology 8(4):1098-1108	State - New Mexico	Riparian forests	Birds	As observed, it is important to maintain vegetation of different ages in these riparian areas. Localized revegetation efforts may be a useful method to maintain avian richness in this riparian ecosystem to control non-native species and enhance the native species there.

Bird Articles Reviewed

Brown SC, Smith CR. 1998. Breeding season bird use of recently restored versus natural wetlands in New York. J. Wildl. Manage. 62(4):1480-1491.	State - New York	Natural and constructed wetlands	Birds	The study looked at relative abundance and density of birds restored and natural wetlands. Bird abundance and densities did not differ between restored and natural wetlands over the course of three years. Bird communities were found to be significantly different between restored and natural sites. Although the wetland restoration project successfully increased the amount of available bird habitat in the region, the restored wetlands did not replace the natural wetland habitat functions in the three years following the study. Appropriate plant communities are important in replacing habitat function.
Brown SC. 1999. Vegetation similarity and avifaunal food value of restored and natural marshes in northern New York. Restoration Ecology 7(1): 56-68.	State - New York	Natural marshes	Birds	The lower slope of the restored wetlands probably contributed to the greater vegetation cover there than in the reference wetlands. However, cattail, an invasive species, was very prevalent on the restored wetlands. The restored wetlands differed from the reference ones significantly with few wetland species and much less cover of wetland plants. This result may be because before restoration the wetland was drained. There should be an understanding of previous conditions before restoring a wetland so that restoration techniques can be implemented successfully.

Bird Articles Reviewed

Ratti JT, Rocklage AM, Giudice JH, Garton EO, Golner DP. 2001. Comparison of avian communities on restored and natural wetlands in North and South Dakota. Journal of Wildlife Management 65(4): 676-684.	State - North and South Dakota	Marshes	Birds	The study found that restored wetlands in North and South Dakota had higher bird density than the natural wetlands. However, the authors caution that no conclusions can be drawn about effectiveness of restored wetlands in fostering bird communities until more comprehensive research has been done. The article provides an example of how bird communities might be used in performance metrics.
Austin JE, Sklebar T, Guntenspergen GR, Buhl TK. 2000. Effects of Roadside Transect Width on Waterfowl and Wetland Estimates. Wetlands. 20(4): 660-670	State - North Dakota	Prairie potholes	Birds -- waterfowl	Results indicate that the distributions of basins were biased most strongly on the transect width closest to the road. strip transects along the road provide biased representation of the larger landscape
Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030	State - Ohio	Created and restored wetlands	126 bird species	The authors seeded one created wetland and left the other unseeded, hypothesizing (based on self-design and self-organization theory) that the two hydrologically similar wetlands would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. After three years, both sites had relatively similar numbers of species (65 versus 54), similar nutrient levels, and similar diversity indices, though the benthic taxon richness was higher in the planted wetland. The study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward functionality (though both experimental wetlands did receive a regulated water supply). The article is relevant to design standards and performance standards based on developmental trajectories.

Bird Articles Reviewed

Buffington JM, Kilgo JC, Sargent RA, Miller KV, Chapman BR. 2000. Effects of restoration techniques on the breeding bird communities in a thermally-impacted bottomland hardwood forest. Ecol. Eng. 15: S115–S120.	State - South Carolina	Bottomland hardwood forest	Birds -- breeding birds	The greater abundance of Red-winged Blackbirds in the lower section versus the upper section likely reflects a gradual change in vegetation downstream. The vegetation there was shorter and there were more frequent grassy openings. This study shows how different species of birds can be indicators of wetland functions.
Naugle DE, Johnson RR, Estey ME, Higgins KF. 2001. A landscape approach to conserving wetland bird habitat in the prairie pothole region of eastern South Dakota. Wetlands 21(1):1-17.	State - South Dakota	Prairie potholes	Birds	The authors observed that human-induced modifications in upland habitats are related to processes within wetland complexes. The authors speculate on and recommend further research into influences of grassland patch size, grassland structure within patches, and configuration of multiple grassland patches on wetland bird use and productivity. Potential may exist to use bird metrics as indicators of vegetation status, and vice-versa.
Ellison LC. 2000. Ecology of a restored wetland in the Trinity River floodplain of Texas. Ph.D. Dissertation. Texas A&M University.	State - Texas	Restored wetlands	Birds	The similarity of Avian community did not correlate with the similarity of habitat in neither winter nor summer. This result may cause problems for those who use birds as an indicator of restoration success. This result also implies that interspecific competition does not drive the structuring of wetland avian communities. Alternatively, this result may reveal the inability of this method to detect the influence of habitat variation on avian community structuring. Careful water management may preserve the grass substrate, thereby optimizing benefits to cattle and water birds.

Bird Articles Reviewed

Melvin SL, Webb JW. 1998. Differences in the avian communities of natural and created Spartina alteriflora salt marshes. Wetlands 18:59–69.	State - Texas (Galveston Bay)	Constructed and natural wetlands	Birds -- community structure	The study found that natural wetlands supported more migratory birds and greater species diversity, whereas created wetlands supported more gulls and terns, with major population spikes in March and May. The authors speculate that the difference probably due to lack of habitat diversity and microhabitats associated with the created wetlands. The results indicate that species composition, diversity, and abundance could be viable taxonomic-type metrics.
Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.	State - Virginia	Tidal marsh	Birds -- utilization	The study examined various elements of constructed and natural wetlands. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush, and use by birds. A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.

Bird Articles Reviewed

Creighton JH, Sayler RD, Tabor JE, Monda MJ. 1997. Effects of wetland excavation on avian communities in eastern Washington. Wetlands 17(2):216-227.	State - Washington	Shallow wetlands -- excavated wetlands that are now permanent shallow wetlands that were once shallow	Birds	The authors compared zooplankton biomass and bird densities in vegetation-filled wetlands excavated to create open water with untreated wetlands. Bird densities differed between excavated and untreated wetlands. Densities of yellow-headed blackbirds were greater on excavated wetlands, while densities of red-winged black birds, Sora, and Virginia rails were greater on unaltered sites. Zooplankton was greater on altered and older excavation sites than in unaltered sites. Study suggests that managers maintain a mix of wetland habitats at the landscape scale to improve population management of diverse wetland bird species. Vegetation was a key factor in determining bird communities, densities, and zooplankton biomass.
Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Birds -- occurrence and density	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.

Bird Articles Reviewed

Cooper CB, Anderson SH. 1996. Significance of invertebrate abundance to dabbling duck brood use of created wetlands. Wetlands 16(4): 557-563.	State - Wyoming	Emergent wetlands	Birds -- dabbling ducks	Much is known about creating habitat for waterfowl use and production. Dabblers use a variety of wetland types, favoring shallow, ephemeral wetlands with some emergent vegetation, but also using deep, permanent wetlands. Higher densities of macroinvertebrates increased brood use of created ponds, most or all of the macroinvertebrates were accessible to dabblers in the water column.
Bartoldus CC. 1999. A Comprehensive Review of Wetland Assessment Procedures: A Guide for Wetland Practitioners. Environ. Concern Inc.	U.S.		Birds	An extensive introduction to 40 different wetland assessment procedures that provide a procedure for identifying, characterizing, or measuring wetland functions and/or social benefits. A very useful book for those involved with wetland assessment.
Ehrenfeld JG. 2000. Defining the limits of restoration: the need for realistic goals. Restor Ecol 8:2-9.	U.S.	Urban wetlands	Birds -- example using Light-footed Clapper Rail	It is important to recognize diversity of conditions so need to have flexibility. Because language is not precise and restoration goals are likely to have different meanings to different players, there needs be a good mechanism to specify goals. There is a problem with species restoration and techno-arrogance when efforts to restore a particular species might negatively affect co-occurring species (microbial, floral, and faunal) that make up the ecosystem. The author points out that restoring one particular service may preclude the provision of other services.

Bird Articles Reviewed

Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.	U.S.	Constructed wetlands	Birds	The article finds that "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time." Limited data indicates that dredged marshes may support a different community of birds, and have lower or smaller values associated with belowground biomass, organic carbon levels, soil nutrient reservoirs, and abundance of polychaetes and crustaceans. Streever also warns against single-season sampling as a way of characterizing wetlands -- though this method is often employed in the literature. Article is particularly relevant because it questions the trajectory model for wetland development.
U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-023.	U.S.	NA	Birds	The development of a IBI for birds is still in its earliest stages, but birds may detect aspects of wetland landscape condition not detected by other commonly used biological indicators. A bird IBI can reveal the condition of ecological systems at wetland site or in the larger landscape (that is, measure landscape integrity); bird IBIs can indicate changes in vegetation structure and diversity, hydrology, salinity, and water quality. The development of a good index requires an understanding of home range sizes and the ecology of target species.

Bird Articles Reviewed

Brooks RP, Cole CA, Wardrop DH, Bishel-Machung L, Prosser DJ, Campbell DA, Gaudette MT. 1996. Wetlands, wildlife, and watershed assessment techniques for evaluation and restoration (W3ATER). Vol. 1, 2A, and 2B, , Penn State Coop. Wetlands Ctr. Rep. No. 96-2, University Park. http://www.cas.psu.edu/docs/CASDEPT/FOREST/wetlands/Research/Publist.htm#1999	U.S. region - Mid-Atlantic		Birds	The authors state that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrate communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.
Brooks RP, O'Connell TJ, Wardrop DH, Jackson LE. 1998. Towards a Regional Index of Biological Integrity: The example of forested riparian ecosystems. Environ. Monitoring and Assessment 51(1-2):131-143.	U.S. region - Mid-Atlantic	Forested riparian ecosystems	Birds	State that measures of ecological indicators and habitat conditions will vary between reference standard and reference impacted sites. Paper illustrates how 4 bioindicators (macroinvertebrates communities, amphibian communities, avian communities, and avian productivity) could be combined to develop an RIBI for forested ecosystems in the Mid-Atlantic states.

Algae Articles Reviewed

Title / Reference information	**Region**	**Wetland type**	**Parameter**	**Comments**
Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.	State - California	Salt marsh	Algae -- focuses on soil amendments, soil composition and relation to nutrient absorption	A constructed marsh had significantly lower levels of nitrogen and organic matter than an adjacent natural marsh. Article sites others which say that constructed marshes may take 15-30 years to develop nitrogen and organic carbon pools equal to those of natural salt marshes. Organic amendments did not increase soil organic content. Soil nitrogen showed few differences that were related to soil amendments. It is unclear whether these marshes need more time or if the amendments are not sufficient.
Harig A, Bain M. 1998. Defining and Restoring Biological Integrity in Wilderness Lakes. Biological Applications 8(1): 71-87.	State - New York (Adirondacks)	Small lakes	Algae -- phytoplankton	Lake communities with high biological integrity were characterized by native fish communities, zooplankton communities, biomass, larger species, and phytoplankton communities. Authors constructed an IBI with six indicators. The species composition of these communities gave the earliest sign of disturbance. Like other articles on small water bodies, there was an indication that they need to rely on multiple taxa to produce sensitive indices.

Algae Articles Reviewed

Mayer PM, Galatowitsch SM. 2001. Assessing ecosystem integrity of restored prairie wetlands from species production-diversity relationships. Hydrobiologia 443 (1-3): 177-185.	State - South Dakota	Prairie wetlands	Diatoms	The authors did not detect a difference in diversity or production between restored and reference wetlands. Production was negatively related to diversity at the restored wetland, but production the reference wetlands was not. Production was dependent on species composition. Based on this finding, the authors concluded that the relationships between diversity and production could be used as a performance standard between restored and reference wetlands.
Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Sediment microalgae	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.

Algae Articles Reviewed

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.	U.S.	Streams and rivers generally	Diatoms	This is one of Karr's earliest articles, in which he first proposes the fish-based IBI. He argues for the evaluation of several major taxa in any IBI, and proposes an IBI that uses 12 fish community parameters, in two categories: species composition and richness and ecological factors. He observes that IBI descriptive accuracy requires an accurate baseline, a representative sample of the fish (or other target species) at the sample site and the larger geographic area of interest, and a scientist’s ability to adjust the IBI to local conditions. Comments that use of diatoms has major deficiencies, mostly relating to difficulty, lack of background information/research
Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf	U.S.	Freshwater wetlands	Algae	The authors generally are not positive about using algae as a reliable indicator. They note that "The exact nutrients that contribute to algal community shift are often difficult to identify due to correlation among many nutrients. . .chemical constituents of water, particularly pH altering bicarbonates, can regulate the response of algae to nutrient additives" etc. If algae are to be used, they say that: species composition is a better measure than biomass in most cases; identifying algae at the genus level or coarser is both useful and perhaps the only practical way of using algae as an indicator; and they recommend grouping species per their reputed tolerances and using the group as an indicator (via weighted average regression analysis) in order to reduce problems associated with variability.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Algae to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-021.	U.S.	NA	Algae	This documents spells out why algae are widely used indicators of biological integrity and physio-chemical conditions in wetland systems. "Species composition of algae, particularly diatoms, is commonly used das an indicator of biological integrity of wetlands and the physical and chemical conditions in wetlands." Sampling methods for algae on plants and sediment are well established. although there are no IBIs for algae at date of report. Authors note that algae characteristics can vary considerably among habitats within a wetland and that sensitivity to environmental change may also vary, thus algae must be sampled in a consistent manner across wetlands to assess changes precisely.
U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Vegetation to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.	U.S.	Wetlands generally	Algae	The reviewed section focuses on the problems associated with high variability of algal communities, between and within wetlands, and makes recommendations for use of algae as indicators: researchers should use taxonomic measures rather than metabolic measures, engage in composite sampling in order to diminish problems associated with variability/sensitivity, carefully choose algal indicators because algae are responsive to multiple specific stressors, and engage in repeat sampling to reduce variability effects. The article notes a need for a more precise characterization of expected algal conditions in wetlands, that algal indicator choice should depend on whether research interest is short or long-term, and that evaluative techniques that use introduced substrate/lab tests can eliminate some variability.

Algae Articles Reviewed

Dixit SS, Smol JP, Charles DF, Hughes RM, Paulsen SG, Collins GB. 1999. Assessing water quality changes in the lakes of the northeastern United States using sediment cores. Canadian Journal of Fisheries and Aquatic Science 56(1): 131-152.	U.S. region - Adirondacks, New England Uplands, Coastal Lowlands/Plains	Lakes	Algae -- 406 diatom taxa identified from study sites; 235 were common	The top-layer diatoms represented present-day conditions, and bottom-layer samples represented reference conditions. The values were compared site by site. The authors discuss the advantages of sediment core sampling: it can be collected during any window, it is not influenced by time of year, it integrates diatoms from many habitats within lake. Ca, Cl, TP, depth, pH, and macrophytes were significant algal influences, accounting for 66% if variance. Authors developed inferred models for pH, TP, and Cl. They discuss how optimum values for algae were calculated and how the predictive ability for inferred models were tested.
Hill BH, Herlihy AT, Kaufmann PR, Stevenson RJ, McCormick FH. 2000. The use of periphyton assemblage data as an index of biotic integrity. J N Am Benthol Soc 19:50-67.	U.S. region - Eastern	Streams and rivers	Algae	PIBI and component metrics worked well as an index for monitoring ecological integrity conditions in streams in eastern U.S. There is a question to whether this supports use of this index in lentic waterbodies.
McNair SA, Chow-Fraser P. 2003. Change in biomass of benthic and planktonic algae along a disturbance gradient for 24 Great Lakes coastal wetlands. Can. J. Fisheries and Aquatic Sciences 60(6):676-689.	U.S. region - Great Lakes	Coastal wetlands -- 24 sites representing a range of environmental conditions	Periphytic and planktonic algae	The authors sampled a range of wetlands from low to high functioning, assessing water quality, species, percent cover of submerged macrophytes, and chlorophyll content of planktonic algae and benthic algae. They concluded that "periphytic and planktonic chlorophyll biomass are good indicators of human-induced water-quality degradation, " and recommend that both benthic and planktonic algal biomass be routinely monitored as part of an effective wetland management program.

Mammal Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.	State - Maine	Isolated vernal pools	Mammals -- Small mammals; water shrews	Following loss of small wetlands, elevated extinction risk response for 3 of the 5 taxa. The most dispersive taxa studied, turtles and birds, were most prone to extinction. Small wetlands are likely critical for the maintenance of taxa endemic to those habitats.
Jorgensen EE. 2002. Small mammals: consequences of stochastic data variation for modeling indicators of habitat suitability for a well-studied resource. Ecological Indicators 1(4):313-321.	U.S.	NA	Small mammals	The article provides a summary on stochastic data variation in small mammal data -- specifically, small mammal data are affected by capture technique. The author also notes that population abundance exhibits ecologically important and often high spatial and temporal variability. These considerations are relevant to sampling and data-gathering that would inform the specification of performance standards.
Morley SA, Karr JR. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Con. Bio. 16(6):1498-1509.	U.S. region - Pacific Northwest (Puget Sound basin)	Second- and third-order streams	Mammals	The high variability in number of plant species and diversity index for reference wetlands found in this study supports other researcher claims that a population of wetlands should be used for comparison, rather than one reference wetland. This study specifically cautions against using just one wetland for these two indicators of plant diversity. For example, while the study found that the mean number of species was significantly less for constructed wetlands, it also found “considerable overlap between individual constructed and reference sites.”

Vegetation Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Burchett MD, Allen C, Pulkownik A, Macfarlane G. 1999. Rehabilitation of Saline Wetland, Olympics 2000 Site, Sydney (Australia)—II: Saltmarsh Transplantation Trials and Application. Marine Pollution Bulletin 37(8-12):526-534.	International - Australia	Salt marshes -- transplant experiment	Vegetation -- above-ground biomass index	The aim of this study was to determine best transplantation techniques for salt marsh species (3 of which were rare). The spring/summer transplant had slightly higher survival and rooting rates as well as better field survival and growth rates. More detailed survival descriptions along elevation gradients are provided for the 6 species transplanted, as well as for colonizers. Rare species were not among the colonizers observed in the study even though species existed nearby; found that the mangrove belt clearly delineated by the low water mark and the mean high tide mark & the salt marsh zone between the mean high and the high-high tide marks; substrate should be similar to natural wetland communities rather than the sandy fill used in the experiment, which may have skewed the results, especially for the rare species.
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh	Vegetation	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.

Detenbeck NE, Galatowitsch SM, Atkinson J, Ball H. 1999. Evaluating perturbations and developing restoration strategies for inland wetlands in the Great Lakes Basin. Wetlands 19(4):477-489.	International - Canada	Freshwater palustrine wetlands	Vegetation	The paper presents a detailed example of restoration strategies for the Great Lakes Basin. In this study, the highest ranking impacts were sedimentation/turbidity, retention time, eutrophication, and changes in hydrologic timing. Responses to disturbance activities included shifts in plant species composition, reduction in wildlife production, increased flood peaks/frequency, increased above ground production, decreased water quality downstream, loss of aquatic plant species with high light compensation points. The authors recommend that restoration goals be based, at a minimum, on information on historic patterns of wetland distribution and loss, land-use changes and activities responsible for wetland loss and degradation, and knowledge of habitat requirements for wetland-dependent species or special concern and common species.

Weiher E, Wisheu IC, Keddy PA, Moore DRJ. 1996. Establishment, persistence, and management implications of experimental wetland plant communities. Wetlands 16(2):208-218.	International - Canada (Ontario)	Riverine and lacustrine wetlands	Vegetation	The authors examined the importance of seed banks in wetland restoration. They inoculated 120 wetland microcosms representing 24 different environmental treatments with seeds from 20 wetland plant species; seeds were selected to represent a range of morphologies and life history types. After five years only six plant species were found in large numbers on the microcosms and Lythrum was one of those species. The rapid loss of species suggests that in the absence of disturbance, competitive exclusion by Lythrum can occur within five years. Flooding and fertility remained the main factors affecting species composition. Study results suggest that high diversity, low biomass wetlands will be difficult to create; therefore, protection of such wetlands may deserve a higher priority.
Henry CP, Amoros C, Roset N. 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhone River, France. Ecological Engineering 18:543-554.	International - France (Rhone River)	Riverine wetlands	Vegetative composition, name of species seen and change in species seen	The study concludes that a restored system that was neither stable or self-sustaining 2 years after restoration achieved both goals within 5 years. The authors emphasize that this success would not have been noted without monitoring that extended beyond 2 years (a short time period wherein monitoring results were influenced by hydrologic and climatic variability), and argue for longer assessment periods. The articles discusses the use of Principle Component Analysis (PCA) to delineate zones within the channel based on vegetative composition and assess and project temporal trajectories for changes in vegetation; PCA might be a useful tool in specification of performance standards.

Odland A. 2002. Patterns in the secondary succession of a Carex vesicaria L. wetland following a permanent drawdown. Aquatic Botany 74:233–244 235.	International - Norway	Sedge marsh -- natural wetland disturbed/altered by a drawdown	Percent cover, number of flowering shoots	This study analyzed the vegetative secondary successional changes that occurred following a permanent drawdown of a lake. The main trend was a gradual decreased cover of C. vesicaria and an increase in the cover of P. arundinacea and C. purpurea, and a linear decrease in the number of C. vesicaria's fertile shoots. The study concluded that a clonal wetland sedge may survive a major drawdown for more than 14 years, and demonstrates that permit conditions should probably take into account the effect of hydrologic extremes over the years on species compositions in floodplains.The authors contend that flowering/fertile shoot counts and flowering frequencies of these species can indicate healthy or unhealthy wetland functioning, though the values can be variable due to the plants' sensitvity to environmental factors; nonetheless, in a stressed environment, these metrics are more accurate measures of species performance than vegetative cover alone.
Amoros C, Bornette G, Henry CP. 2000. A vegetation-based method for ecological diagnosis of riverine wetlands. Environ. Manage. 25(2):211-227.	International - Rhone River	Riverine wetlands	Vegetation -- aquatic macrophytes	Authors promote the use of aquatic macrophytes and helophyte as a method of ecological health of riverine systems. Plant communities were recommended because they are easy to survey and provide information on the origin of water supply (groundwater, seepage, surface river water), water nutrient content, effects of flood disturbances, and the terrestrializaton processes. This paper is not relevant to our study and should be deleted from the bibliography.

Vegetation Articles Reviewed

Kaenel-Barbara R. 1998. Effects of plant cutting and dredging on habitat conditions in streams. Hydrobiologica. 143(3):257-273.	International - Switzerland	Streams	Vegetation	The study measured plant biomass and physical parameters before and after plant removal in two streams. Accumulation of fine sediments did not change, but spatial heterogeneity and habitat parameters varied with plant biomass in both streams. The author notes that "Plant and habitat conditions exhibited different recovery trajectories in the two streams, with faster recovery in streams where plants were cut before flowering." The article's discussion of vegetative recovery trajectories is informative.
Henry CP, Amoros C. 1996. Restoration ecology of riverine wetlands. III. Vegetation survey and monitoring optimization. Ecological Engineering 7(1):35-58.	NA	Riverine wetlands	Species richness, total vegetative cover, floristic composition	The authors evaluated the effects of restoration on a dredged channel and found that the system was non self-sustaining after 2 years, due to poor colonization and lack of vegetative cover. Concerning performance standards, the authors suggest that because different parts of the restored channel often behave differently, performance standards may need to be modified within the marsh to account for temporal and reach differences; multiple transects are necessary for the sampling that informs performance standards, and sampling should occur at least 3 times and account for seasonal patterns; and changes in floristic composition (in whic ase, from eutrophic to mesotrophic species) could be a success indicator, if adjusted for local conditions.

Vegetation Articles Reviewed

Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.	State - California	Salt marshes	Vegetation	The intertidal area of the mitigated (created) marsh was dominated by eurhaline sticklebacks and topsmelts. This area did not replace the intertidal and subtidal habitat of the natural marsh, which had more stable salinity and water temperatures and was used extensively by juvenile English sole. Possible performance indicators include (1) stability of salinity and water temperatures relative to a reference/control site, and (2) fish composition -- numbers of juvenile sole vs. other species.
Clairain EJ Jr. 2000. Ecological models for assessing functions of hard claypan vernal pool wetlands in the Central Valley of California using the hydrogeomorphic (HGM) approach for wetland assessment. Ph.D. Dissertation. The Louisiana State University and Agricultural and Mechanical College.	State - California	Vernal pools	Vegetation	The conclusions drawn from the analysis indicated that three variables (disturbance quotient, maximum depth, and percent native to nonnative plant species) were proven to best assess relative disturbance. Five wetland functions were identified as being relevant to vernal pools and ecological models were developed for each function. The ecological models can be used to assess the capacity of wetlands to perform different functions, calculate project impacts on those functions, compute mitigation requirements to offset unavoidable impacts, and assess mitigation success.

Vegetation Articles Reviewed

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.	State - California	Salt marsh	Vegetation biomass, height and density of Spartina foliosa	A constructed marsh had significantly lower levels of nitrogen and organic matter than an adjacent natural marsh. Article sites others which say that constructed marshes may take 15-30 years to develop nitrogen and organic carbon pools equal to those of natural salt marshes. Organic amendments did not increase soil organic content. Soil nitrogen showed few differences that were related to soil amendments. It is unclear whether these marshes need more time or if the amendments are not sufficient.
Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.	State - California	Intertidal wetlands	Vegetation to restore the endangered salt marsh bird's beak (plant)	Measures of individual species abundance and relative assemblage structure (fish) in constructed channels were not equivalent to those in natural wetlands. Soil salinity and nitrogen concentration (lack of) were linked to failure to replicate habitats of certain fish species. The proportion of two fish species differed significantly.
Sanderson EW, Foin TC, Ustin SL. 2001. "A simple empirical model of salt marsh plant spatial distributions with respect to a tidal channel network." Ecological Modeling 139: 293-307.	State - California	Tidal salt marshes	Channel size and location as main predictors of vegetative species distribution	Study applied an ecological model to a marsh area with known vegetative parameters and assessed the accuracy of the model. Researchers found a large distribution of species in the large channels and a small distribution of species in the smaller channels. Distribution of species predicted by CISD conformed well with prior independent observations of the marsh area studied however results are highly dependant on the model form. Further study needs to be done.

Vegetation Articles Reviewed

Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restoration Ecol 7:69-73.	State - California	Salt marshes	Measures of plant growth and plant canopies	The constructed and reference sites exhibited high interannual variation and lack of directional change for the variables studied, and results suggest little chance that relevant targets for the restoration sites would be met in the near future. The authors argue that hypothetical models that suggest restoration and creation sites follow a smooth path of development toward conditions in natural reference sites, though rampant in the literature, are generally wrong-headed. They suggest alternative management and mitigation models and policies.
Scataloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16(1): 24-37.	State - California (San Diego Bay)	Salt marshes	Vascular plant coverage; abundance	The natural, fully-vegetated marsh studied by the authors had two to three times as many individuals (epibenthics) as the four-year-old constructed marsh. The articles hypothesize that coarser sediment, lower organic matter, and relatively more sparse vegetative cover were potential causes of the significantly lower abundance in constructed marshes. The article suggests that epibenthic populations can serve as indicators for soil and vegetative wetland components, and also emphasizes the influence of these components on wetland development generally.

Vegetation Articles Reviewed

Talley TS, Levin LA. 1999. Macrofaunal Succession and Community Structure in Salicornia Marshes of Southern California. Estuarine, Coastal and Shelf Science 49(5):713-731.	State - California (Southern)	Salt marshes	Vegetation composition, belowground biomass	This study examined macrofaunal assemblage succession and the effect of vegetation and sediment attributes on assemblages in natural and created Salicornia marshes. It also comments on differences between Spartina and Salicornia marshes and the applicability of research concerning either type to the other. The study asserts that physical disturbance, rather than marsh age, may be a significant determinant of differences between created and natural wetlands. The development trajectories identified in the study indicate an increasing similarity between the created and natural marsh assemblages over time, but the authors conclude that faunal development in the created marshes toward natural conditions may require ten years or more, and "functional characteristics such as food web support, nutrient cycling, population size structure or parasites loads may remain different.”

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Zedler JB. 1993. Canopy architecture of natural and planted cordgrass marshes: selecting habitat evaluation criteria. Ecological Applications 3(1)123–138.	State - California (Southern)	Salt marshes	Percent cover, biomass, height and density	This highly useful study looked at nesting vegetative requirements of intertidal cordgrass (Spartina foliosa) marshes for the endangered light-footed clapper rail that could be used for mitigation performance standards. It found that nesting failure, in either constructed or natural marshes, was primarily caused by tidal inundation due to inadequate cordgrass heights or densities, and predation. The study concluded that cordgrass height distributions and density parameters were more effective as measures of canopy structure than biomass, TSL, or other more commonly-used measures. It also focused on sampling methodology, noting that typically high variability (interannually and spatially) requires several years of monitoring and the use of many reference wetlands, that sampling must be carefully executed in cases where Type II errors will have serious environmental consequences, and specific considerations for measuring height and density. Finally, it identified factors important for attracting rails to constructed wetlands.
Brawley AH, Warren RS, Askins RA. 1998. Bird use of restoration and reference marshes within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. Environ. Manage. 22(4):625-633.	State - Connecticut	Estuarine, tidal marsh	Vegetation	This study compared restored tidal marshes to control site. Study found that reintroduction of tidal flooding can effectively restore important ecological functions to previously impounded tidal marshes based on vegetation, macroinvertebrate, and fish species richness and frequency.

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David PG. 1999. Response of exotics to restored hydroperiod at Dupuis Reserve, Florida. Restoration Ecology 7(4): 407-410.	State - Florida	Emergent freshwater marsh	Vegetation -- coverage, frequency of occurrence, density	This paper is about hydrology as it related to controlling/engorging native and exotic wetland vegetation. The ditch plugs used to create hydroperiods were able to bring back native species to the wetland and nearly eliminate the invasive species. Existing seeds in nearby wetlands may have provided existing seeds/plants. The author illustrates how important hydrologic function is to vegetation in a wetland.
Lewis RR. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. Ecological Engineering 15(3-4):191-198.	State - Florida	Mangrove forest and tidal marshes	Vegetation	This review paper focused on goals of marsh and mangrove restoration projects in southern Florida and claims that though these goals now typically seek functional equivalency and ecological restoration, rather than more simplistic aims (such as establishment of persistent vegetative cover), political will does not exist to properly fund wetland compensatory mitigation programs; thus, programs are unlikely to effectively meet new goals. The authors comment on multiple flaws of the Florida restoration projects, and their observations are highly relevant to improving design standards. They observe that because the science of functional analsys has lagged behind permitting for construction of mitigation wetlands, goal setting and success criteria based on functionality have been set in ad hoc and inconsistent manners -- and recommend that generally accepted criteria based on functionality be set and applied by managers who have been given effective training and understand principles of adaptive management.

Vegetation Articles Reviewed

Chambers JC, Brown RW, Williams BD. 1994. An evaluation of reclamation success on Idaho's phosphate mines. Restoration Ecology 2:4-16.	State - Idaho		Vegetation	Both soil and scrub/grass vegetation on spoil from phosphate mines were examined after rehabilitation. They found that after four years there was no difference in biomass and species composition between the spoil treatments and the control treatments on different soil types. However, after fourteen years seeded and mulched reclamation treatment plots had a better cover and biomass than other treatments and controls. A number of soil properties showed that the reclamation methods were responsible for soil differences and consequently the differences in plant species composition and biomass."
Delphey PJ, Dinsmore JJ. 1993. Breeding bird communities of recently restored and natural prairie potholes. Wetlands 13: 200-206.	State - Iowa	Prairie potholes	Vegetation	Reference wetlands had the four types of vegetation normal for those wetlands. Restored wetlands were missing some of these types of vegetation. Restored wetlands may need more time for the other types of vegetation to emerge.
Fairbairn SE, Dinsmore JJ. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21(1):41-47	State - Iowa	Prairie potholes	Vegetation	EMERG% was the most important variable that was measured in this study when analyzing species richness; wetlands with much emergent vegetation typically have several veg zones and are more likely to support a diverse bird community. Migrating birds use general features of the landscape to decide whether to further investigate the land for nesting.

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Galatowitsch SM, van der Valk A. 1996. The vegetation of restored and natural prairie wetlands. Ecol Appl 6:102-112.	State - Iowa	Prairie potholes	Vegetation	The study demonstrated that rewetting a wetland was not enough to support all the native species after three years. After restoration natural wetlands had a mean of 46 species compared to 27 species in restored wetlands. The patterns of recolonization appeared to be a factor of seed dispersal ability rather than an efficient-community situation. This suggests that revegetation and restoration recovery will be affected by proximity to a propogate source and by additional seeding or planting. Since it is almost impossible to have an effective dispersal of seeds to these isolated wetlands of today revegetation becomes an essential restoration tool.
Morgan PA, Short FT. 2002. Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restoration Ecology 10(3):461-473.	State - Maine and New Hampshire	Salt marsh	Vegetation	The study found that overall, mean values for constructed wetlands were significantly lower than natural reference values for aboveground biomass, soil organic matter content, and plant species richness. However, the study supports functional trajectory development via "space-for-time substitution" (that is, comparing marshes of different ages rather than one marsh over many years): it found that some wetland functions (primary production, sediment deposition, plant species richness) "may reach natural site values relatively quickly (<10 years)," though other functions (soil organic matter content) would take longer to reach natural values. The study also notes that debate continues over whether development trajectories can be specified and used as performance metrics.

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Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.	State - Massachusetts	Forested wetlands	Vegetation	Study concluded that deciduous wetlands provide healthy breeding grounds for a diverse, dense population of birds. Results also showed bird populations to be positively correlated with vegetation and surface hydrology. Bird community characteristics could serve as indicators for these latter wetland components.
Brown SC, Veneman PLM. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, U.S.A. Wetlands 21(4):508-518.	State - Massachusetts	Freshwater wetlands	Vegetation	12 years - 391 project files analyzed between 1983 and 1994 and 114 field sites; field work from 5 July 1997 to 15 Oct. 1997. The authors analyzed 391 wetland projects to see if the goal of no-net-loss of wetlands was being met. The state failed. It did not meet regulatory requirements that mitigated wetlands function in a manner similar to the wetland that were replaced. Most of the failures were due to plant communities that were dramatically different from the impacted site. Detailed project designs and follow-up could increase the success rate of wetland mitigation in MA.
Simon TP. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3):407-418.	State - Michigan	Palustrine and vernal ponds	Suggests that plant assemblages be included in a more complete IBI; does not measure	Authors construct an IBI to measure anthropogenic impact. Article observed that for small wetlands and vernal ponds, and IBI that includes a mix of taxonic groups is most appropriate. Crayfish are a little-used indicator taxon, but exhibit well-structure assemblage differences between degraded and non-habitats and could be valuable components of an IBI. Also, the article found higher numbers amphibians, crayfish in higher quality wetlands and vernal ponds.

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Drake MT, Pereira DL. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. N. AM. J. of Fisheries Management 22(4):1105-1123.	State - Minnesota	Lakes	Forestation, agricultural use, extent of development, vegetation-dwelling species	The study found that species richness and community composition metrics describing intolerant or habitat specialist species were the most sensitive to differences in human-induced stress in the lakes studied, and that the IBI scores reflected differences in land-use patterns, trophic state, and aquatic vegetation. Relative biomass metrics showed a stronger response than relative abundance metrics in measuring integrity. The article emphasizes that effective IBIs should be subject to independent measures of lake ecosystem integrity.
Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites represent a land use gradient (18 categories)	175 plant species	The article notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.

Vegetation Articles Reviewed

Budelsky RA, Galatowitsch SM. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.	State - Minnesota	Sedge wetlands	Vegetation	The results of this study reveals that there is a sensitivity of immature sedges to both abiotic and biotic conditions. Therefore measuring a wetland at such a young stage in its development may not yield results that are conclusive.
Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressonal wetlands	Vegetation -- 573 plant taxa	Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.
Padgett DJ, Crow GE. 1994. A vegetation and floristic analysis of a created wetland in Southeastern New Hampshire. Rhodora 96(885):1-29.	State - New Hampshire	Constructed wetland	Vegetation	The book includes methods for designing amphibian studies, including sampling methods, equipment, data collection and interpretation. The authors propose using multiple methods to achieve a comprehensive profile of lentic amphibian assemblages. This information would be useful in the specification of an amphibian-based performance standard.

Vegetation Articles Reviewed

Zampell, Robert and Bunnell, John. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645-658.	State - New Jersey (Mullica River Basin)	Streams	Measured plant cover, though for a separate study; comments on its impact on species richness	Authors use natural stream set to construct and apply an IBI measuring degradation. The main purpose of article is to highlight use of PCA and DCA statistical tools in constructing IBIs based on fish assemblages. The article found that fish assemblage may change subtly with watershed disturbance gradients; the major difference associated with declining water quality concerned the occurrence of nonnative. Presence/absence of species was equally valid measure as relative abundance.
Farley GH, Ellis LM, Stuart JN, Scott NJ Jr. 1994. Avian species richness in different-aged stands of riparian forest along the middle rio grande, new Mexico. Conservation Biology 8(4):1098-1108	State - New Mexico	Riparian forests	Vegetation	As observed, it is important to maintain vegetation of different ages in these riparian areas. Localized revegetation efforts may be a useful method to maintain avian richness in this riparian ecosystem to control non-native species and enhance the native species there.
Brown SC, Bedford BL. 1997. Restoration of wetland vegetation with transplanted wetland soil: An experimental study. Wetlands 17(3):424-437.	State - New York		Vegetation	Hydrology was the key factor in this study. At small sites there were lower wetland index values in the first year, and they had more wetland species and wetland plant cover than control sites in both years. At the large study site, soil transplantation significantly increased both the number of species, the amount of wetland plant cover, and wildlife food plants. This study is relevant to wetland design and function from the standpoint that soil transplanted from nearby remnant drainage ditches to sites selected for restoration may be an effective technique for improving wetland plant establishment.

Vegetation Articles Reviewed

Brown SC. 1999. Vegetation similarity and avifaunal food value of restored and natural marshes in northern New York. Restoration Ecology 7(1): 56-68.	State - New York	Natural marshes	Vegetation	The lower slope of the restored wetlands probably contributed to the greater vegetation cover there than in the reference wetlands. However, cattail, an invasive species, was very prevalent on the restored wetlands. The restored wetlands differed from the reference ones significantly with few wetland species and much less cover of wetland plants. This result may be because before restoration the wetland was drained. There should be an understanding of previous conditions before restoring a wetland so that restoration techniques can be implemented successfully.
Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh	Vegetation -- above and below-ground biomass	This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.
Craft C, Reader J, Sacco JN, Broome SW. 1999. Twenty-five years of ecosystem development of constructed Spartina alterniflora (Loisel) marshes. Ecol. Appl. 9:1405–1419.	State - North Carolina	Saltwater marshes	Vegetation -- aboveground biomass	Study found that aboveground biomass for the 2 constructed wetlands initially overshot the reference wetland values (after 3 years), then dropped to the reference wetland values.

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Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecol. Manage. 8(2/3):197-207.	State - North Carolina	Saltwater marshes	Vegetation -- NPP of emergent vegetation	Development of a benthic invertebrate community depends on MOM and organic matter inputs; the quality of the organic matter, based on soil N content, also may be important. It make take more than 10-15 years for the organic-rich surface layer characteristic of natural marshes to develop in created ones. Necessary time depends on duration and frequency of inundation, NPP of emergent vegetation, tidal amplitude, and other factors.
Craft CB, Seneca ED, and Broome SW. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152(2):187-200.	State - North Carolina	Saltwater marshes	Vegetation	After five years, when emergent vegetation was established, there had not been a complete conversion from upland porewater and soil properties to normal wetland properties. According to the author these results may infer that creating wetlands on graded upland sites, may not initially duplicate that of the natural wetlands, which have been established for numerous years.
Fonseca MS, Kenworthy WJ, Colby DR, Rittmaster KA, Thayer GW. 1990. Comparisons of fauna among natural and transplanted eelgrass Zostera marina meadows: criteria for mitigation. Marine Ecology Progress Series 65: 251-264.	State - North Carolina	Eelgrass meadow	Vegetation -- eelgrass density and maturation, connection of these to faunal characteristic s	Article is innovative in that it applies vector-graphical analysis as an alternative method of quantifying marsh maturation. Functional equivalence is measured by the faunal/eelgrass shoot abundance ratio of the natural and mitigated sites. The diagnostic parameter is percentage similarity/species shared. Hypothesis (mostly confirmed) was: faunal population stabilizes when a given eelgrass population stabilizes. "Fish abundance and composition in a 1.9-year-old transplanted bed and a 6-month-old seed-developed bed were indistinguishable from natural eelgrass beds."

Vegetation Articles Reviewed

Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.	State - North Carolina	Salt marshes	Vegetation	The study also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the "results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction."
Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030	State - Ohio	Created and restored wetlands	Vegetation -- cover and richness	The authors seeded one created wetland and left the other unseeded, hypothesizing (based on self-design and self-organization theory) that the two hydrologically similar wetlands would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. After three years, both sites had relatively similar numbers of species (65 versus 54), similar nutrient levels, and similar diversity indices, though the benthic taxon richness was higher in the planted wetland. The study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward functionality (though both experimental wetlands did receive a regulated water supply). The article is relevant to design standards and performance standards based on developmental trajectories.

Vegetation Articles Reviewed

Magee TK, Ernst TL, Kentula ME, Dwire KA. 1999. Floristic comparison of freshwater wetlands in an urbanizing environment. Wetlands 19(3):517-53.	State - Oregon	Palustrine wetlands	Vegetation	The authors evaluated freshwater palustrine wetlands to characterize plant species richness and composition of naturally occurring versus mitigated wetlands, and found significantly different species assemblages among the two groups. Though overall species richness was high (365 plant taxa), over 50% of these species were introduced and only 14 species occurred on more than half the sites -- and nine of them were invasive introduced species. The floristic composition of the mitigated wetlands varied with the level of development in the surrounding landscape and wetland age, and there was a strong relationship between percent cover of water and HGM class. The paper is pertinent in that it addresses the issue of realistic in restoration goals for urban areas.
Bishel-Machung L, Brooks RP, Yates SS, Hoover KL. 1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. Wetlands 16(4):532-541.	State - Pennsylvania	Palustrine -- slope, depression, floodplain, fringed open water	Vegetation	Soils in created wetlands were significantly different than those in reference wetlands. Created wetlands contained more sand and less clay than natural wetlands. Most of the created wetlands were open water, and none were dominated by forest or scrub-shrub vegetation. Performance standards: soil sampling

Vegetation Articles Reviewed

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423-428.	State - Pennsylvania	Palustrine wetlands -- 24 sites	Herbaceous aboveground & belowground biomass	The authors present a strong case for the value of using hydrology to assess relative function over a range of wetlands in a watershed or region. The study suggests guidance that could be implemented for measuring biomass as a performance criteria, and a possible way to obtain (better) averaged data. They suggest that it may be better to look at overall biomass, rather than separating results based on species composition because created and natural wetlands usually do not have the same plant communities for direct comparison. The authors assert that biomass by itself would not be a good performance measure because the composition of plants seems to play an important role in biomass values.
Cole CA. 2002. The assessment of herbaceous plant cover in wetlands as an indicator of function. Ecological Indicators 2:287-293.	State - Pennsylvania		Vegetation -- percent herbaceous cover	This review paper questions the use of vegetative structure (e.g., percent cover) as an indicator of wetland function. Overall, the author asserts that geomorphology, tree density, or tree basal area would be better performance measures than percent herbaceous plant cover for 6 functions he reviews. He further argues that modifying percent cover in regulatory permit conditions to target hyrdophytes or to exclude exotics/invasive species is not enough because there is not enough information to link percent herbaceous plant cover to wetland functions. Other structural measures that may be better performance indicators include basin morphometry, soil organic matter, hydroperiod, and vertical structure.

Vegetation Articles Reviewed

Kulp CJ, McCoy RW. 1992. An Evaluation of 30 Wetland Mitigation Sites Constructed by the PADOT Between 1983 and 1990. U. S. Fish and Wildlife Service. Pennsylvania Field Office Special Project Report 92-3.	State - Pennsylvania	Constructed wetlands	Vegetation	The evaluation metric employed by PADOT was influenced by EPA's delineation manual and was based on five parameters: vegetation type, plant vigor, percentage bare ground (>5% = failure), soils and hydrology, and size. The study did not incorporate data on the prior functions or prior values of wetland components (i.e., historic references to inform restoration targets). Results showed that older sites usually were more diverse, but in no case had scrub-scrub or forested wetlands developed.
Stauffer AL, Brooks RP. 1997. Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1): 90-105.	State - Pennsylvania	Marsh	Hydrophytic vegetation, diversity of vegetation	Plots amended with salvaged marsh soils (SMS) had significantly greater species richness than control plots, but not significantly greater density; significantly more cover than control plots and more hydric plants. The Shannon index (diversity) was significantly higher on SMS than control plots and SMS plots had significantly more organic matter than control plots after the first, but not second, season. Leaf litter plots contained more organic matter than hand-planted plots after the first season. The article is not very relevant to performance standards except for its comment that “Without the correct hydrology, failure of the newly created wetland is likely.”

Vegetation Articles Reviewed

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265-278.	State - Pennsylvania	Slope, headwater floodplain, and mainstem floodplain wetlands.	Vegetation	The authors compared the hydrology characteristics of three HGM subclasses using comparable long-term data sets. The study found strong differences between OR and PA in each of the 3 HGM subclasses. Although the 2 regions were similar in climate, there were very different water regimes. The most successful comparisons were with slope wetlands, and big difference between the forested and mainstem floodplain. This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models.
LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	Species composition, percent cover, number of stems, height, below-ground indicators, density, biomass	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.

Vegetation Articles Reviewed

Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.	State - Texas (Galveston Bay)	Salt marshes	Macro-organic vegetation	The study's results showed that the size of daggerblade shrimp in created marshes was smaller than in natural marshes, and densities of four other shrimp types were lower in created vs. natural marshes. Globe and pinfish densities, sediment macro-organic matter and density and species richness of macroinfauna all were lower in created marshes. The authors concluded that differences in nekton densities primarily were related to tidal flooding -- created marshes had wider flooding duration ranges than natural marshes, and ranged to a much lower level. This hypothesis suggests that performance standards based on range of tidal inundation, or on hydrologic factors generally, might be appropriate.
Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.	State - Virginia	Tidal marsh	Vegetation -- community type, stem density, cover	The study examined various elements of constructed and natural wetlands. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush, and use by birds. A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Plant species frequency, percent cover, shoot density, aboveground & belowground biomass, emergent marsh vegetation	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.

Hunt RJ, Walker JF, Krabbenhoft DP. 1999. Characterizing hydrology and the importance of ground water discharge in natural and constructed wetlands. Wetlands 19:458–472.	State - Wisconsin	Natural and constructed wetlands	Vegetation -- root zone and soil temperature related to plant growth	The authors studied hydrology and ground water discharge at constructed and natural wetlands and found that sites with greater ground-water discharge had high water tables and more stable hydrographs. Ground-water direction and amount, magnitude of shallow ground-water flow, and areas of higher ground-water discharge influenced environmental factors such as physical hydrology, root-zone saturation, root-zone temperatures, and porewater chemistry; however, the authors observe that more research into wetland hydrology is necessary before researchers can accurately predict its dynamics. This study reveals the importance of hydrologic factors to wetland development. If also found that the constructed wetlands had root zones that remained frozen longer than the root zones of natural wetlands, due to greater plant cover and litter accumulation.

Vegetation Articles Reviewed

Reinartz JA, Warne EL. 1993. Development of vegetation in small created wetlands in southeastern Wisconsin. Wetlands 13(3):153-164.	State - Wisconsin	Created depressional wetlands	Vegetation	This study looked at natural colonization by vascular plants in 11 created wetlands. The vegetation in the created wetlands was sampled and compared to five wetlands seeded with native wetland plant seeds. The seeded wetlands had much higher diversity and richness of native wetland species than unseeded wetlands after two years. The proportion of total plant cover comprised of native wetland species increased over time, and the diversity and richness of native wetland species increased with wetland age, size, and proximity to the nearest established wetland. The article could inform design standards (because it supports seeding), and suggests that diversity and vegetative species richness may follow developmental trajectories.
Ashworth SM. 1997. Comparison between restored and reference sedge meadow wetlands in south-central Wisconsin. Wetlands 17(4):518-527.	State - Wisconsin	Sedge meadow	Vegetation	Hydrology and soil parameters are important component for vegetation diversity. Although the goal of study in revegetating the site was met, the plant species diversity and distribution were different then the reference site. Performance standards can benefit
Cooper CB, Anderson SH. 1996. Significance of invertebrate abundance to dabbling duck brood use of created wetlands. Wetlands 16(4): 557-563.	State - Wyoming	Emergent wetlands	Vegetation	Much is known about creating habitat for waterfowl use and production. Dabblers use a variety of wetland types, favoring shallow, ephemeral wetlands with some emergent vegetation, but also using deep, permanent wetlands. Higher densities of macroinvertebrates increased brood use of created ponds, most or all of the macroinvertebrates were accessible to dabblers in the water column.

Vegetation Articles Reviewed

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf	U.S.	Freshwater wetlands	Vegetation removal and its impacts	Reviewed section of this document is a literature review of attempts to construct IBIs for wetland fish assemblages and studies on fish response to variance stressors. Adamus and co-authors comment on a wetland IBI proposed by Galatowitsch and co-authors, noting that the following variables are strong indicators of wetland health in the noted wetland type: small river floodplain -- species richness and proportion Cyprinids; medium river floodplain - species richness; large river floodplain -- proportion piscivores, fish abundance, proportion Catostomids; non-calcareous littoral wetlands -- total fish abundance; calcareous wetlands -- species richness, abundance, proportion Cyprinids, and number sunfish; forest and prairie glacial marshes -- total richness and abundance. The authors also discusses an IBI proposed by Schultz and co-authors.
Barker JR, Ringold, PL, Bollman M. 2002. Patterns of tree dominance in coniferous riparian forests. Forest Ecology and Management 166:311-329.	U.S.	Riparian forests	Vegetation -- trees in riparian forests	In this study the researchers developed an importance value index (IVI), which was the summation of tree relative density, relative frequency, and relative basal area, whose values were used to define tree dominance. This index can be useful for performance standards since it is able to measure the vegetation of a wetland.
Pielow EC. 1985. Assessing the diversity and composition of restored vegetation. Canadian Journal of Botany 64:1344-1348. Website http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio.pdf	U.S.	NA	Vegetation	The author provides a tool to compare diversity between restored and native vegetation without calculating diversity indices.

Ettema CH, Coleman DC, Vellidis G, Lowrance R, Rathbun SL. 1998. Spatiotemporal distributions of bacterivorous nematodes and soil resources in a restored riparian wetland. Ecology 79 (8): 2721–2734	U.S. region	Riparian wetlands	Vegetation	This study was limited for examining soil and vegetation performance standards and no reference sites were used for comparison.
Wilcox DA, Meeker JE, Hudson PL, Armitage BJ, Black MG, Uzarski DG. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. Wetlands 22(3):588-615.	U.S. region - Great Lakes, Midwest	Lake coastal wetlands	Vegetation	This study compared natural and constructed wetlands, examining nesting by the endangered light-footed clapper rail and associated trends in intertidal cordgrass (Spartina foliosa) growth. The author found that a marsh's failure to foster nesting primarily was caused by tidal inundation related insufficient cordgrass height and density, and predation. When evaluating marsh vegetation, the author recommends using cordgrass height distributions and density parameters, rather than canopy structure measures; grouping density and height distribution data together in a single indicator; and monitoring for an extended time period in order to account for interannual and spatial variability and lag effects. The author also points out that sampling methodology is critical for accurate assessment, and makes many suggestions concerning research design components.
Galatowitsch SM, van der Valk AG. 1996. Characteristics of Recently Restored Wetlands in the Prairie Pothole Region. Wetlands 16(1):75-83.	U.S. region - Iowa, Minnesota, South Dakota	Prairie potholes	Vegetation	After three years most of the vegetation in the restored wetlands was sparse indicating that 5 years is not a long enough time to determine effectiveness of restoration wetlands. Most of the hydrologically implemented projects were successful. Sustaining diversity of plant guilds, especially those with limited seed production and dispersal capabilities, depends on the density of natural wetlands in a region.

Vegetation Articles Reviewed

Werner KJ, Zedler JB. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands 22 (3):451-466.	U.S. region - Midwest	Wetland meadows	Vegetation	The authors documented the role of sediment accumulation in the conversion of species-rich sedge meadows to stands of Phalaris arundinacea and Typha spp. The three wetland sites were selected on the basis that they had a history of urban stormwater inputs, sediment accumulation, and stands of Phalaris or Typha adjacent to Carex meadows. Results showed that microtopography of Carex tussocks facilitates the presence of other wetland plant species and is itself influenced by vegetative cover. Inflowing sediments reduced microtopograhic relief. Article implies that a measure of success for a mitigated sedge meadow would be the maintenance of micotopography and a standard for maximum sediment accumulation over time.
Zedler JB. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Front Ecol Environ 1(2):65-72.	U.S. region - Midwest, Iowa, Illinois, Indiana, other Midwest	Palustrine and wet prairie wetlands	Vegetation	Effective wetland restoration requires careful planning, and ideally involves landscape-design and adaptive management models. Typical problems with restoration include restoring the correct hydrology (often water levels are too high or low, plantings may die, and animals may fail to use the site) and restoring biodiversity. In areas of high historic disturbance, the best restoration approach may be to aim for structural and functional equivalence, but be willing to recognize that the wetland system may no longer be up to functioning at that level due to alterations in the surrounding uplands and watershed.

Vegetation Articles Reviewed

Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.	U.S. region - Pacific Northwest	Saltwater marshes	Vegetation	Study focuses on restoration of multiple wetlands in multiple river sites. The authors argue that fish occurrence and abundance are not sufficient to measure mitigation success. Habitat assessment must be functional, not focused on structure. They suggest three types of metrics to assess wetlands -- capacity, opportunity, and realized function metrics. Also, assessment must address landscape and system attributes.
Richter KO, Azous AL. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound Basin. Wetlands 15(3):305-312.	U.S. region - Pacific Northwest (Puget Sound basin)	Palustrine wetlands -- 19 wetlands representing a range of conditions	Vegetation -- used NWI classification	The authors assessed amphibian species richness in the context of wetland size, vegetation class, presence of bullfrog and fish predators, hydrologic characteristics of water flow, fluctuation, and permanence, and land use. Low velocity flow and low fluctuation were correlated with high amphibian species richness, and increasing mean water-level fluctuation and percent watershed urbanization were correlated with low species richness. The authors recommend that flow velocity be minimized in developing wetland watersheds -- this recommendation could be relevant both to design and performance standards.

Vegetation Articles Reviewed

DeKeyser ES, Kirby DR, Ell MJ. 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3(2):119-133.	U.S. region (Midwest)	Prairie wetlands	Vegetation	Plant communities in 46 seasonal wetlands were sampled. Plant data analyzed using PC.s and cluster analysis, resulting in five quality classes from very poor to very good. Using this classification system, plant communities of additional seasonal wetlands can be assessed and placed in quality classes for mitigation or ecological purposes, such as tracking the improvement of restored or reclaimed wetlands, wildlife habitat evaluation, HGM assessments and evaluation of other ecological functions.
Barry WJ, Garlo AS, Wood CA. 1996. Duplicating the mound-and-pool microtopography of forested wetlands. Restoration and Management Notes 14(1): 15-21.	U.S. region (New England)	Forested wetland	Vegetation -- trees in riparian forests	This is a predominantly non-scientific description of a wetland mitigation (creation) project in which the mitigation attempted to duplicate the mound-and-pool microtopography of a ground-water fed forested wetland. The study does not provide quantitative assessments of success, only qualitative statements such as all of the vegetation was doing well due to the irrigation (one year after construction) along with a list out species present on the site. This study would need follow-up to see if the design parameters used are effective and quantitative evaluation measurements.

Vegetation Articles Reviewed

Dawe NK, Bradfield GE, Boyd WS, Trethewey DEC, Zolbrod AN. 2000. Marsh creation in a northern Pacific estuary: is thirteen years of monitoring vegetation dynamics enough? Conservation Eco. 4(2):12. [online] URL: http://www.consecol.org/vol4/iss2/art12	U.S. region (Pacific Northwest)	Marshes, estuaries, and created wetlands	Vegetation	Percentages of crustaceans, isopods, and Ephemeroptera-Plecoptera-Trichoptera (EPT) were significantly higher at the reference site than the two most impacted sites, probably due to abundance of leaf litter and lower temperatures. Conversely, percentages of diptera were significantly higher in the agriculturally-impacted sites; due probably to the presence of silty, nutrient-rich water. During the intermittent period when natural stresses were high the sites were more similar in percentages of dominant family, burrowers, chironomids, and diptera.

Hydrology Articles Reviewed

Title / Reference information	**Region**	**Wetland type**	**Parameter**	**Comments**
Balian LV, Ghasabian MG, Adamian MS, Klem D Jr. 2002. Changes in the waterbird community of the Lake Sevan–Lake Gilli area, Republic of Armenia: a case for restoration. Biological Conservation. 106(2): 157-163.	International - Armenia	Lake	Hydrology -- drained lakes for production of hydroelectric power and agricultural irrigation	Authors of this article found loss of fish farming ponds is estimated to result in the loss of as much as 80% of the waterbird species breeding in Armenia. To address this problem, authors recommend the restoration of Lake Gilli and its extensive surrounding wetland area. Performance standards can benefit from this study because it addresses the importance of the relationship between wetlands and bird species and why it may be important to preserve wetlands or restore them to a healthy state.
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh	Water quality -- temperature, turbidity, water height, current	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.

Hydrology Articles Reviewed

Weiher E, Wisheu IC, Keddy PA, Moore DRJ. 1996. Establishment, persistence, and management implications of experimental wetland plant communities. Wetlands 16(2):208-218.	International - Canada (Ontario)	Riverine and lacustrine wetlands	Hydrology -- flooding	The authors examined the importance of seed banks in wetland restoration. They inoculated 120 wetland microcosms representing 24 different environmental treatments with seeds from 20 wetland plant species; seeds were selected to represent a range of morphologies and life history types. After five years only six plant species were found in large numbers on the microcosms and Lythrum was one of those species. The rapid loss of species suggests that in the absence of disturbance, competitive exclusion by Lythrum can occur within five years. Flooding and fertility remained the main factors affecting species composition. Study results suggest that high diversity, low biomass wetlands will be difficult to create; therefore, protection of such wetlands may deserve a higher priority.
Amoros C, Bornette G, Henry CP. 2000. A vegetation-based method for ecological diagnosis of riverine wetlands. Environ. Manage. 25(2):211-227.	International - France (Rhone River)	Riverine wetlands	Hydrology	Authors promote the use of aquatic macrophytes and helophyte as a method of ecological health of riverine systems. Plant communities were recommended because they are easy to survey and provide information on the origin of water supply (groundwater, seepage, surface river water), water nutrient content, effects of flood disturbances, and the terrestrializaton processes. This paper is not relevant to our study and should be deleted from the bibliography.

Hydrology Articles Reviewed

Barry WJ, Garlo AS, Wood CA. 1996. Duplicating the mound-and-pool microtopography of forested wetlands. Restoration and Management Notes 14(1): 15-21.	NA	Forested wetland	Hydrology -- hydrologic levels targeted	This is a predominantly non-scientific description of a wetland mitigation (creation) project in which the mitigation attempted to duplicate the mound-and-pool microtopography of a ground-water fed forested wetland. The study does not provide quantitative assessments of success, only qualitative statements such as all of the vegetation was doing well due to the irrigation (one year after construction) along with a list out species present on the site. This study would need follow-up to see if the design parameters used are effective and quantitative evaluation measurements.
Niswander SF, Mitsch WJ. 1995. Functional-analysis of a 2-year-old created in-stream wetland - hydrology, phosphorus retention, and vegetation survival and growth. Wetlands 15(3):212-225.	Ohio	In-stream wetland	Hydrology, created stream	The article provides a functional analysis of first two years of site development in a created wetland. The authors simulated 50 years growth to determine the ultimate state of wetland. The article provides an example of applied functional analysis.
Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.	State - California	Salt marshes	Water quality -- water temperature	The intertidal area of the mitigated (created) marsh was dominated by euhaline sticklebacks and topsmelts. This area did not replace the intertidal and subtidal habitat of the natural marsh, which had more stable salinity and water temperatures and was used extensively by juvenile English sole. Possible performance indicators include (1) stability of salinity and water temperatures relative to a reference/control site, and (2) fish composition -- numbers of juvenile sole vs. other species.

Hydrology Articles Reviewed

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.	State - California	Salt marsh	Water quality -- Redox potentials, pH, sediment salinities	A constructed marsh had significantly lower levels of nitrogen and organic matter than an adjacent natural marsh. Article sites others which say that constructed marshes may take 15-30 years to develop nitrogen and organic carbon pools equal to those of natural salt marshes. Organic amendments did not increase soil organic content. Soil nitrogen showed few differences that were related to soil amendments. It is unclear whether these marshes need more time or if the amendments are not sufficient.
Sanderson EW, Foin TC, Ustin SL. 2001. “A simple empirical model of salt marsh plant spatial distributions with respect to a tidal channel network.” Ecological Modeling 139: 293-307.	State - California	Tidal salt marshes	Tidal volume, influx, and general hydrology	Study applied an ecological model to a marsh area with known vegetative parameters and assessed the accuracy of the model. Researchers found a large distribution of species in the large channels and a small distribution of species in the smaller channels. Distribution of species predicted by CISD conformed well with prior independent observations of the marsh area studied however results are highly dependant on the model form. Further study needs to be done.
Williams GD, Zedler JB. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: Relative influence of channel morphology and restoration history. Estuaries 22(3A):702-716.	State - California	Tidal wetlands	Stream order, width and depth, bank slope, temp., salinity, DO	Fish species richness and density did not vary significantly between constructed and natural channels, though California killifish was in higher densities in the constructed channels. Focus of article: assemblage and composition is related to channel physical properties/characteristics, so it is important to design projects with natural hydrologic features and use assessment tools that measure fish habitat function.

Hydrology Articles Reviewed

Talley TS, Levin LA. 1999. Macrofaunal Succession and Community Structure in Salicornia Marshes of Southern California. Estuarine, Coastal and Shelf Science 49(5):713-731.	State - California (southern)	Salt marshes	Salinity	This study examined macrofaunal assemblage succession and the effect of vegetation and sediment attributes on assemblages in natural and created Salicornia marshes. It also comments on differences between Spartina and Salicornia marshes and the applicability of research concerning either type to the other. The study asserts that physical disturbance, rather than marsh age, may be a significant determinant of differences between created and natural wetlands. The development trajectories identified in the study indicate an increasing similarity between the created and natural marsh assemblages over time, but the authors conclude that faunal development in the created marshes toward natural conditions may require ten years or more, and "functional characteristics such as food web support, nutrient cycling, population size structure or parasites loads may remain different."
Adamus PR. 1995. Validating a habitat evaluation method for predicting avian richness. Wildlife Soc. Bull. 23(4):743-749.	State - Colorado	Lowland and riparian wetlands	Hydrology- artificially high water table	Study about the new avian richness evaluation method (AREM), which was tested at 76 wetlands and riparian areas for accuracy. Could be useful for performance standards to predict the viability of whether a constructed or restored wetland can sustain a livable habitat that would imitate that of the wetland it is replacing.

Hydrology Articles Reviewed

Brawley AH, Warren RS, Askins RA. 1998. Bird use of restoration and reference marshes within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. Environ. Manage. 22(4):625-633.	State - Connecticut	Estuarine, tidal marsh	Hydrology -- tidal flooding (exchange)	This study compared restored tidal marshes to control site. Study found that reintroduction of tidal flooding can effectively restore important ecological functions to previously impounded tidal marshes based on vegetation, macroinvertebrate, and fish species richness and frequency.
David PG. 1999. Response of exotics to restored hydroperiod at Dupuis Reserve, Florida. Restoration Ecology 7(4): 407-410.	State - Florida	Emergent freshwater marsh	Hydrology -- period of inundation	This paper is about hydrology as it related to controlling/engorging native and exotic wetland vegetation. The ditch plugs used to create hydroperiods were able to bring back native species to the wetland and nearly eliminate the invasive species. Existing seeds in nearby wetlands may have provided existing seeds/plants. The author illustrates how important hydrologic function is to vegetation in a wetland.
Vose FE, Bell SS. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: evaluation of habitat restoration by hydrologic modification. Estuaries 17(3):585-596.	State - Florida	Salt marshes	Periodicity of water cover	Fish abundance, biomass, and mean monthly number of species decreased after tidal flow was established. Pre and post-breach community similarity of fish, amphipod, and polychaete assemblages increased during last year of sampling but remained generally low. Suggests that differences between a natural and modified wetland can be observed in a short time frame.

Hydrology Articles Reviewed

Kolka RK, Singer JH, Coppock CR, Casey WP, Trettin CC. 2000. Influence of restoration and succession on bottomland hardwood hydrology. Ecological Engineering 15:S131–S140.	State - Georgia and South Carolina	Forested wetlands	Hydrology	Vegetation (an indicator of hydrologic character) records were similar to vegetation observed in this study. Bottomland interflow and losses to the stream were functions of higher water tables present in both the upland and bottomland. This study analyzed vegetation as an indicator of hydrologic character. Thus, the observed vegetation in this study indicates that the observed hydrologic character in this study is similar to that of past since vegetation records from the past are similar to the observed vegetation.
Schwartz JS. 2002. Stream Habitat Characterized by Stage-Specific Flows and Three-Dimensional Geomorphological Complexity: Development of Ecological Criteria for Stream Restoration Design. PhD Dissertation	State - Illinois	Third-order streams	Hydrology, fluvial habitats	The ecological relationship discussed in this dissertation illustrate the importance of the pool-riffle sequence in maintaining fish community diversity, and the importance of bed and bank morphology during high-flow stages for hydrodynamic conditions necessary for fish refugia. This discussion implies that HGM factors clearly are important to both wetland design and performance.
Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.	State - Massachusetts	Forested wetlands	Hydrology	Study concluded that deciduous wetlands provide healthy breeding grounds for a diverse, dense population of birds. Results also showed bird populations to be positively correlated with vegetation and surface hydrology. Bird community characteristics could serve as indicators for these latter wetland components.

Hydrology Articles Reviewed

Brown SC, Veneman PLM. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, U.S.A. Wetlands 21(4):508-518.	State - Massachusetts	Freshwater wetlands	Replication of hydrology	12 years - 391 project files analyzed between 1983 and 1994 and 114 field sites; field work from 5 July 1997 to 15 Oct. 1997. The authors analyzed 391 wetland projects to see if the goal of no-net-loss of wetlands was being met. The state failed. It did not meet regulatory requirements that mitigated wetlands function in a manner similar to the wetland that were replaced. Most of the failures were due to plant communities that were dramatically different from the impacted site. Detailed project designs and follow-up could increase the success rate of wetland mitigation in MA.
Drake MT, Pereira DL. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. N. AM. J. of Fisheries Management 22(4):1105-1123.	State - Minnesota	Lakes	Depth, area, alkalinity, percent littoral, shoreline development index, human induced-stress	The study found that species richness and community composition metrics describing intolerant or habitat specialist species were the most sensitive to differences in human-induced stress in the lakes studied, and that the IBI scores reflected differences in land-use patterns, trophic state, and aquatic vegetation. Relative biomass metrics showed a stronger response than relative abundance metrics in measuring integrity. The article emphasizes that effective IBIs should be subject to independent measures of lake ecosystem integrity.

Hydrology Articles Reviewed

Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites represent a land use gradient (18 categories)	Hydrology - disturbance, temperature, conductivity, pH	The article notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.
Budelsky RA, Galatowitsch SM. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.	State - Minnesota	Sedge wetlands	Hydrology	The results of this study reveals that there is a sensitivity of immature sedges to both abiotic and biotic conditions. Therefore measuring a wetland at such a young stage in its development may not yield results that are conclusive.

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606-627.	State - Minnesota and Wisconsin	Streams	Hydrological variability/stability	Fish data from a large set of streams were collected and analysis sought correlation between assemblages and stream HGM; data from databases. The authors assessed fish assemblages in streams along a gradient of hydrologic variability, and found that fish attributes were correlated with nature of the hydrologic environment. Variable aquatic habitats were characterized by resource generalists, more silt-associated fish, slower fish, more small stream and wide-ranging fish species, weakly interactive opportunists, substratum generalists, more planktivores, omnivores, and generalist invertebrates, and fewer parasitic fish. Stable aquatic environments were characterized by a higher proportion of specialist species, highly interactive and limited by stable resources, more benthic invertebrates and parasitic fish, fewer omnivores, generalist invertebrates and planktivores, faster fish, and more rubble-associated fish. The results demonstrate that fish attributes can serve as indicators of environmental conditions.

Hydrology Articles Reviewed

Zampell, Robert and Bunnell, John. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645-658.	State - New Jersey (Mullica River Basin)	Streams	pH, specific conductance used to measure disturbance	Authors use natural stream set to construct and apply an IBI measuring degradation. The main purpose of article is to highlight use of PCA and DCA statistical tools in constructing IBIs based on fish assemblages. The article found that fish assemblage may change subtly with watershed disturbance gradients; the major difference associated with declining water quality concerned the occurrence of nonnative. Presence/absence of species was equally valid measure as relative abundance.
Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh	Hydrology -- development/ maintenance of aboveground biomass	This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.

Hydrology Articles Reviewed

Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecol. Manage. 8(2/3):197-207.	State - North Carolina	Saltwater marshes	Hydrology -- frequency of inundation and tidal amplitude	Development of a benthic invertebrate community depends on MOM and organic matter inputs; the quality of the organic matter, based on soil N content, also may be important. It make take more than 10-15 years for the organic-rich surface layer characteristic of natural marshes to develop in created ones. Necessary time depends on duration and frequency of inundation, NPP of emergent vegetation, tidal amplitude, and other factors.
Craft CB, Seneca ED, and Broome SW. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152(2):187-200.	State - North Carolina	Saltwater marshes	Hydrology -- water level, temperature, salinity, dissolved oxygen, pH, redox potential, Fe, Mn, hydraulic conductivity	After five years, when emergent vegetation was established, there had not been a complete conversion from upland porewater and soil properties to normal wetland properties. According to the author these results may infer that creating wetlands on graded upland sites, may not initially duplicate that of the natural wetlands, which have been established for numerous years.

Hydrology Articles Reviewed

Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.	State - North Carolina	Salt marshes	Tidal flooding	The study notes importance of tidal flooding in prompting Spartina stem growth. Also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the "results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction."

Hydrology Articles Reviewed

Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030	State - Ohio	Created and restored wetlands	Hydrology	The authors seeded one created wetland and left the other unseeded, hypothesizing (based on self-design and self-organization theory) that the two hydrologically similar wetlands would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. After three years, both sites had relatively similar numbers of species (65 versus 54), similar nutrient levels, and similar diversity indices, though the benthic taxon richness was higher in the planted wetland. The study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward functionality (though both experimental wetlands did receive a regulated water supply). The article is relevant to design standards and performance standards based on developmental trajectories.

Hydrology Articles Reviewed

Magee TK, Ernst TL, Kentula ME, Dwire KA. 1999. Floristic comparison of freshwater wetlands in an urbanizing environment. Wetlands 19(3):517-53.	State - Oregon	Palustrine wetlands	Hydrology, percent water cover	The authors evaluated freshwater palustrine wetlands to characterize plant species richness and composition of naturally occurring versus mitigated wetlands, and found significantly different species assemblages among the two groups. Though overall species richness was high (365 plant taxa), over 50% of these species were introduced and only 14 species occurred on more than half the sites -- and nine of them were invasive introduced species. The floristic composition of the mitigated wetlands varied with the level of development in the surrounding landscape and wetland age, and there was a strong relationship between percent cover of water and HGM class. The paper is pertinent in that it addresses the issue of realistic in restoration goals for urban areas.
Shaffer PW, Ernst T. 1999. Distribution of soil organic matter in freshwater emergent open water wetlands in the Portland, Oregon metropolitan area. Wetlands 19(3):505-516.	State - Oregon	Freshwater emergent and open-water wetlands	Hydrology	The article surveyed the soil organic matter of natural wetlands and mitigation wetlands and found lower concentrations in mitigation wetlands. SOM accumulation was not significantly related to land use, but was related to soil series, texture class and association, and hydrogeomorphic class. Soil organic matter levels did not significantly increase over 6 years in the created wetlands. The finding indicates that a long time scale may be necessary for measuring performance, and/or that equivalence between natural and mitigated wetlands cannot always or quickly be achieved -- particularly if managers do not find more effective ways of managing SOM in design and construction processes.

Hydrology Articles Reviewed

Shaffer PW, Kentula ME, Gwin SE. 1999. Characterization of wetland hydrology using hydrogeomorphic classification. Wetlands 19(3):490-504.	State - Oregon	Freshwater emergent, open-water, and riverine wetlands	Hydrology	The study found that no relationship between hydrologic attributes and land use, soil associations, or wetland area. They did find highly significant differences in wetlands with or without a water-retention structure, and by wetland type (natural or created). In addition, they found significant differences in hydrologic variables for wetlands in different HGM classes. They argue for the development of regional wetland subclasses; other authors reinforce this point when they address the importance of accurate wetland classification as a prerequisite for accurate IBI baselines.
Cole CA, Brooks RP, Wardrop DH. 1997. Wetland hydrology and water quality as a function of hydrogeomorphic (HGM) subclass. Wetlands 17(4):456–467.	State - Pennsylvania	Palustrine wetlands	Hydrology, water quality	Position within the landscape and source of water flow seem to be prime determinants in characterizing hydrology. Authors state that it is essential that the regulations and managers are able to assign a wetland to an HGM subclass and derive an wetland function based on that classification.

Hydrology Articles Reviewed

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423-428.	State - Pennsylvania	Palustrine wetlands -- 24 sites	Hydrology	The authors present a strong case for the value of using hydrology to assess relative function over a range of wetlands in a watershed or region. The study suggests guidance that could be implemented for measuring biomass as a performance criteria, and a possible way to obtain (better) averaged data. They suggest that it may be better to look at overall biomass, rather than separating results based on species composition because created and natural wetlands usually do not have the same plant communities for direct comparison. The authors assert that biomass by itself would not be a good performance measure because the composition of plants seems to play an important role in biomass values.
Cole CA, Brooks RP. 2000. Patterns of wetland hydrology in the Ridge and Valley province, Pennsylvania, USA. Wetlands 20(3):438-447.	State - Pennsylvania	Palustrine wetlands	Hydrology	The results of this study confirmed their findings from an earlier statewide wetland assessment that indicated there are clear distinctions in median depth of water by HGM subclass and confirms their belief that HGM is an excellent method to assess general hydrologic characteristics, although its effectiveness varied among wetland types. The authors found that disturbance played a large role in determining hydrologic behavior. They conclude that knowledge HGM subclass is a reasonable and much less expensive technique for assessing hydrology than extensive site-specific sampling.

Hydrology Articles Reviewed

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265-278.	State - Pennsylvania	Slope, headwater floodplain, and mainstem floodplain wetlands.	Hydrology	The authors compared the hydrology characteristics of three HGM subclasses using comparable long-term data sets. The study found strong differences between OR and PA in each of the 3 HGM subclasses. Although the 2 regions were similar in climate, there were very different water regimes. The most successful comparisons were with slope wetlands, and big difference between the forested and mainstem floodplain. This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models.
Cole CA, Brooks RP. 2000. A comparison of the hydrologic characteristics of natural and created mainstem floodplain wetlands in Pennsylvania. Ecol. Eng. 14(3):221-231.	State - Pennsylvania	Floodplain wetlands	Water depth and frequency	This study compared the hydrology of natural and created wetlands. The study found that while natural wetlands in the area normally had a deeper median depth to water, there were certain times when soils were saturated or inundated, and there was less time where water was in the root zone than in the created wetlands. Most natural sites in the region are vegetated with little open water. In contrast, the created wetlands were wetter, were wetter for longer periods of time, and contained a large component of open water. For performance measures, it is important to tailor the hydrologic requirements depending on the wetland to ensure correct functioning. The hydrological behavior must be equivalent to the targeted HGM subclass.

Hydrology Articles Reviewed

Delaney TP, Webb JW, Minello TJ. 2000. Comparison of Physical Characteristics Between Created and Natural Estuarine Marshes in Galveston Bay, Texas. Wetlands Ecology and Management 8(5):343-352.	State - Texas	Estuarine marshes	Hydrology	Differences in shoreline undulation and reticulation amounted to differences in vegetation growth; created marshes had expansive areas of growth while natural marshes had more fragmented growth areas. Design of a wetland can significantly affect function of the wetland.
Delaney TP, Webb JW, Minello TJ. 2000. Comparison of Physical Characteristics Between Created and Natural Estuarine Marshes in Galveston Bay, Texas. Wetlands Ecology and Management 8(5):343-352.	State - Texas (Galveston Bay)	Estuarine marshes	Hydrology	In this study, differences in shoreline undulation and reticulation amounted to differences in vegetation growth; created marshes had expansive areas of growth while natural marshes had more fragmented growth areas. The study demonstrates that the design of a wetland can significantly affect function of the wetland.
Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.	State - Texas (Galveston Bay)	Salt marshes	Tidal flooding	The study's results showed that the size of daggerblade shrimp in created marshes was smaller than in natural marshes, and densities of four other shrimp types were lower in created vs. natural marshes. Globe and pinfish densities, sediment macro-organic matter and density and species richness of macroinfauna all were lower in created marshes. The authors concluded that differences in nekton densities primarily were related to tidal flooding -- created marshes had wider flooding duration ranges than natural marshes, and ranged to a much lower level. This hypothesis suggests that performance standards based on range of tidal inundation, or on hydrologic factors generally, might be appropriate.

Hydrology Articles Reviewed

Contreras-Balderas S, Edwards RJ, Lozano-Vilano MD, Garcia-Ramirez ME. 2002. Fish biodiversity changes in the Lower Rio Grande/RioBravo, 1953-1996 - A review. Reviews in Fish Biology and Fisheries. 12(2):219-240.	State - Texas and Mexico	River -- altered system (shifts over time in pollution, temp, salinity, turbidity)	Hydrology -- lower runoff levels, turbidity, temperature; salinity	Survey results are being incorporated into a fish IBI. Changes over 43 years demonstrated change in fish fauna with a loss of the majority of freshwater species replaced by marine invaders due to shifts in whole-basin ecology including higher water temp, salinity, turbidity, and lower runoff levels and maybe pollution.
Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.	State - Virginia	Tidal marsh	Salinity, Temperature, DO	The study examined various elements of constructed and natural wetlands. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush, and use by birds. A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.

Hydrology Articles Reviewed

Pepin AL. 1998. The Relative Importance of Hydrology and Substrate in the Vegetation Dynamics of Restored Freshwater Wetlands (Wetland Restoration). Ph.D. Dissertation. George Mason University.	State - Virginia	Freshwater wetlands	Hydrology	The authors address the question of whether hydrology or substrate is more important in controlling the vegetation dynamics of freshwater wetlands, engaging in a descriptive study of the vegetation of twelve restored wetlands of various ages and an experimental study of the growth and germination of two species. Both study indicated that hydrology, as expressed by vegetation zone (i.e., the relative elevation of subplots), is the primary controlling factor in the vegetation dynamics of these restored wetlands, across and within sites. However, the study also revealed direct evidence that within a particular hydrologic regime, substrate characteristics can affect the growth and germination of wetland plants and, at the landscape level, the nature of freshwater wetland plant communities. By implication, the article suggests that performance standards based on either variable would be valuable, and provides information to inform the specification of either type.
Ashworth SM. 1997. Comparison between restored and reference sedge meadow wetlands in south-central Wisconsin. Wetlands 17(4):518-527.	State - Wisconsin	Sedge meadow	Hydrology as related to vegetation and species composition	Hydrology and soil parameters are important component for vegetation diversity. Although the goal of study in revegetating the site was met, the plant species diversity and distribution were different then the reference site. Performance standards can benefit.

Hydrology Articles Reviewed

Dodson SI, Lillie RA. 2001. Zooplankton communities of restored depressional wetlands in Wisconsin, U.S.A. Wetlands 2(2):292-300.	State - Wisconsin	Depressional wetlands -- 17 impacted sites	Hydrology	The authors sampled wetlands for zooplankton communities and collected data on water chemistry in 56 wetlands where some had no impact and others were impacted. Taxonomic richness, abundance, and sex ratios of Daphnia were compared to detect differences in wetland zooplankton community structure. The effect of age of restoration on taxon richness was examined.
Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf	U.S.	Freshwater wetlands	Contaminant toxicity, enrichment, eutrophication, reduced DO	Adamus and co-authors comment on a wetland IBI proposed by Galatowitsch and co-authors, noting that the following variables are strong indicators of wetland health in the noted wetland type: small river floodplain -- species richness and proportion Cyprinids; medium river floodplain - species richness; large river floodplain -- proportion piscivores, fish abundance, proportion Catostomids; non-calcareous littoral wetlands -- total fish abundance; calcareous wetlands -- species richness, abundance, proportion Cyprinids, and number sunfish; forest and prairie glacial marshes -- total richness and abundance. The authors also discusses an IBI proposed by Schultz and co-authors.

Hydrology Articles Reviewed

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf	U.S.	Freshwater wetlands	Algal response to hydrologic variables	The authors generally are not positive about using algae as a reliable indicator. They note that "The exact nutrients that contribute to algal community shift are often difficult to identify due to correlation among many nutrients. . .chemical constituents of water, particularly pH altering bicarbonates, can regulate the response of algae to nutrient additives" etc. If algae are to be used, they say that: species composition is a better measure than biomass in most cases; identifying algae at the genus level or coarser is both useful and perhaps the only practical way of using algae as an indicator; and they recommend grouping species per their reputed tolerances and using the group as an indicator (via weighted average regression analysis) in order to reduce problems associated with variability.
Beck MW, Heck KL, Able KW, Childers DL, Eggleson DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. Issues in Ecology 11 (Spring): 1-12.	U.S.	Salt marshes, mangroves, seagrass meadows	Hydrology	Article comments on wetlands as nurseries, but much is generally applicable. Emphasizes the need for assessment that accounts for growth and juvenile migration to adult habitats. Wetland characteristics must be assessed on a unit-area basis.
Bedford B. 1996. The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. Ecological Applications 6:57-68.	U.S.	Freshwater wetlands	Hydrology	The most comprehensive framework for making mitigation decisions would consider both ecoregions and hydrologic units. She states that hydrology alone is not good enough to predict hydrological functions at a wetland site. Landscape is one of the main factors that need to be included when studying hydrological functions of a wetland.

Hydrology Articles Reviewed

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Vegetation to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.	U.S.	Wetlands generally	Hydrology	The reviewed section focuses on the problems associated with high variability of algal communities, between and within wetlands, and makes recommendations for use of algae as indicators: researchers should use taxonomic measures rather than metabolic measures, engage in composite sampling in order to diminish problems associated with variability/sensitivity, carefully choose algal indicators because algae are responsive to multiple specific stressors, and engage in repeat sampling to reduce variability effects. The article notes a need for a more precise characterization of expected algal conditions in wetlands, that algal indicator choice should depend on whether research interest is short or long-term, and that evaluative techniques that use introduced substrate/lab tests can eliminate some variability. "Hydrology is less important than water chemistry in determining periphyton structure and function. . .many attributes of the wetland algal community are less sensitive to hydrologic modification as compared with macrophytes"

Hydrology Articles Reviewed

McNair SA, Chow-Fraser P. 2003. Change in biomass of benthic and planktonic algae along a disturbance gradient for 24 Great Lakes coastal wetlands. Can. J. Fisheries and Aquatic Sciences 60(6):676-689.	U.S. region - Great Lakes	Coastal wetlands -- 24 sites representing a range of environmental conditions	Water quality, turbidity	The authors sampled a range of wetlands from low to high functioning, assessing water quality, species, percent cover of submerged macrophytes, and chlorophyll content of planktonic algae and benthic algae. They concluded that "periphytic and planktonic chlorophyll biomass are good indicators of human-induced water-quality degradation, " and recommend that both benthic and planktonic algal biomass be routinely monitored as part of an effective wetland management program.
Galatowitsch SM, van der Valk AG. 1996. Characteristics of Recently Restored Wetlands in the Prairie Pothole Region. Wetlands 16(1):75-83.	U.S. region - Iowa, Minnesota, South Dakota	Prairie potholes	Hydrology	After three years most of the vegetation in the restored wetlands was sparse indicating that 5 years is not a long enough time to determine effectiveness of restoration wetlands. Most of the hydrologically implemented projects were successful. Sustaining diversity of plant guilds, especially those with limited seed production and dispersal capabilities, depends on the density of natural wetlands in a region.
Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.	U.S. region - Pacific Northwest	Saltwater marshes	Bathymetry, channel sinuosity, erosion, other properties	Study focuses on restoration of multiple wetlands in multiple river sites. The authors argue that fish occurrence and abundance are not sufficient to measure mitigation success. Habitat assessment must be functional, not focused on structure. They suggest three types of metrics to assess wetlands -- capacity, opportunity, and realized function metrics. Also, assessment must address landscape and system attributes.

Hydrology Articles Reviewed

Morley SA, Karr JR. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Con. Bio. 16(6):1498-1509.	U.S. region - Pacific Northwest (Puget Sound basin)	Second- and third-order streams	Hydrology	The high variability in number of plant species and diversity index for reference wetlands found in this study supports other researcher claims that a population of wetlands should be used for comparison, rather than one reference wetland. This study specifically cautions against using just one wetland for these two indicators of plant diversity. For example, while the study found that the mean number of species was significantly less for constructed wetlands, it also found "considerable overlap between individual constructed and reference sites."
Richter KO, Azous AL. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound Basin. Wetlands 15(3):305-312.	U.S. region - Pacific Northwest (Puget Sound basin)	Palustrine wetlands -- 19 wetlands representing a range of conditions	Hydrology -- flow, permanence, water level fluctuation	The authors assessed amphibian species richness in the context of wetland size, vegetation class, presence of bullfrog and fish predators, hydrologic characteristics of water flow, fluctuation, and permanence, and land use. Low velocity flow and low fluctuation were correlated with high amphibian species richness, and increasing mean water-level fluctuation and percent watershed urbanization were correlated with low species richness. The authors recommend that flow velocity be minimized in developing wetland watersheds -- this recommendation could be relevant both to design and performance standards.

Hydrology Articles Reviewed

Minello TJ, Able KW, Weinstein MP, Hays CG. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progression Series 246: 39-59.	U.S. region - various, but mainly Gulf and Atlantic Coast	Seagrass meadow, salt marsh, non-vegetated marsh, and open sea	Salinity regime, tidal range, wind-induced currents influence nekton patterns	Review of data from 32 studies (world-wide, but mainly in US) to evaluate hypotheses about density, growth, and survival. The article mainly compares the value of salt marshes, seagrass meadows, and open water for the fostering (that is, the nursery capacity of each habitat) of nekton. It is not particularly useful for study of performance standards. It does emphasize the need to include metrics assessing growth rates of transient nekton in any performance standard, but discusses the problems associated with this inclusion -- no single good technique for measuring growth rates, problematic tidal dynamics, and others.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Title / Reference information	Region	Wetland type	Substrate	Sediment	Soil/Nutrient	Comments
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh		Sediment -- texture significant to invertebrate distribution in artificial marshes	Nutrients -- nutrient and organic content significant to invertebrate distribution in artificial marshes	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.
Kaenel-Barbara R. 1998. Effects of plant cutting and dredging on habitat conditions in streams. Hydrobiologica. 143(3):257-273.	International - Switzerland	Streams		Accumulation of fine sediment		The study measured plant biomass and physical parameters before and after plant removal in two streams. Accumulation of fine sediments did not change, but spatial heterogeneity and habitat parameters varied with plant biomass in both streams. The author notes that "Plant and habitat conditions exhibited different recovery trajectories in the two streams, with faster recovery in streams where plants were cut before flowering." The article's discussion of vegetative recovery trajectories is informative.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Chessman BC, Trayler KM, Davis JA. 2002. Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research 53(5):919-930.	International - Western Australia	Coastal wetlands			Nutrients - testing for nutrient enrichment	The authors developed a macroinvertebrate pollution sensitivity biotic index for wetlands. Grades between 1 and 100 were assigned to macroinvertebrates at the family and species levels to reflect the sensitivities of these taxa to human impacts. Scores for both family and species levels detected strong correlation with cultural eutrophication and other human disturbances, but the correlations were generally higher for species level scores. The species level index was also better at distinguishing between individual wetlands. The authors feel this method would work well in routine and rapid wetland assessment and monitoring. This study offers support for the use of macroinvertebrates as rapid wetland assessment tools and for use in biomonitoring.
Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.	State - California	Salt marsh			Soils -- Relative texture (percent sand, silt, clay), decomposition rates	A constructed marsh had significantly lower levels of nitrogen and organic matter than an adjacent natural marsh. Article sites others which say that constructed marshes may take 15-30 years to develop nitrogen and organic carbon pools equal to those of natural salt marshes. Organic amendments did not increase soil organic content. Soil nitrogen showed few differences that were related to soil amendments. It is unclear whether these marshes need more time or if the amendments are not sufficient.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.	State - California	Intertidal wetlands		Sediment -- soil salinity and nitrogen concentration		Measures of individual species abundance and relative assemblage structure (fish) in constructed channels were not equivalent to those in natural wetlands. Soil salinity and nitrogen concentration (lack of) were linked to failure to replicate habitats of certain fish species. The proportion of two fish species differed significantly.
Williams GD, Zedler JB. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: Relative influence of channel morphology and restoration history. Estuaries 22(3A):702-716.	State - California	Tidal wetlands		Sediment composition		Fish species richness and density did not vary significantly between constructed and natural channels, though California killifish was in higher densities in the constructed channels. Focus of article: assemblage and composition is related to channel physical properties/characteristics, so it is important to design projects with natural hydrologic features and use assessment tools that measure fish habitat function.

Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restoration Ecol 7:69-73.	State - California	Salt marshes			Soil organic matter, soil nitrogen	The constructed and reference sites exhibited high interannual variation and lack of directional change for the variables studied, and results suggest little chance that relevant targets for the restoration sites would be met in the near future. The authors argue that hypothetical models that suggest restoration and creation sites follow a smooth path of development toward conditions in natural reference sites, though rampant in the literature, are generally wrong-headed. They suggest alternative management and mitigation models and policies.
Scataloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16(1): 24-37.	State - California (San Diego Bay)	Salt marshes			Soil texture, sand vs. clay as indicator, nitrogen content as limiting factor	The natural, fully-vegetated marsh studied by the authors had two to three times as many individuals (epibenthics) as the four-year-old constructed marsh. The articles hypothesize that coarser sediment, lower organic matter, and relatively more sparse vegetative cover were potential causes of the significantly lower abundance in constructed marshes. The article suggests that epibenthic populations can serve as indicators for soil and vegetative wetland components, and also emphasizes the influence of these components on wetland development generally.

Talley TS, Levin LA. 1999. Macrofaunal Succession and Community Structure in Salicornia Marshes of Southern California. Estuarine, Coastal and Shelf Science 49(5):713-731.	State - California (southern)	Salt marshes		Sand content	Organic matter content	This study examined macrofaunal assemblage succession and the effect of vegetation and sediment attributes on assemblages in natural and created Salicornia marshes. It also comments on differences between Spartina and Salicornia marshes and the applicability of research concerning either type to the other. The study asserts that physical disturbance, rather than marsh age, may be a significant determinant of differences between created and natural wetlands. The development trajectories identified in the study indicate an increasing similarity between the created and natural marsh assemblages over time, but the authors conclude that faunal development in the created marshes toward natural conditions may require ten years or more, and "functional characteristics such as food web support, nutrient cycling, population size structure or parasites loads may remain different.”
Zedler JB. 1990. A Manual for Assessing Restored and Natural Coastal Wetlands with Examples from Southern California. Report. No. T-CSGCP-021. La Jolla: California Sea Grant College.	State - California (southern)	Salt marshes			Soils	Low available nitrogen and soil organic matter in constructed tidal marshes may be a key factor in poor performance outcomes.

Nair VD, Graetz DA, Reddy KR, Olila OG. 2001. Soil development in phosphate-mined created wetlands of Florida, USA. Wetlands 21(2): 232-239.	State - Florida	Constructed wetlands -- sites were phosphate-mined	Substrate soil		Soil compaction, bulk density, organic matter – carbon and nitrogen content, C:N ratio, available and total nutrient contents, soil acidity	The study found that soil organic matter (SOM) accumulation could be an indicator of a functional wetland; SOM increases with age, but age is not the only significant influence on accumulation. The article comments that bulk density decreases, total C increases, and nitrogen concentration increases with age -- but nitrogen increases at a faster rate than carbon concentration. Hence, a decreasing C:N ratio could be used as a performance standard, indicating increasing stabilization and amounts of SOM. Yet the authors observe that "Caution. . .must be exercised in using C:N ratio as one of the characteristic equilibrium values for soils. . .The use of C:N ratio in evaluating progression of created wetlands requires due consideration of other indicators and parameters such as organic matter content and accumulation, soil development, and established vegetation."

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Kolka RK, Singer JH, Coppock CR, Casey WP, Trettin CC. 2000. Influence of restoration and succession on bottomland hardwood hydrology. Ecological Engineering 15:S131–S140.	State - Georgia and South Carolina	Forested wetlands			Soils	Vegetation (an indicator of hydrologic character) records were similar to vegetation observed in this study. Bottomland interflow and losses to the stream were functions of higher water tables present in both the upland and bottomland. This study analyzed vegetation as an indicator of hydrologic character. Thus, the observed vegetation in this study indicates that the observed hydrologic character in this study is similar to that of past since vegetation records from the past are similar to the observed vegetation.
Delaune RD, Buresh RJ, Patrick Jr WH. 1979. Relationship of soil properties to standing crop biomass of Spartina alterniflora in a Louisiana marsh. Estuarine Coastal Marine Sci. 8:477–487.	State - Louisiana	Marsh (saltwater)			Soil	There was a strong positive correlation between soil nutrient density (g/cm3 wet soil) and plant biomass. Thus, it is important for soil and substrates to be healthy in a wetland for the success of plant growth and the health of the wetland.

Poach ME, Faulkner SP. 1998. Soil Phosphorus Characteristics of Created and Natural Wetlands in the Atchafalaya Delta, LA. Estuarine, Coastal and Shelf Science 46(2):195-203.	State - Louisiana (Atchafalaya Delta)	Estuary		Sediment phosphorus fractions and characteristics	Phosphorus, organic matter, soils and soil chemistry	The study examined the phosphorus content of old & intermediate aged wetlands versus comparatively aged natural wetlands to determine whether differences usually found between constructed and (usually mature) natural wetlands with the same hydrologic regime generally were due to age differences, or whether they were due to difference in wetland function. The authors found that created wetlands tend to develop natural phosphorus characteristics over time due to sediment deposition during river flooding, and, if provided a natural flooding cycle, could begin to develop natural phosphorus characteristics between 10 and 20 years after formation. The article highlights the importance of hydrology to wetland development, and suggests that a phosphorus content metric could be used in a development trajectory.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Morgan PA, Short FT. 2002. Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restoration Ecology 10(3):461-473.	State - Maine and New Hampshire	Salt marsh			Sediment deposition, percentage soil organic matter	The study found that overall, mean values for constructed wetlands were significantly lower than natural reference values for aboveground biomass, soil organic matter content, and plant species richness. However, the study supports functional trajectory development via "space-for-time substitution" (that is, comparing marshes of different ages rather than one marsh over many years): it found that some wetland functions (primary production, sediment deposition, plant species richness) "may reach natural site values relatively quickly (<10 years)," though other functions (soil organic matter content) would take longer to reach natural values. The study also notes that debate continues over whether development trajectories can be specified and used as performance metrics.
Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.	State - Massachusetts	Forested wetlands			Surface moisture of muck directly related to species density and richness	Study concluded that deciduous wetlands provide healthy breeding grounds for a diverse, dense population of birds. Results also showed bird populations to be positively correlated with vegetation and surface hydrology. Bird community characteristics could serve as indicators for these latter wetland components.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Brown SC, Veneman PLM. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, U.S.A. Wetlands 21(4):508-518.	State - Massachusetts	Freshwater wetlands		Replication of sediment control functions		12 years - 391 project files analyzed between 1983 and 1994 and 114 field sites; field work from 5 July 1997 to 15 Oct. 1997. The authors analyzed 391 wetland projects to see if the goal of no-net-loss of wetlands was being met. The state failed. It did not meet regulatory requirements that mitigated wetlands function in a manner similar to the wetland that were replaced. Most of the failures were due to plant communities that were dramatically different from the impacted site. Detailed project designs and follow-up could increase the success rate of wetland mitigation in MA.
Budelsky RA, Galatowitsch SM. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.	State - Minnesota	Sedge wetlands			Soils	The results of this study reveals that there is a sensitivity of immature sedges to both abiotic and biotic conditions. Therefore measuring a wetland at such a young stage in its development may not yield results that are conclusive.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Brown SC, Bedford BL. 1997. Restoration of wetland vegetation with transplanted wetland soil: An experimental study. Wetlands 17(3):424-437.	State - New York				Soils	Hydrology was the key factor in this study. At small sites there were lower wetland index values in the first year, and they had more wetland species and wetland plant cover than control sites in both years. At the large study site, soil transplantation significantly increased both the number of species, the amount of wetland plant cover, and wildlife food plants. This study is relevant to wetland design and function from the standpoint that soil transplanted from nearby remnant drainage ditches to sites selected for restoration may be an effective technique for improving wetland plant establishment.
Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh			Soils -- MOM, other soil characteristics	This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.

Craft C, Broome SW, Seneca ED. 1988. Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils. Estuaries 11(4):272-289.	State - North Carolina	Tidal marsh		Sediment	Soil	Levels of available nitrogen, soil organic matter and epibenthic invertebrates were found to be significantly lower in constructed vs. natural marshes and that it could take 15-30 years or longer to reach comparable levels. It is often important to extend studies of created/restored wetlands over long periods of time.
Craft C, Reader J, Sacco JN, Broome SW. 1999. Twenty-five years of ecosystem development of constructed Spartina alterniflora (Loisel) marshes. Ecol. Appl. 9:1405–1419.	State - North Carolina	Saltwater marshes			Macro organic matter (MOM)	Study found that aboveground biomass for the 2 constructed wetlands initially overshot the reference wetland values (after 3 years), then dropped to the reference wetland values.
Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecol. Manage. 8(2/3):197-207.	State - North Carolina	Saltwater marshes			Soils -- soil characteristics, MOM	Development of a benthic invertebrate community depends on MOM and organic matter inputs; the quality of the organic matter, based on soil N content, also may be important. It make take more than 10-15 years for the organic-rich surface layer characteristic of natural marshes to develop in created ones. Necessary time depends on duration and frequency of inundation, NPP of emergent vegetation, tidal amplitude, and other factors.

Craft CB, Seneca ED, and Broome SW. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152(2):187-200.	State - North Carolina	Saltwater marshes			Soil nutrients (organic C, N, P), bulk soil density, texture, porosity	After five years, when emergent vegetation was established, there had not been a complete conversion from upland porewater and soil properties to normal wetland properties. According to the author these results may infer that creating wetlands on graded upland sites, may not initially duplicate that of the natural wetlands, which have been established for numerous years.
Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.A36	State - North Carolina	Salt marshes	Subsurface, deposit-feeding oligochaetes	Surface deposit-feeding polychaetes, sediment organic content, sediment size and composition	Soil	The study also mentions that trajectory curves can help establish effective sampling rates and sampling time frames. This study extrapolates how long and how often sampling should occur to be effective for monitoring: for this study area, the "results indicate that to assess the functions of primary production, maintenance of sediment organic matter, sediment trapping, and maintenance of plant diversity, monitoring should occur frequently for the first five years. Also, although the soil organic matter content should be monitored for up to 35 years, aboveground biomass measurements may not be necessary beyond 8 to 10 years after construction."

Sacco JN, Seneca ED, Wentworth TR. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17(2):489-500.	State - North Carolina	Salt marshes		Sediment particle size, sedimentation rate	Soils	Sediment particle size and sedimentation rate influence infaunal development, and the connection between different sediment types and different types of infaunal assemblages – finer grained sediment in the natural marshes = responsible for the larger proportion of sub-surface-deposit. The study found that though natural and artificial marshes showed nearly equal proportions of surface feeders and sub-surface deposit feeders, the absolute densities of infaunal organisms were significantly greater in the natural marshes. The authors concluded that though artificial marshes are capable of supporting infaunal structures similar to those of natural marshes, they are unable to support similar densities due to their lower organic matter content. Yet marsh age is not the dominant influence on soil organic matter accumulation -- the authors discuss other factors that influence accumulation. The article highlights the importance of soil characteristics in determining wetland function, suggesting the potential value of soil-based performance standards.

Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030	State - Ohio	Created and restored wetlands		Yes	Yes	The authors seeded one created wetland and left the other unseeded, hypothesizing (based on self-design and self-organization theory) that the two hydrologically similar wetlands would be similar in function in the beginning, diverge in function during the middle years, and ultimately converge in structure and function. After three years, both sites had relatively similar numbers of species (65 versus 54), similar nutrient levels, and similar diversity indices, though the benthic taxon richness was higher in the planted wetland. The study suggests that the introduction of plant species may not always be necessary to start wetlands on a trajectory toward functionality (though both experimental wetlands did receive a regulated water supply). The article is relevant to design standards and performance standards based on developmental trajectories.

Shaffer PW, Ernst T. 1999. Distribution of soil organic matter in freshwater emergent open water wetlands in the Portland, Oregon metropolitan area. Wetlands 19(3):505-516.	State - Oregon	Freshwater emergent and open-water wetlands			Soil organic matter (SOM)	The article surveyed the soil organic matter of natural wetlands and mitigation wetlands and found lower concentrations in mitigation wetlands. SOM accumulation was not significantly related to land use, but was related to soil series, texture class and association, and hydrogeomorphic class. Soil organic matter levels did not significantly increase over 6 years in the created wetlands. The finding indicates that a long time scale may be necessary for measuring performance, and/or that equivalence between natural and mitigated wetlands cannot always or quickly be achieved -- particularly if managers do not find more effective ways of managing SOM in design and construction processes.
Bishel-Machung L, Brooks RP, Yates SS, Hoover KL. 1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. Wetlands 16(4):532-541.	State - Pennsylvania	Palustrine (range of types) in slopes, depressions, floodplains or fringed open water sties	Substrate -- used HGM to classify wetland location in the landscape		Soil Organic Matter (SOM); soil organic matter content, matrix chroma, bulk density, total nitrogen,	Soils in created wetlands were significantly different than those in reference wetlands. Created wetlands contained more sand and less clay than natural wetlands. Most of the created wetlands were open water, and none were dominated by forest or scrub-shrub vegetation. Performance standards: soil sampling

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423-428.	State - Pennsylvania	Palustrine wetlands -- 24 sites			Soil organic matter	The authors present a strong case for the value of using hydrology to assess relative function over a range of wetlands in a watershed or region. The study suggests guidance that could be implemented for measuring biomass as a performance criteria, and a possible way to obtain (better) averaged data. They suggest that it may be better to look at overall biomass, rather than separating results based on species composition because created and natural wetlands usually do not have the same plant communities for direct comparison. The authors assert that biomass by itself would not be a good performance measure because the composition of plants seems to play an important role in biomass values.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Stauffer AL, Brooks RP. 1997. Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1): 90-105.	State - Pennsylvania	Marsh	Substrate		Typical soils in constructed vs. natural wetlands	Plots amended with salvaged marsh soils (SMS) had significantly greater species richness than control plots, but not significantly greater density; significantly more cover than control plots and more hydric plants. The Shannon index (diversity) was significantly higher on SMS than control plots and SMS plots had significantly more organic matter than control plots after the first, but not second, season. Leaf litter plots contained more organic matter than hand-planted plots after the first season. The article is not very relevant to performance standards except for its comment that "Without the correct hydrology, failure of the newly created wetland is likely."
Wardrop DH, Brooks RP, Bishel-Machung L, Cole CA. 1998. Hydrogeomorphic (HGM) functional assessment models for Pennsylvania wetlands. Report 98–6. Penn State Cooperative Wetlands Center, University Park, PA.	State - Pennsylvania	Freshwater wetlands		Sediment removal		Found that in non-depressional wetlands, the mechanism for sediment removal appears to be related to the level of structural diversity of vegetation as well as to site microtopography. Microtopography also is important to short-term flood storage. Performance or design standards could be based on any of these variables.

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265-278.	State - Pennsylvania	Slope, headwater floodplain, and mainstem floodplain wetlands.			Soils, nutrients	The authors compared the hydrology characteristics of three HGM subclasses using comparable long-term data sets. The study found strong differences between OR and PA in each of the 3 HGM subclasses. Although the 2 regions were similar in climate, there were very different water regimes. The most successful comparisons were with slope wetlands, and big difference between the forested and mainstem floodplain. This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models.
LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh		Proportions of sand, salt, clay	Organic content of sediment	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.

Wigginton JD, Lockaby BG, Trettin CC. 2000. Soil organic matter formation and sequestration across a forested floodplain chronosequence. Ecol. Eng. 15:S141–S155.	State - South Carolina	Forested floodplain			Soil organic matter	This study looked at soil organic matter formation and carbon sequestration in a site-for-time replacement. Results supported the authors' assertion that constructed wetland functional trajectories of carbon accumulation during succession of forested wetlands involve an increase and then decrease. The study used regression analysis to show that the wetlands will require 25 years to reach 50% of the reference wetland values for soil C and 50 yrs to reach 75%.
Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.	State - Texas (Galveston Bay)	Salt marshes	Infauna and macroinfauna density	Sediment macro-organic matter and density		The study's results showed that the size of daggerblade shrimp in created marshes was smaller than in natural marshes, and densities of four other shrimp types were lower in created vs. natural marshes. Globe and pinfish densities, sediment macro-organic matter and density and species richness of macroinfauna all were lower in created marshes. The authors concluded that differences in nekton densities primarily were related to tidal flooding -- created marshes had wider flooding duration ranges than natural marshes, and ranged to a much lower level. This hypothesis suggests that performance standards based on range of tidal inundation, or on hydrologic factors generally, might be appropriate.

Contreras-Balderas S, Edwards RJ, Lozano-Vilano MD, Garcia-Ramirez ME. 2002. Fish biodiversity changes in the Lower Rio Grande/RioBravo, 1953-1996 - A review. Reviews in Fish Biology and Fisheries. 12(2):219-240.	State - Texas and Mexico	River -- altered system (shifts over time in pollution, temp, salinity, turbidity)		Sediment -- turbidity, erosion and siltation	Soils, nutrients -- total dissolved solids	Survey results are being incorporated into a fish IBI. Changes over 43 years demonstrated change in fish fauna with a loss of the majority of freshwater species replaced by marine invaders due to shifts in whole-basin ecology including higher water temp, salinity, turbidity, and lower runoff levels and maybe pollution.
Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.	State - Virginia	Tidal marsh			Organic carbon	The study examined various elements of constructed and natural wetlands. The authors found overall that the constructed wetland attained similar level of function as compared with a nearby natural wetland, except for soil organic carbon values, density of mature saltbush, and use by birds. A possible design performance standard might include physical marsh zone percentages, as this study's constructed wetland had a considerably greater percentage of subtidal zone area, compared with the two natural surrounding marshes. In addition, one might develop a performance standard that considers evidence of bird breeding (rather than just abundance of a species) and addresses plants that provide important known structural components to a wetland.

Pepin AL. 1998. The Relative Importance of Hydrology and Substrate in the Vegetation Dynamics of Restored Freshwater Wetlands (Wetland Restoration). Ph.D. Dissertation. George Mason University.	State - Virginia	Freshwater wetlands	Substrate related to vegetation dynamics			The authors address the question of whether hydrology or substrate is more important in controlling the vegetation dynamics of freshwater wetlands, engaging in a descriptive study of the vegetation of twelve restored wetlands of various ages and an experimental study of the growth and germination of two species. Both study indicated that hydrology, as expressed by vegetation zone (i.e., the relative elevation of subplots), is the primary controlling factor in the vegetation dynamics of these restored wetlands, across and within sites. However, the study also revealed direct evidence that within a particular hydrologic regime, substrate characteristics can affect the growth and germination of wetland plants and, at the landscape level, the nature of freshwater wetland plant communities. By implication, the article suggests that performance standards based on either variable would be valuable, and provides information to inform the specification of either type.

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries		Grain size and organic content, accretion		The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.

Hunt RJ, Walker JF, Krabbenhoft DP. 1999. Characterizing hydrology and the importance of ground water discharge in natural and constructed wetlands. Wetlands 19:458–472.	State - Wisconsin	Natural and constructed wetlands			Soils -- temperature and type as related to vegetation growth	The authors studied hydrology and ground water discharge at constructed and natural wetlands and found that sites with greater ground-water discharge had high water tables and more stable hydrographs. Ground-water direction and amount, magnitude of shallow ground-water flow, and areas of higher ground-water discharge influenced environmental factors such as physical hydrology, root-zone saturation, root-zone temperatures, and porewater chemistry; however, the authors observe that more research into wetland hydrology is necessary before researchers can accurately predict its dynamics. This study reveals the importance of hydrologic factors to wetland development. If also found that the constructed wetlands had root zones that remained frozen longer than the root zones of natural wetlands, due to greater plant cover and litter accumulation.
Ashworth SM. 1997. Comparison between restored and reference sedge meadow wetlands in south-central Wisconsin. Wetlands 17(4):518-527.	State - Wisconsin	Sedge meadow			Soil -- condition as related to plant growth and species diversity	Hydrology and soil parameters are important component for vegetation diversity. Although the goal of study in revegetating the site was met, the plant species diversity and distribution were different then the reference site. Performance standards can benefit

Soil/Sediment/Substrate/Nutrient Articles Reviewed

Ehrenfeld JG. 2000. Defining the limits of restoration: the need for realistic goals. Restor Ecol 8:2-9.	U.S.	Urban wetlands		Sediment -- example what happened with too fine	Nutrients -- Nitrogen cycling.	It is important to recognize diversity of conditions so need to have flexibility. Because language is not precise and restoration goals are likely to have different meanings to different players, there needs be a good mechanism to specify goals. There is a problem with species restoration and techno-arrogance when efforts to restore a particular species might negatively affect co-occurring species (microbial, floral, and faunal) that make up the ecosystem. The author points out that restoring one particular service may preclude the provision of other services.
Goodin J, Sudol M, Hough P. 2003. Mitigation guidance and action plan make improvements, outline future. National Wetlands Newsletter 25(2):3-17	U.S.	Freshwater wetlands				This article is a response to Sibbing's article in the NWN regarding how the new RGL fell short in its expectations. This rebuff admits that there is truth in past failures but they highlight areas of the agency's commitment to supporting no-net-loss through science-based decisions and a watershed perspective.

Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.	U.S.	Constructed wetlands			Soils	The article finds that "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time." Limited data indicates that dredged marshes may support a different community of birds, and have lower or smaller values associated with belowground biomass, organic carbon levels, soil nutrient reservoirs, and abundance of polychaetes and crustaceans. Streever also warns against single-season sampling as a way of characterizing wetlands -- though this method is often employed in the literature. Article is particularly relevant because it questions the trajectory model for wetland development.
Ettema CH, Coleman DC, Vellidis G, Lowrance R, Rathbun SL. 1998. Spatiotemporal distributions of bacterivorous nematodes and soil resources in a restored riparian wetland. Ecology 79 (8): 2721–2734	U.S. region	Riparian wetlands			Soils	This study was not very helpful for examining soil and vegetation performance standards and no reference sites were used for comparison.

Werner KJ, Zedler JB. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands 22 (3):451-466.	U.S. region - Midwest	Wetland meadows -- 3 wetlands with known history of stormwater inputs, sediment accumulation, and stands of Phalaris or Typha adjacent to Carex meadows			Soil profiles, soil organic matter content and nutrients, soil bulk density	The authors documented the role of sediment accumulation in the conversion of species-rich sedge meadows to stands of Phalaris arundinacea and Typha spp. The three wetland sites were selected on the basis that they had a history of urban stormwater inputs, sediment accumulation, and stands of Phalaris or Typha adjacent to Carex meadows. Results showed that microtopography of Carex tussocks facilitates the presence of other wetland plant species and is itself influenced by vegetative cover. Inflowing sediments reduced microtopograhic relief. Article implies that a measure of success for a mitigated sedge meadow would be the maintenance of micotopography and a standard for maximum sediment accumulation over time.
Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.	U.S. region - Pacific Northwest	Saltwater marshes		Erosion and sedimentation metrics		Study focuses on restoration of multiple wetlands in multiple river sites. The authors argue that fish occurrence and abundance are not sufficient to measure mitigation success. Habitat assessment must be functional, not focused on structure. They suggest three types of metrics to assess wetlands -- capacity, opportunity, and realized function metrics. Also, assessment must address landscape and system attributes.

McNair SA, Chow-Fraser P. 2003. Change in biomass of benthic and planktonic algae along a disturbance gradient for 24 Great Lakes coastal wetlands. Can. J. Fisheries and Aquatic Sciences 60(6):676-689.	U.S. region (Great Lakes)	Coastal wetlands -- 24 sites representing a range of environmental conditions			Water nutrient level	The authors sampled a range of wetlands from low to high functioning, assessing water quality, species, percent cover of submerged macrophytes, and chlorophyll content of planktonic algae and benthic algae. They concluded that "periphytic and planktonic chlorophyll biomass are good indicators of human-induced water-quality degradation, " and recommend that both benthic and planktonic algal biomass be routinely monitored as part of an effective wetland management program.

HGM/Geochemistry Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.	International - Belgium	Estuarine marsh	Geochemistry -- salinity, DO, channel morphology	There was no clear difference in species composition between natural and artificial marsh. Community structures were seasonally similar. Biomass was significantly higher in mature marsh, and abundance and length of frequency distribution also differed significantly. The dissimilarities between the two sites suggest that the estuarine nekton used the habitat differently in the different marshes. Article suggests that the lower amount of macroorganic material (food source) may explain the lower density and biomass of macrobenthics and thus, nekton.
Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.	State - California	Salt marshes	Geochemistry -- fish channels, salinity, elevation	The intertidal area of the mitigated (created) marsh was dominated by eurhaline sticklebacks and topsmelts. This area did not replace the intertidal and subtidal habitat of the natural marsh, which had more stable salinity and water temperatures and was used extensively by juvenile English sole. Possible performance indicators include (1) stability of salinity and water temperatures relative to a reference/control site, and (2) fish composition -- numbers of juvenile sole vs. other species.

HGM/Geochemistry Articles Reviewed

Clairain EJ Jr. 2000. Ecological models for assessing functions of hard claypan vernal pool wetlands in the Central Valley of California using the hydrogeomorphic (HGM) approach for wetland assessment. Ph.D. Dissertation. The Louisiana State University and Agricultural and Mechanical College.	State - California	Vernal pools	HGM	The conclusions drawn from the analysis indicated that three variables (disturbance quotient, maximum depth, and percent native to nonnative plant species) were proven to best assess relative disturbance. Five wetland functions were identified as being relevant to vernal pools and ecological models were developed for each function. The ecological models can be used to assess the capacity of wetlands to perform different functions, calculate project impacts on those functions, compute mitigation requirements to offset unavoidable impacts, and assess mitigation success.
Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.	State - California	Intertidal wetlands	Geochemistry	The composition of fish assemblages was related to particular physical parameters of channel habitats rather than natural vs. constructed status. Measures of individual species abundance and relative assemblage structure (fish) in constructed channels were not equivalent to those in natural wetlands. Soil salinity and nitrogen concentration (lack of) were linked to failure to replicate habitats of certain fish species. The proportion of two fish species differed significantly.

HGM/Geochemistry Articles Reviewed

Sanderson EW, Foin TC, Ustin SL. 2001. "A simple empirical model of salt marsh plant spatial distributions with respect to a tidal channel network." Ecological Modeling 139: 293-307.	State - California	Tidal salt marshes	Geochemistry / HGM	Study applied an ecological model to a marsh area with known vegetative parameters and assessed the accuracy of the model. Researchers found a large distribution of species in the large channels and a small distribution of species in the smaller channels. Distribution of species predicted by CISD conformed well with prior independent observations of the marsh area studied however results are highly dependant on the model form. Further study needs to be done.
Scataloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16(1): 24-37.	State - California (San Diego Bay)	Salt marshes	Elevation	Elevation impacts abundance of invertebrates. The natural, fully-vegetated marsh studied by the authors had two to three times as many individuals (epibenthics) as the four-year-old constructed marsh. The articles hypothesize that coarser sediment, lower organic matter, and relatively more sparse vegetative cover were potential causes of the significantly lower abundance in constructed marshes. The article suggests that epibenthic populations can serve as indicators for soil and vegetative wetland components, and also emphasizes the influence of these components on wetland development generally.

Lewis RR. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. Ecological Engineering 15(3-4):191-198.	State - Florida	Mangrove forest and tidal marshes	Elevation, tidal streams	This review paper focused on goals of marsh and mangrove restoration projects in southern Florida and claims that though these goals now typically seek functional equivalency and ecological restoration, rather than more simplistic aims (such as establishment of persistent vegetative cover), political will does not exist to properly fund wetland compensatory mitigation programs; thus, programs are unlikely to effectively meet new goals. The authors comment on multiple flaws of the Florida restoration projects, and their observations are highly relevant to improving design standards. They observe that because the science of functional analysis has lagged behind permitting for construction of mitigation wetlands, goal setting and success criteria based on functionality have been set in ad hoc and inconsistent manners -- and recommend that generally accepted criteria based on functionality be set and applied by managers who have been given effective training and understand principles of adaptive management.
Dionne M, Short FT, Burdick DM. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.	State - Maine and New Hampshire	Salt marsh	Geochemistry	Importance of elevation and patterns of tidal inundation on fish assemblages. The study notes the importance of biannual sampling, at least. There is also a discussion of the importance of tidal inundation patterns and elevation. From the results of the study, determinations cannot be made about fish growth/survival in disturbed marshes and compare them to natural marshes.

Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.	State - Minnesota	Low-order streams -- sites represent a land use gradient (18 categories)	HGM	The article discusses HGM extensively; sites chosen based on type and level of disturbance. Notes that a metric that combines ideas from IBI and HGM-focused approaches would most effectively evaluate riparian wetlands of streams. Specifically, the ideal assessment would consider the optimal scale for land use impacts on biota, and evaluate at that level: fish diversity and richness are highly correlated with land use at the 2500 m scale, and abundance at the 5000 m scale (catchments/watershed level); shrub carr, amphibians, and birds are influenced by landscape at a smaller scale (500 and 1000 m). The authors conclude that fish and birds are the strongest indicators of land use impacts, vegetation, amphibians, and invertebrates less so; these suggestions could inform selection of performance metrics.

Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressional wetlands	Geochemistry	This study discusses changes in upland areas as they affect species composition; discusses connection between land use and community characteristics -- 18 categories land use studied. Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606-627.	State - Minnesota and Wisconsin	Streams	HGM	Discusses importance of HGM in determining fish assemblage. Fish data from a large set of streams were collected and analysis sought correlation between assemblages and stream HGM; data from databases. The authors assessed fish assemblages in streams along a gradient of hydrologic variability, and found that fish attributes were correlated with nature of the hydrologic environment. Variable aquatic habitats were characterized by resource generalists, more silt-associated fish, slower fish, more small stream and wide-ranging fish species, weakly interactive opportunists, substratum generalists, more planktivores, omnivores, and generalist invertebrates, and fewer parasitic fish. Stable aquatic environments were characterized by a higher proportion of specialist species, highly interactive and limited by stable resources, more benthic invertebrates and parasitic fish, fewer omnivores, generalist invertebrates and planktivores, faster fish, and more rubble-associated fish. The results demonstrate that fish attributes can serve as indicators of environmental conditions.

Hauer FR, Smith RD. 1998. The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A. Freshwater Biol 40(3):517-530.	State - Montana	Riparian wetlands	HGM	This paper discusses the values of the HGM approach to measuring wetland functions in riparian wetlands. The authors found that HGM approach to the functional assessment of wetlands was a robust and easy method for protecting riparian wetlands. The authors explain that the HGM approach can be used to determine functional capacity of a wetland before a project, to predict likely functional performance after impact, aid in mitigation or restoration efforts, and monitor future success of mitigation and restoration. The authors mention that the similarities of implementation between IBI bioassessment and the HGM are many because both approaches combine biological and/or physical variable measurements into an index. Both methods compare data to reference sites.
Zampell, Robert and Bunnell, John. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645-658.	State - New Jersey (Mullica River Basin)	Streams	Land use, basin area, stream discharge	Land use to evaluate disturbance, basin area and stream discharge considered as impacts on species richness. Authors use natural stream set to construct and apply an IBI measuring degradation. The main purpose of article is to highlight use of PCA and DCA statistical tools in constructing IBIs based on fish assemblages. The article found that fish assemblage may change subtly with watershed disturbance gradients; the major difference associated with declining water quality concerned the occurrence of nonnative. Presence/absence of species was equally valid measure as relative abundance.

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh	Geochemistry	Development of wetland soil characteristics was positively related to marsh elevation. This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.
Craft C, Broome SW, Seneca ED. 1988. Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils. Estuaries 11(4):272-289.	State - North Carolina	Tidal marsh	Soil chemistry	Levels of available nitrogen, soil organic matter and epibenthic invertebrates were found to be significantly lower in constructed vs. natural marshes and that it could take 15-30 years or longer to reach comparable levels. It is often important to extend studies of created/restored wetlands over long periods of time.

Craft CB, Seneca ED, and Broome SW. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152(2):187-200.	State - North Carolina	Saltwater marshes	Geochemistry -- organic C, N, P, NH4, NO3, PO4, chemical characteristics	After five years, when emergent vegetation was established, there had not been a complete conversion from upland porewater and soil properties to normal wetland properties. According to the author these results may infer that creating wetlands on graded upland sites, may not initially duplicate that of the natural wetlands, which have been established for numerous years.
Sacco JN, Seneca ED, Wentworth TR. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17(2):489-500.	State - North Carolina	Salt marshes	Elevation	Notes importance of elevation to infaunal development (that is, should resemble natural conditions). The study found that though natural and artificial marshes showed nearly equal proportions of surface feeders and sub-surface deposit feeders, the absolute densities of infaunal organisms were significantly greater in the natural marshes. The authors concluded that though artificial marshes are capable of supporting infaunal structures similar to those of natural marshes, they are unable to support similar densities due to their lower organic matter content. Yet marsh age is not the dominant influence on soil organic matter accumulation -- the authors discuss other factors that influence accumulation. The article highlights the importance of soil characteristics in determining wetland function, suggesting the potential value of soil-based performance standards.

HGM/Geochemistry Articles Reviewed

Shaffer PW, Kentula ME, Gwin SE. 1999. Characterization of wetland hydrology using hydrogeomorphic classification. Wetlands 19(3):490-504.	State - Oregon	Freshwater emergent, open-water, and riverine wetlands	HGM	The study found that no relationship between hydrologic attributes and land use, soil associations, or wetland area. They did find highly significant differences in wetlands with or without a water-retention structure, and by wetland type (natural or created). In addition, they found significant differences in hydrologic variables for wetlands in different HGM classes. They argue for the development of regional wetland subclasses; other authors reinforce this point when they address the importance of accurate wetland classification as a prerequisite for accurate IBI baselines.
Stauffer AL, Brooks RP. 1997. Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1): 90-105.	State - Pennsylvania	Marsh	pH	Plots amended with salvaged marsh soils (SMS) had significantly greater species richness than control plots, but not significantly greater density; significantly more cover than control plots and more hydric plants. The Shannon index (diversity) was significantly higher on SMS than control plots and SMS plots had significantly more organic matter than control plots after the first, but not second, season. Leaf litter plots contained more organic matter than hand-planted plots after the first season. The article is not very relevant to performance standards except for its comment that “Without the correct hydrology, failure of the newly created wetland is likely.”

Wardrop DH, Brooks RP, Bishel-Machung L, Cole CA. 1998. Hydrogeomorphic (HGM) functional assessment models for Pennsylvania wetlands. Report 98–6. Penn State Cooperative Wetlands Center, University Park, PA.	State - Pennsylvania	Freshwater wetlands	HGM	Found that in non-depressional wetlands, the mechanism for sediment removal appears to be related to the level of structural diversity of vegetation as well as to site microtopography. Microtopography also is important to short-term flood storage. Performance or design standards could be based on any of these variables.
Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265-278.	State - Pennsylvania	Slope, headwater floodplain, and mainstem floodplain wetlands.	HGM	The authors compared the hydrology characteristics of three HGM subclasses using comparable long-term data sets. The study found strong differences between OR and PA in each of the 3 HGM subclasses. Although the 2 regions were similar in climate, there were very different water regimes. The most successful comparisons were with slope wetlands, and big difference between the forested and mainstem floodplain. This is discouraging because the use of HGM has been limited by the length of time needed to develop appropriate data sets and functional assessment models.
Buffington JM, Kilgo JC, Sargent RA, Miller KV, Chapman BR. 2000. Effects of restoration techniques on the breeding bird communities in a thermally-impacted bottomland hardwood forest. Ecol. Eng. 15: S115–S120.	State - South Carolina	Bottomland hardwood forest	Geochemistry	Thermal discharge negatively impacted forest. The greater abundance of Red-winged Blackbirds in the lower section versus the upper section likely reflects a gradual change in vegetation downstream. The vegetation there was shorter and there were more frequent grassy openings. This study shows how different species of birds can be indicators of wetland functions.

HGM/Geochemistry Articles Reviewed

Kirkman LK, Lide RF, Wein G, Sharitz RR. 1996. Vegetation Changes and Land Use Legacies of Depressional Wetlands of the Western Coastal Plain of South Carolina. Wetlands Vol.16, No. 4.	State - South Carolina	Depressional wetlands	HGM	The authors found that it was not possible to separate recovery trajectories from other successional pathways, initial hydrogeomorphic differences, and/or continued human influences. They also found that the many of the sites developed into relatively stable, herb-dominated bays, a progression not necessarily part of succession toward hardwood forest. Both observations cast doubt on the viability of specifying accurate development trajectories for performance standards.
LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	Salinity	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Topography, water chemistry, temperature	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.
Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf	U.S.	Freshwater wetlands	Acidification, salinization, thermal alteration, turbidity, shade, dehydration, inundation	Authors comment on a wetland IBI proposed by Galatowitsch and co-authors, noting that the following variables are strong indicators of wetland health in the noted wetland type: small river floodplain -- species richness and proportion Cyprinids; medium river floodplain - species richness; large river floodplain -- proportion piscivores, fish abundance, proportion Catostomids; non-calcareous littoral wetlands -- total fish abundance; calcareous wetlands -- species richness, abundance, proportion Cyprinids, and number sunfish; forest and prairie glacial marshes -- total richness and abundance. The authors also discusses an IBI proposed by Schultz and co-authors.

Beck MW, Heck KL, Able KW, Childers DL, Eggleson DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. Issues in Ecology 11 (Spring): 1-12.	U.S.	Salt marshes, mangroves, seagrass meadows	HGM	Article comments on wetlands as nurseries, but much is generally applicable. Emphasizes the need for assessment that accounts for growth and juvenile migration to adult habitats. Wetland characteristics must be assessed on a unit-area basis.
Brinson MM. 1995. The HGM approach explained. National Wetland Newsletter. 17(6):7-13.	U.S.		HGM	An explanation of HGM. The strengths of HGM are evaluation of wetlands within a landscape setting based on functional assessment and a solid format to measure compensation for wetland loss and gains. Brinson argues that the because HGM uses reference wetlands that there is little room for false interpretation - or traps, that it is a rigorous articulation of functions and a separation of functions from values. Brinson claims that one of the goals of the HGM approach was to make it rapid.

Brinson MM. 1996. Assessing wetland functions using HGM. National Wetland Newsletter. 18(1):10-16.	U.S.		HGM	Brinson describes how a function is estimated. First, he says, is to distinguish between natural variation and variation that is a result of human activities -- it is human alteration of wetlands that HGM is designed to detect and measure. The downside seems to be that the method requires a team of wetland scientists (hydrology, biogeochemistry, soils, plant ecology, animal community or wildlife ecology). Brinson himself states that he is concerned that -as of 1996- there appeared to be a low level of support for implementing the HGM approach despite the perceived need for a functional accounting system.
Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.	U.S.	Streams and rivers generally	HGM	Notes that fish assessments reflect a holistic picture which includes HGM, also hydrology and water quality. This is one of Karr's earliest articles, in which he first proposes the fish-based IBI. He argues for the evaluation of several major taxa in any IBI, and proposes an IBI that uses 12 fish community parameters, in two categories: species composition and richness and ecological factors. He observes that IBI descriptive accuracy requires an accurate baseline, a representative sample of the fish (or other target species) at the sample site and the larger geographic area of interest, and a scientist's ability to adjust the IBI to local conditions.

Developmental Trajectory Articles Reviewed

Title / Reference information	Region	Wetland type	Other	Comments
Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restoration Ecol 7:69-73.	State - California	Salt marshes	Developmental trajectories	The constructed and reference sites exhibited high interannual variation and lack of directional change for the variables studied, and results suggest little chance that relevant targets for the restoration sites would be met in the near future. The authors argue that hypothetical models that suggest restoration and creation sites follow a smooth path of development toward conditions in natural reference sites, though rampant in the literature, are generally wrong-headed. They suggest alternative management and mitigation models and policies.
Morgan PA, Short FT. 2002. Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restoration Ecology 10(3):461-473.	State - Maine and New Hampshire	Salt marsh	Developmental trajectories	The study found that overall, mean values for constructed wetlands were significantly lower than natural reference values for aboveground biomass, soil organic matter content, and plant species richness. However, the study supports functional trajectory development via "space-for-time substitution" (that is, comparing marshes of different ages rather than one marsh over many years): it found that some wetland functions (primary production, sediment deposition, plant species richness) "may reach natural site values relatively quickly (<10 years)," though other functions (soil organic matter content) would take longer to reach natural values. The study also notes that debate continues over whether development trajectories can be specified and used as performance metrics.

Developmental Trajectory Articles Reviewed

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.	State - North Carolina	Saltwater marsh	Developmental trajectories	This study measures vegetation and soil development in a constructed wetland. It is a good commentary on functional trajectories for soil. Craft et al. (1999) AG biomass and MOM of Spartina were found to follow non-linear trajectories with age before reaching equivalence. Spartina alterniflora AG biomass in lower elevations frequently developed to levels similar to natural reference wetlands within 3-5 yrs and maintained those levels for 15 yrs of the study. MOM developed at approximately the same pattern (but slower) as AG biomass; MOM (0 to 10cm): consistently reached ref site "equivalence" in the S. alterniflora stands after 2 yrs.
LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	Developmental trajectories	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.

Developmental Trajectory Articles Reviewed

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.	State - Washington (Puget Sound)	Estuaries	Developmental trajectories	The authors are critical of the hypothesis that wetland components follow developmental trajectories. They found that "Taxa richness of epibenthic organisms and fishes, and densities of fishes, all approached asymptotic trajectories within 3-5 years, and three indicators of bird usage. . .(but) sediment organic content. . .infauna taxa richness and density, and proportion of harpacticods and oligochaetes in the epibenthos increases slowly or remained relatively depressed." They emphasize that landscape patterns often determine wetland function, and argue that it ultimately may be necessary to supplant current descriptive means of assessing functional equivalency with simple, controlled manipulative experiments.
Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.	U.S.	Constructed wetlands	Developmental trajectories	The article finds that "Cumulative quantitative data do not support the contention that dredged material sites become increasingly similar to nearby natural marshes over time." Limited data indicates that dredged marshes may support a different community of birds, and have lower or smaller values associated with belowground biomass, organic carbon levels, soil nutrient reservoirs, and abundance of polychaetes and crustaceans. Streever also warns against single-season sampling as a way of characterizing wetlands -- though this method is often employed in the literature. Article is particularly relevant because it questions the trajectory model for wetland development.

Landscape/General Articles Reviewed

Title / Reference information	Region	Wetland type	Parameter	Comments
Cao Y, Bark AW, Williams WP. 1996. Measuring the response of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic and diversity indices. Hydrobiologia 341: 1-19.	International - United Kingdom	Lowland river	Effectiveness of different statistical methods in revealing differences along a pollution gradient	Authors report that species abundance patterns in their study were sig. different among sites of varying water quality with more rare species in the least impacted site. Further, they stress that species abundance patterns are most likely to vary among sites and samples in any study and some sample methods delete rare spp. or spp that occur infrequently (as is often the case with rare species) and that this results in an inadequate or flat out wrong interpretation of the biological condition of the site. The authors provide results that demonstrate that sample size can greatly affect the comparison of species richness and may underestimate differences among sites.
Breaux A, Serefiddin F. 1999. Validity of performance criteria and a tentative model for regulatory use in compensatory wetland mitigation permitting. Environ. Manage. 24(3):327-336.	State - California	Riparian, perennial tidal, perennial nontidal, and seasonal wetlands	Measures generally as well as citing a few specific examples in various categories	Authors stress the need for standardized language. Overall, they found that vegetation was the most commonly measured mitigation feature with hydrology in second place. Wildlife was measured, but usually as a qualitative assessment as "evidence of use" and target wildlife generally included or was restricted to endangered spp. Water quality, soils, and invertebrates were the least cited criteria. In sum, they feel no-net-loss can't be realized until performance criteria are set. They argue that vegetation and wildlife measures used in coordination is the most promising approach to evaluate performance standards.

Landscape/General Articles Reviewed

Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.	State - Minnesota	Riverine, littoral, and depressional wetlands	Impact of habitat dynamics on species composition	Five metrics were consistently related to specific land use (or disturbance) across several sites: proportion wetland birds, wetland bird richness, proportion insectivorous species, importance of the plant Carex, importance of invasive perennials. Authors state that birds are most useful in wetland monitoring while amphibians are the least. The note that changes in species composition cannot be measured or affected only changes in the wetland itself. Changes also may reflect upland changes, habitat isolation, matrix conditions, barriers to animal movement, other factors.
Fore LS, Karr JR, Conquest LL. 1994. Statistical properties of an index of biological integrity used to evaluate water resources. Canadian J. Fish. Aquat. Sci. 51: 1077-1087.	State - Ohio	Stream	General	Statistical properties of IBI supported the use of standard analysis techniques such as ANOVA for hypothesis testing. IBI is an effective monitoring tool that can be used to communicate qualitative assessments. The article also notes IBI problems -- cannot provide independent, replicate measurements. The author states uncertainties about the IBI's ability to measure changes (over time and location). There is a tendency of the IBI's to overestimate quality at degraded sites and underestimate it for pristine sites.
Fore LS, Karr JR, Wisseman RW. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. J N Am Benthol Soc 15(2):212-231.	State - Oregon	Streams -- disturbed habitat (logging and associated roads)	General	Benthic IBI were used to compare disturbed from minimally disturbed sites and found that IBI scores were significantly lower for streams in watersheds with higher levels of human activity. Also tested were rapid bioassessment protocols but found these failed to detect differences among sites that IBI did detect.

Landscape/General Articles Reviewed

LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.	State - South Carolina	Saltwater marsh	General	The proportions of sand, silt, clay and organic content were similar between marsh zones and nearby natural marsh. Values of above and below-ground biomass compared well with reported values for natural marshes, and species composition, fish and shellfish assemblages, were all similar/normal. The article is useful mainly because it substantiates claims that establishing a functionally-similar marsh is possible in a short time frame.
Morgan KL, Roberts TH. 2003. Characterization of wetland mitigation projects in Tennessee, U.S.A. Wetlands 23(1):65-69.	State - Tennessee	Constructed wetlands -- 11 enhancement, 10 preservation	1987 USACE Wetland delineation manual requirements	This study evaluated whether wetland mitigation projects resulted in jurisdictional wetlands. It identified design problems associated with the studied projects, including the failure of mitigation projects to create appropriate water budgets, inappropriate excavation depths, excavations that lacked bottom contours, inappropriately steep upland boarders, vegetation planted at inappropriate elevations, failure to properly follow the approved mitigation plan, failure to create canopy gaps for shade-intolerant species, and planting species not approved in the permit. The study found that the majority (72%) of the wetlands studied contained less wetland area than specified in the permit. All of these considerations are relevant both to design standards and performance assessments.
Bartoldus CC. 1999. A Comprehensive Review of Wetland Assessment Procedures: A Guide for Wetland Practitioners. Environ.. Concern Inc.	U.S.		General	An extensive introduction to 40 different wetland assessment procedures that provide a procedure for identifying, characterizing, or measuring wetland functions and/or social benefits. A very useful book for those involved with wetland assessment.

Landscape/General Articles Reviewed

Ehrenfeld JG. 2000. Evaluating wetlands within an urban context. Ecological Engineering. 15(3-4): 253-265.	U.S.	Urban wetlands	Urban	The author addresses the fact that urbanization often alters wetland hydrology, geomorphology, and ecology, and wetlands in these settings often function differently than those in non-urban lands. Therefore, evaluation of restoration success in urban settings will be on a different scale than those in non-urban settings. This paper discusses two levels of assessment for wetland restoration in urban settings: 1) An assessment of the extent of urban influence that restricts the potential for performance of the conventionally defined functions and takes into consideration social valuation, and 2) The development of a modified assessment for functional capacity within the urban context. This paper offers thoughtful insight for wetland managers in an urban setting.
Karr J. 1991. Biological integrity: a long-neglected aspect of water resources management. Ecological Applications 1(1): 66-84.	U.S.	Water resources generally	Invertebrate Community Index (ICI), Rapid Bioassessment Protocol (RBP)	The article describes in detail the original Karr IBI, its advantages and disadvantages. It also discusses techniques for modification. Karr observes that an IBI that includes greater numbers of metrics assessing multiple taxa will be relatively more likely to be widely applicable and relevant to different environmental conditions. He also notes that the intelligent development of an IBI and its component metrics is relatively more important than the choice of any one (relatively reasonable) component, noting that "I believe that just about any taxon could be selected and produce a reasonable level of insight about the water resource if appropriate wisdom is brought to bear on development of robust and general metrics."

Landscape/General Articles Reviewed

Kentula ME. 2000. Perspectives on setting success criteria for wetland restoration Ecological Engineering 15(3-4):199-209.	U.S.	Restored wetland	General	This theoretical article focuses on how stakeholders in the restoration and mitigation process define "performance success" and similar, related terms. The author calls for more research into the basic structure and function of wetland ecosystems and the functionality of restored or created wetlands, arguing that continued information-gathering and adaptive management policies eventually will allow for the development of more successful and effective design specifications and performance standards.
Zedler JB. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Front Ecol Environ 1(2):65-72.	U.S. region - Midwest	Palustrine and wet prairie wetlands	General	Effective wetland restoration requires careful planning, and ideally involves landscape-design and adaptive management models. Typical problems with restoration include restoring the correct hydrology (often water levels are too high or low, plantings may die, and animals may fail to use the site) and restoring biodiversity. In areas of high historic disturbance, the best restoration approach may be to aim for structural and functional equivalence, but be willing to recognize that the wetland system may no longer be up to functioning at that level due to alterations in the surrounding uplands and watershed.

REFERENCES

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf.

Adamus PR, Danielson TJ, Gonyaw A. 2001. Indicators for Monitoring Biological Integrity of Inland, Freshwater Wetlands: A Survey of North American Technical Literature (1990-2000), Office of Water, U.S. Environmental Protection Agency, Washington, DC. http://www.epa.gov/owow/wetlands/bawwg/monindicators.pdf

Adamus PR. 1995. Validating a habitat evaluation method for predicting avian richness. Wildlife Soc. Bull. 23(4):743-749.

Amoros C, Bornette G, Henry CP. 2000. A vegetation-based method for ecological diagnosis of riverine wetlands. Environ. Manage. 25(2):211-227.

Aronson J, Floret C, Le Floc'h E, Ovalle C, Pontanier R. 1993. Restoration and rehabilitation of degraded ecosystems in arid and semi-arid lands. I. A review from the South. Restoration Ecology 1:8-17.

Ashworth SM. 1997. Comparison between restored and reference sedge meadow wetlands in south-central Wisconsin. Wetlands 17(4):518-527.

Austin JE, Sklebar T, Guntenspergen GR, Buhl TK. 2000. Effects of Roadside Transect Width on Waterfowl and Wetland Estimates. Wetlands. 20(4): 660-670

Azous AL, Bowles MB, Richter KO. 1998. Reference Standards and Project Performance Standards for the Establishment of Depressional Flow-Through Wetlands in the Puget Lowlands of Western Washington. Renton, WA: King County Department of Development and Environmental Services. http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio

Babbitt KJ, Tanner GW. 2000. Use of temporary wetlands by anurans in a hydrologically modified landscape. Wetlands 20(2):313-322.

Balian LV, Ghasabian MG, Adamian MS, Klem D Jr. 2002. Changes in the waterbird community of the Lake Sevan–Lake Gilli area, Republic of Armenia: a case for restoration. Biological Conservation. 106(2): 157-163.

Barbour MT, Gerritsen J. 1996. Sub-sampling of benthic samples: A defense of the fixed-count method. J. North Am. Benthol. Soc. 15:386-391.

Barker JR, Ringold, PL, Bollman M. 2002. Patterns of tree dominance in coniferous riparian forests. Forest Ecology and Management 166:311-329.

Barry WJ, Garlo AS, Wood CA. 1996. Duplicating the mound-and-pool microtopography of forested wetlands. Restoration and Management Notes 14(1): 15-21.

Bartoldus CC. 1999. A Comprehensive Review of Wetland Assessment Procedures: A Guide for Wetland Practitioners. Environ.. Concern Inc.

Beck MW, Heck KL, Able KW, Childers DL, Eggleson DB, Gillanders BM, Halpern BS, Hays CG, Hoshino K, Minello TJ, Orth RJ, Sheridan PF, Weinstein MP. 2003. The role of nearshore ecosystems as fish and shellfish nurseries. Issues in Ecology 11 (Spring): 1-12.

Bedford B. 1996. The need to define hydrologic equivalence at the landscape scale for freshwater wetland mitigation. Ecological Applications 6:57-68.

Bedford BL 1999. Cumulative effects on wetland landscapes: Links to wetland restoration in the United States and Canada. Wetlands 19(4):775-788.

Berger JJ. 1991. A generic framework for evaluating complex restoration and conservation projects. The Environmental Professional 13:254-262.

Bishel-Machung L, Brooks RP, Yates SS, Hoover KL. 1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. Wetlands 16(4):532-541.

Blair RB. 1996. Land use and avian species diversity along an urban gradient. Ecol. Appl. 6: 107-112.

Blocksom KA. 2003. A performance comparison of metric scoring methods for a multimetric index for Mid-Atlantic highlands streams. Environ. Manage. 31(5):670-682.

Bolscher B. 1995. Niche requirements of birds in raised bogs: Habitat attributes in relation to bog restoration. In: Wheeler BD, Shaw SC, Fojt WJ, Robertson RA, eds. Restoration of Temperate Wetlands. John Wiley & Sons Ltd. Pp. 359-378.

Brawley AH, Warren RS, Askins RA. 1998. Bird use of restoration and reference marshes within the Barn Island Wildlife Management Area, Stonington, Connecticut, USA. Environ. Manage. 22(4):625-633.

Breaux A, Serefiddin F. 1999. Validity of performance criteria and a tentative model for regulatory use in compensatory wetland mitigation permitting. Environ. Manage. 24(3):327-336.

Brinson MM, Rheinhardt R. 1996. The role of reference wetlands in functional assessment and mitigation. Ecol. Appl. 6(1):69-76.

Brinson MM. 1993. Changes in the functioning of wetlands along environmental gradients. Wetlands 13(2): 65-74.

Brinson MM. 1995. The HGM approach explained. National Wetland Newsletter. 17(6):7-13.

Brinson MM. 1996. Assessing wetland functions using HGM. National Wetland Newsletter. 18(1):10-16.

Brooks RP, Cole CA, Wardrop DH, Bishel-Machung L, Prosser DJ, Campbell DA, Gaudette MT. 1996. Wetlands, wildlife, and watershed assessment techniques for evaluation and restoration (W3ATER). Vol. 1, 2A, and 2B, , Penn State Coop. Wetlands Ctr. Rep. No. 96-2, University Park. http://www.cas.psu.edu/docs/CASDEPT/FOREST/wetlands/Research/Publist.htm#1999

Brooks RP, O'Connell TJ, Wardrop DH, Jackson LE. 1998. Towards a Regional Index of Biological Integrity: The example of forested riparian ecosystems. Environ. Monitoring and Assessment 51(1-2):131-143.

Brown MT. 1991. Evaluating created wetlands through comparisons with natural wetlands. U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis, OR. www.aswm.org/science/mitigation/

Brown SC, Bedford BL. 1997. Restoration of wetland vegetation with transplanted wetland soil: An experimental study. Wetlands 17(3):424-437.

Brown SC, Smith CR. 1998. Breeding season bird use of recently restored versus natural wetlands in New York. J. Wildl. Manage. 62(4):1480-1491.

Brown SC, Veneman PLM. 2001. Effectiveness of compensatory wetland mitigation in Massachusetts, U.S.A. Wetlands 21(4):508-518.

Brown SC. 1999. Vegetation similarity and avifaunal food value of restored and natural marshes in northern New York. Restoration Ecology 7(1): 56-68.

Budelsky RA, Galatowitsch SM. 2000. Effects of water regime and competition on the establishment of a native sedge in restored wetlands. Journal of Applied Ecology 37: 971-985.

Buffington JM, Kilgo JC, Sargent RA, Miller KV, Chapman BR. 2000. Effects of restoration techniques on the breeding bird communities in a thermally-impacted bottomland hardwood forest. Ecol. Eng. 15: S115–S120.

Burchett MD, Allen C, Pulkownik A, Macfarlane G. 1999. Rehabilitation of Saline Wetland, Olympics 2000 Site, Sydney (Australia)—II: Saltmarsh Transplantation Trials and Application. Marine Pollution Bulletin 37(8-12):526-534.

Campbell DA, Cole CA, Brooks RP. 2002. A Comparison of Created and Natural Wetlands in Pennsylvania, USA. (Probably Wetlands Ecology & Management 10:41-49.

Cao Y, Bark AW, Williams WP. 1996. Measuring the response of macroinvertebrate communities to water pollution: a comparison of multivariate approaches, biotic and diversity indices. Hydrobiologia 341: 1-19.

Carstenn SM. 2000. Self organization and successional trajectories of constructed forested wetlands. Ph.D. Dissertation. University of Florida.

Chamberlain RH, Barnhart RA. 1993. Early use by fish of a mitigation salt marsh, Humbolt Bay, California. Estuaries 16(4):769-783.

Chambers JC, Brown RW, Williams BD. 1994. An evaluation of reclamation success on Idaho's phosphate mines. Restoration Ecology 2:4-16.

Chessman BC, Trayler KM, Davis JA. 2002. Family- and species-level biotic indices for macroinvertebrates of wetlands on the Swan Coastal Plain, Western Australia. Marine and Freshwater Research 53(5):919-930.

Chovanec A. 1994. Man-made wetlands in urban recreational areas: A habitat for endangered species? Landscape and Urban Planning 29(1): 43-54.

Clairain EJ Jr. 2000. Ecological models for assessing functions of hard claypan vernal pool wetlands in the Central Valley of California using the hydrogeomorphic (HGM) approach for wetland assessment. Ph.D. Dissertation. The Louisiana State University and Agricultural and Mechanical College.

Cole CA, Brooks RP, Shaffer PW, Kentula ME. 2002. Comparison of hydrology of wetlands in Pennsylvania and Oregon (U.S.A) as an indicator of transferability of hydrogeomorphic (HGM) functional models between regions. Environ. Manage. 30(2):265-278.

Cole CA, Brooks RP, Wardrop DH. 1997. Wetland hydrology and water quality as a function of hydrogeomorphic (HGM) subclass. Wetlands 17(4):456–467.

Cole CA, Brooks RP, Wardrop DH. 2001. Assessing the relationship between biomass and soil organic matter in created wetlands of central Pennsylvania, U.S.A. Ecological Engineering 17(4):423-428.

Cole CA, Brooks RP. 2000. A comparison of the hydrologic characteristics of natural and created mainstem floodplain wetlands in Pennsylvania. Ecol. Eng. 14(3):221-231.

Cole CA, Brooks RP. 2000. Patterns of wetland hydrology in the Ridge and Valley province, Pennsylvania, USA. Wetlands 20(3):438-447.

Cole CA, Kooser JG. 2002. HGM: hidden, gone, missing? National Wetlands Newsletter 24(2):1-18.

Cole CA. 1997. Study Raises Questions About Use of Restored Mangroves by Birds, Suggests Value of Organic Soil Amendments (Florida). Restoration and Management Notes 15(2):190 - 191.

Cole CA. 2002. The assessment of herbaceous plant cover in wetlands as an indicator of function. Ecological Indicators 2:287-293.

Contreras-Balderas S, Edwards RJ, Lozano-Vilano MD, Garcia-Ramirez ME. 2002. Fish biodiversity changes in the Lower Rio Grande/RioBravo, 1953-1996 - A review. Reviews in Fish Biology and Fisheries. 12(2):219-240.

Cooper CB, Anderson SH. 1996. Significance of invertebrate abundance to dabbling duck brood use of created wetlands. Wetlands 16(4): 557-563.

Craft C, Broome S, Campbell C. 2002. Fifteen years of vegetation and soil development after brackish-water marsh creation. Restoration Ecology 10(2):248-258.

Craft C, Broome SW, Seneca ED. 1988. Nitrogen, phosphorus and organic carbon pools in natural and transplanted marsh soils. Estuaries 11(4):272-289.

Craft C, Reader J, Sacco JN, Broome SW. 1999. Twenty-five years of ecosystem development of constructed Spartina alterniflora (Loisel) marshes. Ecol. Appl. 9:1405–1419.

Craft C. 2000. Co-development of wetland soils and benthic invertebrate communities following salt marsh creation. Wetlands Ecol. Manage. 8(2/3):197-207.

Craft CB, Seneca ED, and Broome SW. 1991. Porewater chemistry of natural and created marsh soils. J. Exp. Mar. Biol. Ecol. 152(2):187-200.

Creighton JH, Sayler RD, Tabor JE, Monda MJ. 1997. Effects of wetland excavation on avian communities in eastern Washington. Wetlands 17(2):216-227.

Dahm CN, et al. 1995. An ecosystem view of the restoration of the Kissimmee River. Restore Ecol 3:225-238.

Dale VH, Beyeler SC. 2001. Challenges in the development and use of ecological indicators. Ecological Indicators 1(1):3-10.

David PG. 1999. Response of exotics to restored hydroperiod at Dupuis Reserve, Florida. Restoration Ecology 7(4): 407-410.

Davis S, Golladay SW, Vellidis G, Pringle CM. 2003. Macroinvertebrate biomonitoring in intermittent coastal plain streams impacted by animal agriculture. J. Environmental Quality 32(3):1036-1043

Dawe NK, Bradfield GE, Boyd WS, Trethewey DEC, Zolbrod AN. 2000. Marsh creation in a northern Pacific estuary: is thirteen years of monitoring vegetation dynamics enough? Conservation Eco. 4(2):12. [online] URL: http://www.consecol.org/vol4/iss2/art12

De Weese JM. 1996. Vernal Pool Construction Monitoring Methods and Habitat Replacement Evaluation: Ecology, Conservation, and Management of Vernal Pool Ecosystems.

DeKeyser ES, Kirby DR, Ell MJ. 2003. An index of plant community integrity: development of the methodology for assessing prairie wetland plant communities. Ecological Indicators 3(2):119-133.

Delaney TP, Webb JW, Minello TJ. 2000. Comparison of Physical Characteristics Between Created and Natural Estuarine Marshes in Galveston Bay, Texas. Wetlands Ecology and Management 8(5):343-352.

Delaney TP, Webb JW, Minello TJ. 2000. Comparison of Physical Characteristics Between Created and Natural Estuarine Marshes in Galveston Bay, Texas. Wetlands Ecology and Management 8(5):343-352.

Delaune RD, Buresh RJ, Patrick Jr WH. 1979. Relationship of soil properties to standing crop biomass of Spartina alterniflora in a Louisiana marsh. Estuarine Coastal Marine Sci. 8:477–487.

Delphey PJ, Dinsmore JJ. 1993. Breeding bird communities of recently restored and natural prairie potholes. Wetlands 13: 200-206.

Detenbeck NE, Galatowitsch SM, Atkinson J, Ball H. 1999. Evaluating perturbations and developing restoration strategies for inland wetlands in the Great Lakes Basin. Wetlands 19(4):477-489.

Dionne M, Short FT, Burdick DM. 1999. Fish utilization of restored, created, and reference salt-marsh habitat in the Gulf of Maine. American Fisheries Society Symposium 22: 384-404.

Dixit SS, Smol JP, Charles DF, Hughes RM, Paulsen SG, Collins GB. 1999. Assessing water quality changes in the lakes of the northeastern United States using sediment cores. Canadian Journal of Fisheries and Aquatic Science 56(1): 131-152.

Doberstein CP, Karr JR, Conquest LL. 2000. The effect of fixed-count subsampling on macroinvertebrate biomonitoring in small streams. Freshwater Bio. 44(2):355-371.

Dodson SI, Lillie RA. 2001. Zooplankton communities of restored depressional wetlands in Wisconsin, U.S.A. Wetlands 2(2):292-300.

Drake MT, Pereira DL. 2002. Development of a fish-based index of biotic integrity for small inland lakes in central Minnesota. N. AM. J. of Fisheries Management 22(4):1105-1123.

Duel H, Specken BPM, Denneman WD, Kwakernaak C. 1995. The habitat evaluation procedure as a tool for ecological rehabilitation of wetlands in the Netherlands. Wat. Sci. Tech. 31(8): 387-391.

Eames JM. 1998. Landscape Features As Predictors of the Functional Performance of wetlands (Palustrine, Illinois, Land Use). Ph.D. Dissertation. University of Illinois at Chicago.

Edwards PJ, Webb NR, Urbanska KM, Bornkamm R. 1997. Chapter 17: Restoration ecology: science, technology, and society. In: Urbanska KM, Webb NR, Edwards PJ, eds. Restoration Ecology and Sustainable Development. Cambridge: University Press.

Ehrenfeld JG. 2000. Defining the limits of restoration: the need for realistic goals. Restor Ecol 8:2-9.

Ehrenfeld JG. 2000. Evaluating wetlands within an urban context. Ecological Engineering. 15(3-4): 253-265.

Ellison LC. 2000. Ecology of a restored wetland in the Trinity River floodplain of Texas. Ph.D. Dissertation. Texas A&M University.

Ettema CH, Coleman DC, Vellidis G, Lowrance R, Rathbun SL. 1998. Spatiotemporal distributions of bacterivorous nematodes and soil resources in a restored riparian wetland. Ecology 79 (8): 2721–2734

Ewel JJ. 1990. Restoration is the ultimate test of ecological theory. In: Jordan WR, ed. Restoration Ecology - a synthetic approach to ecological research. Cambridge: Cambridge University Press.

Fairbairn SE, Dinsmore JJ. 2001. Local and landscape-level influences on wetland bird communities of the prairie pothole region of Iowa, USA. Wetlands 21(1):41-47

Farley GH, Ellis LM, Stuart JN, Scott NJ Jr. 1994. Avian species richness in different-aged stands of riparian forest along the middle rio grande, new Mexico. Conservation Biology 8(4):1098-1108

Fonseca MS, Kenworthy WJ, Colby DR, Rittmaster KA, Thayer GW. 1990. Comparisons of fauna among natural and transplanted eelgrass Zostera marina meadows: criteria for mitigation. Marine Ecology Progress Series 65: 251-264.

Fore LS, Karr JR, Conquest LL. 1994. Statistical properties of an index of biological integrity used to evaluate water resources. Canadian J. Fish. Aquat. Sci. 51: 1077-1087.

Fore LS, Karr JR, Wisseman RW. 1996. Assessing invertebrate responses to human activities: evaluating alternative approaches. J N Am Benthol Soc 15(2):212-231.

Galatowitsch SM, van der Valk A. 1996. The vegetation of restored and natural prairie wetlands. Ecol Appl 6:102-112.

Galatowitsch SM, van der Valk AG. 1996. Characteristics of Recently Restored Wetlands in the Prairie Pothole Region. Wetlands 16(1):75-83.

Galatowitsch SM, Whited DC, Tester JR, Power M. 1998. Development of community metrics to evaluate recovery of Minnesota wetlands. Journal of Aquatic Ecosystem Stress and Recovery 6:217-234.

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetlands 13(1):25-31.

Gibbs JP. 2000. Wetland loss and biodiversity conservation. Conservation Biology 14(1):314-317.

Gibson KD, Zedler JB, Langis R. 1994. Limited response of cordgrass (Spartina foliosa) to soil amendments in constructed salt marshes. Ecological Applications 4:757–767.

Goodin J, Sudol M, Hough P. 2003. Mitigation guidance and action plan make improvements, outline future. National Wetlands Newsletter 25(2):3-17

Griffith MB, Husby P, Hall RK, Kaufmann PR, Hill BH. 2003. Analysis of macroinvertebrate assemblages in relation to environmental gradients among lotic habitats of California's Central Valley. Environ. Monitoring and Assessment 82(3):281-309.

Gwin SE, Kentula ME, Shaffer PW. 1999. Evaluating the effects of wetland regulation through hydrogeomorphic classification and landscape profiles. Wetlands 19(3):477-489.

Haltiner J, Zedler JB, Boyer KE, Williams GD, Callaway JC. 1997. Influence of physical properties on the design, functioning and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4(2): 73-94.

Hampel H, Cattrijsse A, Vincx M. 2003. Habitat value of a developing estuarine brackish marsh for fish and macrocrustaceans. ICES Journal of Marine Science 60(2):278-289.

Hanowski JM, Christian DP, Nelson MC. 1999. Response of breeding birds to shearing and burning in wetland brush ecosystems. Wetlands 19(3):584-593.

Harig A, Bain M. 1998. Defining and Restoring Biological Integrity in Wilderness Lakes. Biological Applications 8(1): 71-87.

Hauer FR, Smith RD. 1998. The hydrogeomorphic approach to functional assessment of riparian wetlands: evaluating impacts and mitigation on river floodplains in the U.S.A. Freshwater Biol 40(3):517-530.

Havens KJ, Varnell LM, Watts BD. 2002. Maturation of a constructed tidal marsh relative to two natural reference tidal marshes over 12 years. Ecological Engineering 18(3):305-315.

Hawkins CP, Bartz KL, Neale CMU. 1997. Vulnerability of riparian vegetation to catastrophic flooding: Implications for riparian restoration. Restoration Ecology 5(4s): 75-88.

Hecnar SJ, M"Closkey RT. 1996. Regional dynamics and the status of amphibians. Ecology 77:2091-2097.

Henderson CJ. 2001. A comparison of three rapid evaluation procedures for pine savanna wetlands. M.S. Thesis. Mississippi State University.

Henry CP, Amoros C, Roset N. 2002. Restoration ecology of riverine wetlands: A 5-year post-operation survey on the Rhone River, France. Ecological Engineering 18:543-554.

Henry CP, Amoros C. 1996. Restoration ecology of riverine wetlands. III. Vegetation survey and monitoring optimization. Ecological Engineering 7(1):35-58.

Heyer WR, Donnelly MA, McDiarmid RW, Hayek LC, Foster MS. 1994. Measuring and monitoring biological diversity: Standard methods for amphibians. Smithsonian Institution Press. Washington and London.

Hill BH, Herlihy AT, Kaufmann PR, Stevenson RJ, McCormick FH. 2000. The use of periphyton assemblage data as an index of biotic integrity. J N Am Benthol Soc 19:50-67.

Hotaling NEM, Kuenzel WJ, Douglass LW. 2002. Breeding season bird use of restored wetlands in eastern Maryland. Southeastern Naturalist 1(3):233-252.

Hunt RJ, Walker JF, Krabbenhoft DP. 1999. Characterizing hydrology and the importance of ground water discharge in natural and constructed wetlands. Wetlands 19:458–472.

Jeanneret P, Schupbach B, Pfiffner L, Walter T. 2003. Arthropod reaction to landscape and habitat features in agricultural landscapes. Landscape Ecology 18(3):253-263.

Jorgensen EE. 2002. Small mammals: consequences of stochastic data variation for modeling indicators of habitat suitability for a well-studied resource. Ecological Indicators 1(4):313-321.

Kaenel-Barbara R. 1998. Effects of plant cutting and dredging on habitat conditions in streams. Hydrobiologica. 143(3):257-273.

Karr J. 1991. Biological integrity: A long-neglected aspect of water resources management. Ecological Applications 1(1): 66-84.

Karr JR, Chu EW. 1999. Restoring Life in Running waters: Better biological Monitoring. Washington, DC: Island Press.

Karr JR. 1981. Assessment of biotic integrity using fish communities. Fisheries 6(6): 21-27.

Kentula M, Sifneos J, Good J, Rylko M, Kunz K. 1992. Trends and patterns in section 404 permitting requiring compensatory mitigation in Oregon and Washington. U.S.A. Environ Manage 16(1):109-119.

Kentula ME. 2000. Perspectives on setting success criteria for wetland restoration Ecological Engineering 15(3-4):199-209.

Kirkman LK, Lide RF, Wein G, Sharitz RR. 1996. Vegetation Changes and Land Use Legacies of Depressional Wetlands of the Western Coastal Plain of South Carolina. Wetlands Vol.16, No. 4.

Kolka RK, Singer JH, Coppock CR, Casey WP, Trettin CC. 2000. Influence of restoration and succession on bottomland hardwood hydrology. Ecological Engineering 15:S131–S140.

Kulp CJ, McCoy RW. 1992. An Evaluation of 30 Wetland Mitigation Sites Constructed by the PADOT Between 1983 and 1990. U. S. Fish and Wildlife Service. Pennsylvania Field Office Special Project Report 92-3.

Kurtz JC, Jackson LE, Fisher WW. 2001. Strategies for evaluating indicators based on guidelines from the Environmental Protection Agency's Office of Research and Development. Ecological Indicators. 1(1): 49-60.

Langston MA, Kent DM. 1997. Fish recruitment to a constructed wetland. Journal of Freshwater Ecology 12(1): 123-129.

LaSalle M, Landin MC, Sims JG. 1991. Evaluation of the flora and fauna of a Spartina alterniflora marsh established on dredged material in Winyah Bay, South Carolina. Wetlands 11(2): 191-209.

Layman CA, Smith DC. 2001. Sampling bias of minnow traps in shallow aquatic habitats on the eastern shore of Virginia. Wetlands 2(1): 145-154.

Lechisin DA, Williams GL, Weler MW. 1992. Factors affecting waterfowl use of constructed wetlands in northwestern Minnesota. Wetlands 12:178-183.

Lewis PA, Klemm DJ, Thoeny WT. 2001. Perspectives on use of a multimetric lake bioassessment integrity index using benthic macroinvertebrates. Northeastern Naturalist 8(2):233-246.

Lewis RR. 2000. Ecologically based goal setting in mangrove forest and tidal marsh restoration. Ecological Engineering 15(3-4):191-198.

Llanso RJ, Scott LC, Hyland JL, Dauer DM, Russell DE, Kutz FW. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the Untied States. II. Index Development. Estuaries 25(6A):1231-1242.

Lockwood JL. 1997. An alternative to succession: Assembly rules offer guide to restoration efforts. Restoration and Management Notes. 15:45-50.

Lougheed VL, Chow-Fraser P. 2002. Development and use of a zooplankton index of wetland quality in the Laurentian Great Lakes basin. Ecological Applications 12(2):474-486.

Lynn DH, Gilron GL. 1992. A brief review of approaches using ciliated protists to assess aquatic ecosystem health. J. Aq. Ecosys. Health 1:263-270.

Lyons et al. 1995. Index of biotic integrity based on fish assemblages for the conservation of streams and rivers in West-Central Mexico. Conservation Biology 9(3): 569-584.

Magee TK, Ernst TL, Kentula ME, Dwire KA. 1999. Floristic comparison of freshwater wetlands in an urbanizing environment. Wetlands 19(3):517-53.

Mason CO, Slocum DA. 1987. Wetland replication - does it work? Proceedings of the 5th Symposium on Coastal Ocean Management, volume 1. New York: American Society of Civil Engineering. 1183-1197.

Mayer PM, Galatowitsch SM. 1999. Diatom communities as ecological indicators of recovery in restored prairie wetlands. Wetlands 19(4):765-774.

Mayer PM, Galatowitsch SM. 2001. Assessing ecosystem integrity of restored prairie wetlands from species production-diversity relationships. Hydrobiologia 443 (1-3): 177-185.

McNair SA, Chow-Fraser P. 2003. Change in biomass of benthic and planktonic algae along a disturbance gradient for 24 Great Lakes coastal wetlands. Can. J. Fisheries and Aquatic Sciences 60(6):676-689.

Melvin SL, Webb JW. 1998. Differences in the avian communities of natural and created Spartina alteriflora salt marshes. Wetlands 18:59–69.

Mensing DM, Galatowitsch SM, Tester JR. 1998. Anthropogenic effects on the biodiversity of riparian wetlands of a northern temperate landscape. Journal of Environmental Management 53: 349-3 77.

Millre RE Jr. 1998. A Rapid Assessment Procedure for Determining the Functionality of Wetlands in South Florida. M.S. Thesis. Florida Atlantic University.

Minello TJ, Able KW, Weinstein MP, Hays CG. 2003. Salt marshes as nurseries for nekton: testing hypotheses on density, growth, and survival through meta-analysis. Marine Ecology Progression Series 246: 39-59.

Minello TJ, Webb JW. 1997. Use of natural and created Spartina alterniflora marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. Mar. Ecol. Prog. Ser. 151:165–179.

Mitsch WJ, Xinyuan W, Nairn RW, Weihe PE, Naiming W, Deal R, Boucher CE. 1998. Creating and restoring wetlands: A whole-ecosystem experiment in self-design. Bioscience 48(12)1019-1030

Morgan KL, Roberts TH. 2003. Characterization of wetland mitigation projects in Tennessee, U.S.A. Wetlands 23(1):65-69.

Morgan PA, Short FT. 2002. Using functional trajectories to track constructed salt marsh development in the Great Bay Estuary, Maine/New Hampshire, U.S.A. Restoration Ecology 10(3):461-473.

Morley SA, Karr JR. 2002. Assessing and restoring the health of urban streams in the Puget Sound basin. Con. Bio. 16(6):1498-1509.

Moy LD, Levin LA. 1991. Are Spartina marshes a replaceable resources? A functional approach to evaluation of marsh creation efforts. Estuaries 14(1):1-16.

Muzaffar SB, Colbo MH. 2002. The effects of sampling technique on the ecological characterization of shallow, benthic macroinvertebrate communities in two Newfoundland ponds. Hydrobiologia 477(1):31-39.

Nair VD, Graetz DA, Reddy KR, Olila OG. 2001. Soil development in phosphate-mined created wetlands of Florida, USA. Wetlands 21(2): 232-239.

Naugle DE, Johnson RR, Estey ME, Higgins KF. 2001. A landscape approach to conserving wetland bird habitat in the prairie pothole region of eastern South Dakota. Wetlands 21(1):1-17.

Niswander SF, Mitsch WJ. 1995. Functional-analysis of a 2-year-old created in-stream wetland - hydrology, phosphorus retention, and vegetation survival and growth. Wetlands 15(3):212-225.

Noon KF. 1996, A Model of Created Wetland Primary Succession. Landscape and Urban Planning 34: 97-123.

Odland A. 2002. Patterns in the secondary succession of a Carex vesicaria L. wetland following a permanent drawdown. Aquatic Botany 74:233–244 235.

Olson DH, Leonard WP, Bury RB (eds). 1997. Sampling Amphibians in Lentic Habitats. Northwest Fauna 4, Olympia, WA, USA.

Padgett DJ, Crow GE. 1994. A vegetation and floristic analysis of a created wetland in Southeastern New Hampshire. Rhodora 96(885):1-29.

Paton PWC and Crouch WB. 2000. Using egg mass counts to monitor wood frog populations. Wildl Soc Bul 28:895-901.

Paton PWC, Crouch WB. 2002. Using the phenology of pond-breeding amphibians to develop conservation strategies. Conservation Biology 16(1):194-204.

Pechmann JHK, Estes RA, Scott DE, Gibbons JW. 2001. Amphibian colonization and use of ponds created for trial mitigation of wetland loss. Wetlands 21(1):93-111.

Pepin AL. 1998. The Relative Importance of Hydrology and Substrate in the Vegetation Dynamics of Restored Freshwater Wetlands (Wetland Restoration). Ph.D. Dissertation. George Mason University.

Petranka JW, Murray SS, Kennedy CA. 2003. Responses of amphibians to restoration of a southern Appalachian wetland: Perturbations confound post-restoration assessment. Wetlands 23(2):278-290.

Pielow EC. 1985. Assessing the diversity and composition of restored vegetation. Canadian Journal of Botany 64:1344-1348. Website http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio.pdf

Poach ME, Faulkner SP. 1998. Soil Phosphorus Characteristics of Created and Natural Wetlands in the Atchafalaya Delta, LA. Estuarine, Coastal and Shelf Science 46(2):195-203.

Poff NL, Allan JD. 1995. Functional organization of stream fish assemblages in relation to hydrological variability. Ecology 76(2): 606-627.

Quammen ML. 1986. Measuring the Success of Wetlands Mitigation. National Wetlands Newsletter 8:6-8. Website http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio.pdf

Race MS. 1985. Critique of Present Wetlands Mitigation Policies in the United States Based on an Analysis of Past Restoration Projects in San Francisco Bay. Environmental Management 9(1): 71-82. Website http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio.pdf

Ranasinghe JA, Frithsen JB, Kutz FW, Paul JF, Russell DE, Batiuk RA, Hyland JL, Scott J, Dauer DM. 2002. Application of two indices of benthic community condition in Chesapeake Bay. Environmentrics 13(5-6):499-511.

Ratti JT, Rocklage AM, Giudice JH, Garton EO, Golner DP. 2001. Comparison of avian communities on restored and natural wetlands in North and South Dakota. Journal of Wildlife Management 65(4): 676-684.

Reinartz JA, Warne EL. 1993. Development of vegetation in small created wetlands in southeastern Wisconsin. Wetlands 13(3):153-164.

Richter KO, Azous AL. 1995. Amphibian occurrence and wetland characteristics in the Puget Sound Basin. Wetlands 15(3):305-312.

Rottonborn SC. 1999. Predicting the impacts of urbanization on riparian bird communities. Biological Conservation 88:289-299.

Rulifson RA. 1991. Finfish utilization of man-initiated and adjacent natural creeks of South Creek Estuary, North Carolina using multiple gear types. Estuaries 14(4):447-464.

Sacco JN, Seneca ED, Wentworth TR. 1994. Infaunal community development of artificially established salt marshes in North Carolina. Estuaries 17(2):489-500.

Sanderson EW, Foin TC, Ustin SL. 2001. "A simple empirical model of salt marsh plant spatial distributions with respect to a tidal channel network." Ecological Modeling 139: 293-307.

Scataloni SR, Zedler JB. 1996. Epibenthic invertebrates of natural and constructed marshes of San Diego Bay. Wetlands 16(1): 24-37.

Schwartz JS. 2002. Stream Habitat Characterized by Stage-Specific Flows and Three-Dimensional Geomorphological Complexity: Development of Ecological Criteria for Stream Restoration Design. PhD Dissertation

Semlitch RD. 2000. Management of aquatic-breeding amphibians. J. Wild. Mange. 64(3):615-631.

Semlitsch RD, Bodie JR. 1998. Are small, isolated wetlands expendable? Conservation Biology 12(5):1129-1133.

Semlitsch RD. 1998. Biological delineation of terrestrial buffer zones for pond-breeding salamanders. Conservation Biology 12(5):1113-1119

Shaffer PW, Ernst T. 1999. Distribution of soil organic matter in freshwater emergent open water wetlands in the Portland, Oregon metropolitan area. Wetlands 19(3):505-516.

Shaffer PW, Kentula ME, Gwin SE. 1999. Characterization of wetland hydrology using hydrogeomorphic classification. Wetlands 19(3):490-504.

Shuwen W, Pei Q, Yang L, Xi-Ping L. 2001. Wetland creation for rare waterfowl conservation: A project designed according to the principles of ecological succession. Ecological Engineering 18(1):115-120.

Sifneos JC, Cake EW, Kentual ME. 1992. Effects of section-404 permitting on fresh-water wetlands in Louisiana, Alabama, and Mississippi. Wetlands 12(1):28-36.

Simenstad CA, Cordell JR. 2000. Ecological assessment criteria for restoring anadromous salmonid habitat in Pacific Northwest estuaries. Ecological Engineering 15(3-4):283-302.

Simenstad CA, Thom RM. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. Ecol Appl 6(1):38-56.

Simon TP. 1998. Modification of an index of biotic integrity and development of reference condition expectations or dunal, palustrine wetland fish communities along the southern shore of Lake Michigan. Aquatic Ecosystem Health and Management 1(1):49-62.

Simon TP. 2000. Modification of an index of biotic integrity for assessing vernal ponds and small palustrine wetlands using fish, crayfish, and amphibian assemblages along southern Lake Michigan. Aquatic Ecosystem Health and Management 3(3):407-418.

Snodgrass JW, Komoroski MJ, Bryan AL, Burger J. 2000. Relationship among isolated wetland size, hydroperiod, and amphibian species richness: Implications for wetland regulations. Conserv. Biol. 14(2):414-419.

Spieles DJ, Mitsch WJ. 2000. Macroinvertebrate community structure in high-and low-nutrient constructed wetlands. Wetlands 20(4):716-729.

Stauffer AL, Brooks RP. 1997. Plant and soil responses to salvaged marsh surface and organic matter amendments at a created wetland in central Pennsylvania. Wetlands 17(1): 90-105.

Streever WJ, Crisman TL. 1993. A comparison of fish populations from natural and constructed marshes in Central Florida. Journal of Freshwater Ecology 8(2): 149-153.

Streever WJ, Crisman TL. 1993. A preliminary comparison of meiobenthic cladoceran assemblages in natural and constructed wetlands in Central Florida. Wetlands 13(4): 229-236.

Streever WJ. 2000. Spartina alterniflora marshes on dredged material: a critical review of the ongoing debate over success. Wetlands Ecol. Manage. 8(5):295-316.

Streever WJ. 1999. Performance standards for wetland creation and restoration under Section 404. Natl Wetlands Newslet 21(3):10-12, 13.

Swift BL, Larson JS, DeGraaf RM. 1984. Relationship of breeding bird density and diversity to habitat variables in forested wetlands. Wilson Bull. 96:48–59.

Swihart RK, Kolozsvary MB. 1999. Habitat fragmentation and the distribution of amphibians: patch and landscape correlates in farmland, Indiana, U.S. Can J. Zool. 77(8):1288-1299.

Talley TS, Levin LA. 1999. Macrofaunal Succession and Community Structure in Salicornia Marshes of Southern California. Estuarine, Coastal and Shelf Science 49(5):713-731.

Tangen BA, Butler MG, Michael JE. 2003. Weak correspondence between macroinvertebrate assemblages and land use in Prairie Pothole Region wetlands, USA. Wetlands 23(1):104-115.

Thom RM. 1997. System-development matrix for adaptive management of coastal ecosystem restoration. Ecological Engineering 8:219-232. http://www.wsdot.wa.gov/eesc/design/roadside/pdf/AnnBiblio.pdf says:

Turner RE, Redmond AM, Zedler JB. 2001. Count it by acre or function - Mitigation Adds Up to Net Loss of Wetlands. National Wetlands Newsletter 23(6): 5-6, 14-16.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-023.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Developing Metrics and Indexes of Biological Integrity. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-016.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Introduction to Wetland Biological Assessment. Office of Water, U.S. Environmental Protection Agency, Washington, DC.EPA-822-R-02-014

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Algae to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-021.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Amphibians in Bioassessments of Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-022.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: using Vegetation to Assess Environmental Conditions in Wetlands. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-020.

U.S. EPA. 2002. Methods for Evaluating Wetland Condition: Wetlands Classification. Office of Water, U.S. Environmental Protection Agency, Washington, DC. EPA-822-R-02-017.

VanRees-Siewert KL, Dinsmore JL. 1996. Influence of wetland age on bird use of restored wetlands in Iowa. Wetlands 16:577-582.

Varnell LM, Evans DA, Havens KJ. 2003. A geomorphological model of intertidal cove marshes with application to wetlands management. Ecological Engineering 19:339/347.

Vose FE, Bell SS. 1994. Resident fishes and macrobenthos in mangrove-rimmed habitats: evaluation of habitat restoration by hydrologic modification. Estuaries 17(3):585-596.

Wardrop DH, Brooks RP, Bishel-Machung L, Cole CA. 1998. Hydrogeomorphic (HGM) functional assessment models for Pennsylvania wetlands. Report 98–6. Penn State Cooperative Wetlands Center, University Park, PA.

Wardrop DH. 1997. The occurrence and impact of sedimentation in central Pennsylvania wetlands. Ph.D. Thesis, Ecology. The Pennsylvania State University, University Park, PA, 189 pp.

Weiher E, Wisheu IC, Keddy PA, Moore DRJ. 1996. Establishment, persistence, and management implications of experimental wetland plant communities. Wetlands 16(2):208-218.

Werner KJ, Zedler JB. 2002. How sedge meadow soils, microtopography, and vegetation respond to sedimentation. Wetlands 22 (3):451-466.

Whigham DF. 1999. Ecological issues related to wetland preservation, restoration, creation and assessment. Sci Total Environ 240(1-3):31-40.

Wigginton JD, Lockaby BG, Trettin CC. 2000. Soil organic matter formation and sequestration across a forested floodplain chronosequence. Ecol. Eng. 15:S141–S155.

Wilcox DA, Meeker JE, Hudson PL, Armitage BJ, Black MG, Uzarski DG. 2002. Hydrologic variability and the application of index of biotic integrity metrics to wetlands: A Great Lakes evaluation. Wetlands 22(3):588-615.

Wilkinson J, Kennedy C, Mott K, Filbey M, King S. 2002. National Wetlands Newsletter 24(5):5-17.

Williams GD, Zedler JB. 1999. Fish assemblage composition in constructed and natural tidal marshes of San Diego Bay: Relative influence of channel morphology and restoration history. Estuaries 22(3A):702-716.

Wolfe CP. 1999. Effects of hydrologic disturbance on a Lake Michigan wetland ecosystem: Developing parameters for restoration. Ph.D. Dissertation. Indiana University.

Zampell, Robert and Bunnell, John. 1998. Use of reference fish assemblages to assess aquatic degradation in Pinelands streams. Ecological Applications 8(3): 645-658.

Zedler JB, Callaway JC. 1999. Tracking wetland restoration: do mitigation sites follow desired trajectories? Restoration Ecol 7:69-73.

Zedler JB, Langis R. 1991. Comparison of created and natural salt marshes of San Diego Bay. Restoration and Management Notes 9:21-25.

Zedler JB, Shabman L. 2001. Compensatory mitigation needs improvement, panel says. National Wetlands Newsletter 23(4):1-14

Zedler JB. 1990. A Manual for Assessing Restored and Natural Coastal Wetlands with Examples from Southern California. Report. No. T-CSGCP-021. La Jolla: California Sea Grant College.

Zedler JB. 1993. Canopy architecture of natural and planted cordgrass marshes: selecting habitat evaluation criteria. Ecological Applications 3(1)123–138.

Zedler JB. 1996. Ecological issues in wetland mitigation: An introduction to the forum. Ecol Appl 6(1):33-37.

Zedler JB. 2003. Wetlands at your service: reducing impacts of agriculture at the watershed scale. Front Ecol Environ 1(2):65-72.

Zentner JJ. 1987. Wetland Restoration Success in Coastal California. In: Increasing Our Wetland Resources, Proceedings, National Wildlife Federation-Corporate Conservation Council, Washington, D.C.

Zuoyue Y, Zhuhao W. 1995. Ecology of the rehabilitation of vegetation on tropical coastal eroded land in Guangdon, China. Journal of Environmental Sciences 7:74-84.

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