Habitat Restoration
Monitoring Toward Success:
A Selective Annotated Bibliography

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U.S. Department of Commerce
National Oceanic and Atmospheric Administration
National Marine Fisheries Service

NOAA Technical Memorandum NMFS-F/SPO-42
May 2000

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U.S. Department of Commerce
William M. Daley, Secretary

National Oceanic and Atmospheric Administration
D. James Baker, Under Secretary for Oceans and Atmosphere

National Marine Fisheries Service
Penelope D. Dalton, Assistant Administrator for Fisheries

INTRODUCTION

Habitat restoration is the process of reestablishing a self-sustaining habitat that, in time, can come to closely resemble a natural condition in terms of structure and function. Measures to monitor the success of restoration projects should include evaluations of these attributes. Structural success criteria include characteristics of the habitat's water quality, sediment type, hydrodynamic properties, topography, morphology, flora and fauna. Functional success criteria include nutrient cycling, oxygen production, persistence and resilience of the created habitat, biomass production, and linkages to adjacent ecological systems. Achieving success is not a pass/fail test; rather, it is the measurement of gradual progress toward ecological recovery.

The annotated bibliography presented in this publication is the result of an intensive literature search on restoration success criteria and monitoring protocols. The search examined both published and unpublished sources from 1990 to 1999 and was compiled using the following electronic search databases:

- Article 1st
- Aquatic Sciences and Fisheries Abstracts
- BasicBIOSIS
- Environmental Sciences and Pollution Management
- GEOBASE

Citations also were derived from a literature search on restoration science and economics performed by Applied Sciences Associates, Inc. on work from 1992-1995. Literature on the following habitats was evaluated during the search process:

- tidal salt marshes
- freshwater wetlands
- mangroves
- seagrasses
- bottomland hardwood forests
- coral reefs
- riverine systems
- riparian streams

The resulting document is not an exhaustive list of all information on success criteria and monitoring protocols but rather is intended as a resource for managers and restoration ecologists engaged in on-the-ground restoration planning and evaluation. Nearly 150 citations were evaluated and 39 were selected for inclusion in this document. Articles involving mitigation and success criteria were reviewed but not included in this document. Abstracts of each were developed by the authors to assist the readers in locating relevant information on restoration monitoring and success criteria. The bibliography is ordered alphabetically by primary author.

The authors would like to thank Drs. Gordon Thayer and Margaret Miller and other NOAA staff for their comments and input on this document.

The NOAA Restoration Center is a division of the National Marine Fisheries Service, Office of Habitat Conservation. The Restoration Center is the focal point for coastal and estuarine habitat restoration within NOAA. Its missions are to:

- Restore fish habitat and other living marine resources that have been injured by anthropogenic activities;
- Advance the science and technology of coastal habitat restoration; and
- Transfer restoration technology to the public, the private sector, and other governmental agencies.

The Center serves NOAA, other federal agencies, and state and local governments. In addition, it works with non-governmental organizations, schools and private industry. The text of the bibliography, as well as additional information on the NOAA Restoration Center, may be found on the World Wide Web at http://www.nmfs.gov/habitat/restoration. Inquiries may also be sent to the NOAA Restoration Center, National Marine Fisheries Service (F/HC3), 1315 East-West Highway, Silver Spring, MD 20910.

ANNOTATED BIBLIOGRAPHY

1. Barrett, N.E. and W.A. Niering. 1993. Tidal marsh restoration: trends in vegetation change using a geographical information system (GIS). *Restoration Ecology* 1(1):18-28.

A study measuring restoration success by extent of geographical similarity between restored vegetation and pre-diked vegetation was carried out in a formerly diked and ditched Connecticut coastal salt marsh. Restoration is a continuous process with salt marsh vegetation communities in constant flux. In addition to vegetation pattern and distribution as structural criteria, ecosystem functioning, such as biomass and nutrient exchange, need to be evaluated as well. Using GIS to compare vegetation coverages between the pre-impounded, impounded, and restored states, tidal reintroduction was found to be a semi-effective restoration tool. Pre-impoundment marsh was dominated by stunted *Spartina alterniflora*. During the impoundment period, marsh vegetation switched to dominance by *Typha*. Following restoration, the wetland became a mosaic of different plant communities with much of the marsh reverting to *S. alterniflora*. The restored marsh was only 28 percent similar to pre-disturbance conditions in terms of vegetation species and coverage. Returning the marsh to pre-disturbance conditions is unlikely but should be viewed as the pinnacle of success against which other projects can be measured. The restored site has reverted to a viable, coastal salt marsh that is reconnected with the estuarine environment.

2. Bradshaw, A.D. 1996. Underlying principles of restoration. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl. 1):3-9.

Restoration should incorporate ecosystem structure and function into habitat development. Restoring a system to its original state may be unrealistic and expensive; thus other options exist, including rehabilitation and replacement. Natural restorative processes should be used whenever possible. These restoration processes are progressive, and success criteria are sometimes difficult to define. If progressive natural processes are to be used for restoration, what level should be achieved and what is considered the predisturbance state? Establishing an appropriate time frame for post-restoration monitoring and evaluation is also difficult. Less than three years is not enough time for aquatic or terrestrial ecosystem development following restoration. One invaluable tool for monitoring is a check list of potential limiting factors or problems in degraded ecosystems that require restoration, i.e. nutrient deficiency. Since restoration must be based on a sound understanding of ecosystem function, it is imperative that experimental studies be conducted in conjunction with restoration. This allows different treatments to be applied to the ecosystem and results to be compared against controls or non-treatments. It is equally important to restoration science that accounts of restoration failures and successes be published.

3. Cintron-Molero, G. 1992. Restoring mangrove systems. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Mangrove restoration or creation historically has occurred as compensation for lost habitats or desire to create new mangrove habitats. Site selection and preparation are essential for successful mangrove restoration. Plantings should be made using the dominant species found in nearby locations with similar tidal heights and flooding regimes. Three basic factors can lead to mangrove restoration failure: 1) failure to recognize factors limiting establishment (need for shelter from wave and wind action, tides and currents); 2) lack of provision for proper hydrologic regime; and 3) failure to provide follow-up, including replacement for mortality and lack of consideration of mangrove stand maintenance. Furthermore, ten broad types of problems or factors that control mangrove establishment and development are addressed. Viable restoration design and strategy are addressed, as well as steps to ensure restoration success.

Criteria used to determine long-term success are highly subjective. No detailed quantitative assessments of structural or functional attributes are available. Eight criteria are cited as quantifiable in terms of measuring stand development through time: 1) species composition; 2) stem density; 3) basal area; 4) vegetation height; 5) percentage canopy cover; 6) leaf area index; 7) mean diameter of the stand; and 8) above-ground biomass. The suggested minimum monitoring duration is 15 to 30 years, in order to allow the system to reach maximum persistent biomass.

4. Coen, L.D., D.M. Knott, E.L. Wenner, N.H. Hadley, A.M. Ringwood, and M.Y. Bobo. 1999.
Intertidal oyster reef studies in South Carolina: design, sampling and experimental focus for evaluating habitat value and function. In *Oyster Reef Habitat Restoration: A Synopsis and Synthesis of Approaches, Proceedings from the Symposium*, eds. M.W. Luckenbach, R. Mann and J.A. Wesson. Williamsburg, VA, Apr. 1995. Virginia Institute of Marine Science, College of William and Mary: VIMS Press.

In South Carolina, *Crassostrea virginica* can be considered a keystone species by forming extensive biogenic reefs, often generating the only three-dimensional structural relief, both as living organisms and dead shell on unvegetated soft-bottoms. Whether these intertidal habitats are functionally analogous to submerged aquatic vegetation (SAV) or marsh, especially where SAV nursery habitats are absent (i.e. South Carolina), is an important question. A past focus of oyster research has been directed toward enhancing oyster harvests; however, our understanding of the role of intact reefs on ecosystem function is limited. Additionally, many states where oysters are commercially harvested, minimally require cultch (shell) replanting; however, no rigorous experimental data presently exist for optimizing shell placement or evaluating the effectiveness of this practice for reef restoration efforts.

Our long-term studies of the oyster ecosystem are designed to: (1) evaluate the utilization of reefs by transient and resident species; (2) examine the tempo and mode of intertidal oyster reef recruitment and succession using rigorous statistical designs; (3) aid in the development of habitat quality criteria; (4) formulate strategies for habitat management of these living resources; and (5) utilize the information to develop restoration and mitigation methodologies. Two study sites were selected, one at a relatively pristine oyster flat, the other at a developed (impacted) area near a marine/condominium complex. Three replicate intertidal experimental reefs per site (each ~ 24 m^2) have been constructed of 156 subunits. We now have established sampling protocols and developed and conducted efficiency tests for sampling transient and resident faunas associated with experimental and adjacent natural reef substrates. Over the next four to six years, we will be following reef development, collecting continuous environmental data and comparing contaminant levels and oyster disease status, along with other life history parameters on both natural and adjacent experimental reefs. By initiating and following the reef development over an extended period, we will be able to explore and model potential changes in reef habitat status and function with reef succession.

5. D'Avanzo, C. 1990. Long-term evaluation of wetland creation projects. In Wetland Creation and Restoration: The Status of the Science, eds. Kusler, J.A. and M.E. Kentula. Washington, DC: Island Press.

Assessment of created wetlands was performed using six criteria for success. These include: 1) comparison of vegetation growth characteristics between created and reference wetlands after two or more growing seasons; 2) habitat requirements of plants colonizing the created site; 3) success of planted species; 4) comparison of animal species composition and biomass between created and reference wetlands; 5) chemical analyses of soils between created and reference wetlands; and 6) evidence of hydrogeologic changes over time.

Many created wetland projects have failed because of improper hydrology, erosion, herbivory, or upland plant invasion. Some projects have never been evaluated or monitored to determine success. One to two years of monitoring is too short; 10-20 years of monitoring is more desirable. Monitoring vegetation characteristics may be useful but does not indicate ecosystem function.

6. Dobson, J.E., E.A. Bright, R.L. Ferguson, D.W. Field, L.L. Wood, K.D. Haddad, H. Iredale III, J.R. Jensen, V.V. Klemas, R.J. Orth, and J.P. Thomas. 1995 Apr. NOAA Coastal Change Analysis Program (C-CAP): Guidance for Regional Implementation. NOAA Technical Report NMFS 123. 92 pp.

The Coastal Change Analysis Program (C-CAP) is developing a nationally standardized database on land-cover and habitat change in the coastal United States. C-CAP is part of the Estuarine Habitat Program of NOAA's Coastal Ocean Program. C-CAP inventories benthic habitats, wetland habitats, and adjacent uplands to learn more about the linkages between coastal and upland habitats, as well as impacts on living marine resources. Through remote sensing technology, C-CAP monitors changes in these habitats on a one- to five-year cycle. Satellite imagery, aerial photography, and field data are meshed in a geographic information system (GIS) for spatial analysis. Ongoing C-CAP research will continue to develop remote sensing techniques to measure biomass, productivity, and functional status of wetlands and other coastal habitats. Land-cover maps will be produced on both local and regional scales for distribution.

7. Fonseca, M.S. 1992. Restoring seagrass systems in the United States. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Seagrass restoration has been carried out as a defensive or remedial action in conjunction with natural resource damages, rather than for the purpose of improving ecological resilience and functioning. In order to protect seagrass habitat, better project goals need to be established from the outset. Goals may include developing persistent cover, generating equivalent acreage, increasing acreage, replacing the same seagrass species as was injured or removed, and restoring faunal production. Monitoring for cover and persistence should last for three years. Site selection remains a major problem in ensuring seagrass restoration success. Eight research needs are stressed to improve seagrass restoration science: 1) a definition of functional restoration; 2) a compilation of population growth and coverage rates; 3) the resource role of mixed species plantings; 4) the impact of substituting pioneer for climax species on faunal composition and abundance; 5) culture techniques for propagule development; 6) transplant-optimization techniques such as the use of fertilizer; 7) the importance of maintaining genetic diversity; and 8) the implementation of a consistent policy on seagrass restoration and management among resource agencies. Permit compliance needs to be strictly enforced through intra- and interagency coordination; a monitoring system that tracks permits and evaluates them for both compliance and performance needs to be developed.

8. Fonseca, M.S., W.J. Kenworthy, and G.W. Thayer. 1998. Chapter 4: Monitoring and Evaluating Success. In *Guidelines for the Conservation and Restoration of Seagrasses in the United States and Adjacent Waters*. NOAA Coastal Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, MD. 222 pp.

Several criteria have been used for evaluating seagrass planting success. However, the simple measures of coverage and persistence are the most cost-effective and efficient. Many habitat functions seem to relate directly to these two structural criteria. Seagrass monitoring should provide for mid-course correction and improved planning of future restoration projects. Structural criteria include planting survival, areal coverage, and number of shoots. Seagrasses should be monitored at least quarterly after the first year and every six months for at least the following four years (total of five years). If replanting is necessary because of shoot failure, the monitoring clock is reset to zero and should continue for five years. In terms of achieving success, a nearby reference site may be used for comparison. An alternative strategy is to compare the monitored site with currently published structural values to gauge restoration performance. Cost estimates per hectare of seagrass restoration are discussed.

9. Galatowitsch, S.M., A.G. van der Valk, and R.A. Budelsky. 1998. Decision-making for prairie wetland restorations. *Great Plains Research* 8(Spring 1998):137-155.

Restoration of prairie pothole wetlands needs to occur on two levels: landscape and site. Reestablishment of wetland complexes and their functions should be the primary goal of prairie pothole restoration. A comprehensive assessment framework on a landscape level is presented. Historic data or reference complexes are also necessary to evaluate success of prairie wetland restoration. Previous assessment frameworks have focused on evaluation of easily observed structural attributes, such as vegetation or topography. The connection between structural attributes and wetland function is still uncertain. A more recent assessment tool is the hydrogeomorphic (HGM) technique that stresses the importance of hydrology in determining wetland function. Certain wetland functions are linked to a certain HGM subclass that has similar hydrogeomorphic properties. Long-term data collection at reference sites is crucial for gauging pre-restoration conditions and evaluating restoration progress. Most wetland functions are difficult and inefficient to measure directly; therefore, useful and reliable indicators of wetland function need to be developed for prairie pothole ecosystems. For example, soil organic matter is easily measurable and is presumed to be indicative of many wetland functions, including denitrification, phosphorus retention, and success of re-establishing plant species.

10. Grayson, J.E., M.G. Chapman, and A.J. Underwood. 1999. The assessment of restoration of habitat in urban wetlands. *Landscape and Urban Planning* 43:227-236.

Wetlands in urban areas are often restored in an attempt to reduce the loss of such habitats. Unfortunately, the success, or otherwise, of restoration programs has rarely been systematically evaluated. Through not knowing whether restoration programs are successful or not, valuable human and economic resources potentially continue to be wasted, wetland habitats remain degraded and restoration methods are not assessed and refined for future projects. Several factors have contributed to poor assessment of restoration of urban wetlands. First, the goals of restoration have often been unrealistic because they failed to consider that wetlands in urban areas are subjected to ongoing and often large-scale anthropogenic disturbances. Second, goals of restoration often have not been clearly defined during planning and, consequently, predictive hypotheses were not formulated to evaluate restoration success. Third, even when restoration success has been assessed, this has not always been adequate because of inappropriate sampling design. Such problems can be overcome by treating habitat restoration as experiments and using the knowledge gained from each project to improve restoration in the future. This will ensure that the remaining semi-natural habitats in urban areas can be more effectively managed.

11. Harris, R.R. 1999. Defining reference conditions for restoration of riparian plant communities: examples from California, USA. *Environmental Management* 24(1):55-63.

Currently, there is an emphasis on restoration of riparian vegetation in the western United States. Deciding on what and where to restore requires an understanding of relationships between riparian plant communities and their environments along with establishment of targets, or reference conditions, for restoration. Several methods, including off-site data and historical analysis have been used for establishing restoration reference conditions. The author proposes criteria for interpreting reference community composition and structure from the results of multivariate cluster analysis. Criteria proposed for establishing a reference community include: (1) abundance of one community relative to others; (2) community complexity, i.e. species richness and structure; (3) presence/absence of exotics; and (4) floristic and structural similarity to reference communities elsewhere in the region. The approach is illustrated with data from streams in the California Sierra Nevada, Central Valley, and southern coastal region to derive descriptions of reference communities for stream reaches and floodplain landforms. Cluster analysis results can be used to quantify the areas of both degraded and reference communities within a floodplain, thereby facilitating restoration cost estimation.

12. Houghton, J.P. and R.H. Gilmour. Ecological functions of a saltmarsh/mudflat complex created using clean dredged material, Jetty Island, Washington. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

The Port of Everett and the U.S. Army Corps of Engineers created a sand berm on Jetty Island, Washington, in 1989-1990. The purpose of the berm was to slow erosion losses on the west side of the island, create additional dune grass habitat, create a protected embayment that would be colonized by marine invertebrates, and demonstrate a beneficial use of clean dredged material. Increased productivity and invertebrate colonization would provide favorable habitat for juvenile salmonids, other fish, waterfowl, and shorebirds. Progress towards meeting these objectives was monitored over five years. Physical monitoring of the site included coastal geomorphology and topography; success was defined as a target rate of erosion. Biological monitoring included epibenthic zooplankton productivity, salmonid habitat evaluation, fish use of the project area, and vegetation percent cover. The project has met the preset criteria in terms of usage by juvenile salmonids and their prey items. Other fish such as juvenile surf smelt have colonized the area due to the high productivity. Percent cover of vegetation in the planted embayment did not differ significantly from that of the reference marsh. Shorebirds seem to benefit the most from creation of the berm and have been observed in greater numbers than elsewhere on the island.

13. Kaly, U.L. and G.P. Jones. 1998. Mangrove restoration: a potential tool for coastal management in tropical developing countries. *Ambio* 27(8):656-661.

Kaly and Thomas discuss a framework for determining whether mangrove restoration has been "successful". Past restoration projects have focused on planting trees and have neglected the reestablishment of complex, long-term ecosystem functioning. The authors discuss a three-step framework. The first step establishes requirements for a "natural" functioning ecosystem and identifies success criteria by which to measure the outcome of restoration. Criteria should be quantifiable and include factors such as slope and height of the substratum, distribution of freshwater inputs, and species composition. Historical data regarding previous mangrove ecosystem structure may be available, but nearby pristine reference mangrove stands likely will have to be used for comparison. Success should be measured by the degree that functional replacement of mangrove ecosystem has been achieved. This is in contrast to previous practice that establishment of vegetative cover over a percentage of the restoration site for a period of approximately two to three years.

14. Kondolf, G.M. 1995. Five elements for effective evaluation of stream restoration. *Restoration Ecology* 3(2):133-136.

Current restoration practices ignore the importance of post-project evaluation and monitoring. This may be due in part to lack of funding and equating monitoring with research, as opposed to applied activities such as restoration construction. Those restoration projects that have been evaluated were failures or proved ineffective. Five elements are cited as crucial for effective evaluation of project success. These are: (1) clear objectives to design an effective project and evaluation plan; (2) baseline data collected as long before the project begins as possible, in order to provide a reference point for quantitative evaluation of success; the choice of variables should follow logically from the project objectives; (3) good study design in order to acquire quantifiable data and results and measure the same variables over the same period of time at other reference sites; (4) commitment to the long term, to allow the system to recover and undergo a natural range of variability; floodplain river systems should be monitored for at least a decade, as well as after major disturbance events; and (5) willingness to acknowledge failure, since each project may be viewed as an experiment from which valuable lessons can be learned for future projects; failures are equally as valuable as successes in refining restoration science.

15. Lenihan, H.S. 1999. Physical-biological coupling on oyster reefs: how habitat structure influences individual performance. *Ecological Monographs* 69(3):251-275.

A large-scale experimental study was conducted to test different aspects of restored reef design on oyster performance. Reef height was the independent variable tested to determine oyster performance and recruitment. Four reef heights were constructed at 3-m water depth in a North Carolina estuary: tall (2 m), short (1 m), dredged (0.6 m), and low (0.1 m). To determine whether oyster performance varied with water depth and hydrographic conditions, tall and short reefs were also constructed at 6-m water depth. The study elicited several physico-chemical and oyster performance variables that may be used as success criteria for oyster reef restoration projects. Flow speed, sedimentation, temperature, salinity, dissolved oxygen, and oyster performance were measured as a function of reef height, position on reef, and water depth over a ten month period. The results indicated that reef height controls habitat quality and quantity indirectly through its effect on flow and rates of sedimentation.

Physical conditions on the experimental reefs had a significant impact on oyster performance. After ten months, oyster recruitment and growth were greatest on the crests of tall and short reefs, where flow speed and quality of suspended food material were highest, and sedimentation was lowest. Growth was greatest overall at the crests of tall reefs located at 6-m depth where flow speed was high, and exposure to hypoxic/anoxic conditions and salinity variation were lowest.

16. Levin, L.A., D. Talley, T. Talley, A. Larson, A. Jones, G. Thayer, C. Currin and C. Lund. 1997. Restoration of *Spartina* marsh function: an infaunal perspective. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

The roles of sediment-dwelling fauna (infauna) in salt marsh function were examined at two sites in North Carolina and California. Despite their ability to cycle organic matter, serve as food for fish, birds and other predators, and link primary producers with higher order consumers in the food web, infauna are not routinely monitored in wetlands restoration. The study investigated factors that influence recovery of restored systems, rates of recovery, and possible causes of compositional differences between created and natural marshes.

Experimental organic matter treatments were applied at the North Carolina site. Macrofaunal densities and species richness were reduced in the created marshes compared to the natural reference marsh, especially at higher elevations. Species composition between created and natural marshes was significantly different, with oligochaetes dominating natural marsh and tube-dwelling, surface-deposit feeders dominating the created marsh. At the California site, planktotrophic organisms were dominant in the created marsh and rarely found in the natural marsh. Densities and species richness in the created marsh were actually higher than in the natural marsh in California. It was concluded that organic treatments should be used if they enhance *Spartina* growth despite an initial retardation of macrofaunal colonization. Although similarities in faunal densities and species richness may readily occur between created and natural marshes (as in California), it is necessary to examine species composition as well. Recovery of salt marsh seems to be site- and taxon-specific, with no guarantees that time alone will yield functional equivalence.

17. McCormick, P.V. and J. Cairns. 1994. Algae as indicators of environmental change. *Journal of Applied Phycology* 6:509-526.

The authors list 16 criteria for ecosystem indicator selection and discuss how algae fit many of these criteria. Despite their ecological importance at the base of the aquatic foodweb, algae are not as widely used as assemblages of benthic invertebrates or fish. This results from the lack of standard monitoring protocols. Measuring structural characteristics of algal condition may be more efficient than monitoring functional characteristics. The authors cite the use of diatoms (*Bacillariophyceae*) in algal assemblage monitoring. They also stress the importance of monitoring several taxonomic groups, rather than algae, fish, or invertebrates alone to gauge overall ecosystem integrity.

18. Minello, T.J. and J.W. Webb, Jr. 1997. Use of natural and created *Spartina alterniflora* salt marshes by fishery species and other aquatic fauna in Galveston Bay, Texas, USA. *Marine Ecology Progress Series* 151: 165-179.

Nekton and infauna densities were compared among five natural and ten created salt marshes in Galveston Bay, Texas, to determine whether these marshes were functionally equivalent. The marshes ranged in age from three to 15 years old. Densities of the most abundant decapod were not significantly different; however, the size of these decapods in created marshes was significantly smaller than in natural marshes. Densities of another decapod and three commercially important crustaceans were significantly lower in created marshes than in natural marshes. Although species richness of nekton were equivalent in created and natural marshes, fish densities in vegetated areas were significantly lower in created marshes than in natural marshes. Sediment macro-organic matter and density and species richness of macroinfauna were significantly lower in created marshes than natural marshes. The conclusion was that marsh elevation and tidal flooding were key characteristics affecting nekton use of salt marshes, more important than marsh age.

19. Minello, T.J. and R.J. Zimmerman. 1992. Utilization of natural and transplanted Texas salt marshes by fish and decapod crustaceans. *Marine Ecology Progress Series* 90:273-285.

Functional habitat utilization of three natural and three transplanted *Spartina alterniflora* marshes in Texas were compared. The created marshes were established on dredged material and were two to five years old. Use of replicate sampling over one year allowed scientists to test the null hypothesis that transplanted marshes on the Texas coast were equivalent to natural marshes. Mean values for stem density and aboveground biomass of *S. alterniflora* were higher in the transplanted marshes than in the natural marshes. Macro-organic matter (MOM) and densities of polychaetes, amphipods, and decapods were lower for transplanted marshes than natural marshes. However, densities of fish were similar between transplanted and natural marshes. These small fish may rely on salt marsh vegetation for cover from predators rather than for enhanced food resources. Comparison of prey abundance between transplanted and natural marshes requires an understanding of the trophic pathways and access to the marsh surface. If tidal flushing of small prey items and detrital matter into open water is the primary mechanism, then natant macrofauna on the marsh surface may not be indicative of relative marsh value for these organisms. Conversely, larger predators may actively move onto the marsh surface to feed, and the densities of decapods and fishes and their prey should reflect habitat value for the marsh.

20. Minns, C.K., J.R.M. Kelso, and R.G. Randall. 1996. Detecting the response of fish to habitat alterations in freshwater ecosystems. *Canadian Journal of Fisheries and Aquatic Sciences* 53(Suppl.1):403-414.

In order to detect fish responses to habitat alterations, e.g. restoration, four components need to be considered: expectations, measures, variability, and scale. Habitat alterations might be expected to cause four types of fish community and ecosystem response: (1) change in total fish biomass and production; (2) change in fish assemblage composition; (3) change in distribution of fish assemblage in time and space; and (4) change in non-fish biotic elements of ecosystem. The presence/absence matrix of these four elements leads to 16 total response patterns, with one being the null hypothesis where no responses occur due to habitat alterations.

Four approaches to dealing with problems of detecting biotic responses to habitat alterations include experimentation, science, ecosystem management, and coordination. Restoration activities should be considered experiments from which lessons can be learned. Scientific hypotheses and predictions need to be made before restoration commences. Ecosystem management is more holistic and ecosystem-oriented, and interdisciplinary cooperation is more important than ever.

21. Mitsch, W.J. and R.F. Wilson. 1996. Improving the success of wetland creation and restoration with know-how, time, and self-design. *Ecological Applications* 6(1):77-83.

Successful wetland creation and restoration projects have three essential requirements: understanding wetland function, giving the system time, and appreciating the notion of self-design. Studies on successful establishment of a biologically viable and sustainable wetland ecosystem revealed a spotty track record. Historically, vegetation cover has been the easiest and most widely implemented monitoring variable. However, it is a poor indicator of wetland function, and usually improper water levels and hydroperiod are more responsible for restoration failure.

The majority of failures in wetland creation can be attributed to lack of general knowledge of wetland science principles, such as the importance of proper hydroperiod. Wetland managers usually expect created or restored ecosystems to develop in a short time span, approximately five years or less. This time horizon is arbitrary and probably too short. A time line of 15-20 years is suggested, and coastal wetlands will require even more, i.e. > 50 years. There is a lack of appreciation for self-design in wetland creation. In other words, wetland managers are more likely to establish "designer" wetlands with planted species as opposed to wetlands that are naturally colonized over time. Wetland scientists need to make the correlation between structural (vegetation density, diversity, productivity) and functional (wildlife use, nutrient cycling, organic sediment accretion) characteristics.

Other tools are provided to reduce the uncertainty of wetland creation and to predict a time frame for success. Larger, ecosystem scale experimentation is recommended over smaller systems to ascertain the true functionality of the landscape. Predictive modeling using tools such as stochastic inputs, adaptive model structure, higher-order modeling languages, and spatially dynamic models can help reduce mitigation uncertainty as well. These tools have not been readily applied yet can effectively expand the time horizon of the project.

22. Moy, L.D. and L.A. Levin. 1991. Are *Spartina* marshes a replaceable resource?: A functional approach to evaluation of marsh creation efforts. *Estuaries* 14(1):1-16.

A study was conducted to compare functional ecological equivalence of a man-made *Spartina* salt marsh (between ages one to three years) with two adjacent natural marshes. Sediment properties, infaunal community composition, and *Fundulus heteroclitus* marsh utilization were the quantifiable criteria measured. Sediment organic content of the planted marsh was much lower than the natural marshes. Infaunal type differences were mirrored in *Fundulus* diets. *Fundulus* abundance in the planted marsh was significantly lower than in the natural marshes, indicating that fewer fish were being supported by the habitat. Furthermore, the planted *Spartina* stem densities were much lower than the natural marshes, affording inadequate protection or spawning habitat for the fundulids. The conclusion was that the planted marsh was not functionally equivalent to the natural marshes after three years. Mitigation success could be improved by increasing tidal flushing to allow marine organisms more access to the salt marsh, as well as adding *Spartina* wrack to increase sediment organic-matter content and porosity. Salt marshes, in general, should not be treated as replaceable resources in the short-term, and it is virtually impossible to replicate functionality of a lost salt marsh on another site.

23. National Research Council (U.S.) Committee on the Role of Technology in Marine Habitat Protection and Enhancement, Marine Board, Commission of Engineering and Technical Systems. 1994. Improving project performance. In Restoring and Protecting Marine Habitat: The Role of Engineering and Technology. Washington, D.C.: National Academy Press. 193 pp.

Performance criteria that are quantitative and measurable need to be established prior to restoration implementation so that all involved parties' expectations are clear. The key to project success is the flexibility of design and implementation. Projects can fail due to several reasons ranging from lack of understanding of ecosystem processes to poor implementation. Each of these reasons leads to failure of one or more ecosystem characteristics, such as proper hydrology, soil/substrate, etc. In order to track project performance, monitoring schemes need to be established. The time period during which performance will be monitored is essential; zero to five years is considered short-term, and beyond five years is considered long-term. Pre-project monitoring and baseline data collected seasonally for a full year is needed for comparison to restored sites. Post-project monitoring should occur at least monthly in the first year following construction completion. After the first year, the sampling schedule can be relaxed to monthly or seasonally. As time progresses, lower frequency monitoring can be phased in to cut down on project costs. In terms of monitoring criteria, all vegetated sites need evaluation in terms of survival rates, percent cover, reproduction, and other indicators of growth. Monitoring of deepwater habitats and seagrass beds also requires tracking of current and wave movements, sediment transport, colonization and habitat use by organisms, topographic changes, and water quality.

24. Northern Coast Range Adaptive Management Area Guide. Chapter 6 – Monitoring. 19 Feb. 1998. http://sequoia.fsl.orst.edu:80/ncama/guidch6.htm (4 Aug. 1999)

The Monitoring and Evaluation Plan in the Northwest Forest Plan establishes a general framework for evaluation criteria. Existing guidance on ecosystem monitoring is broad and not detailed; specific measures still need to be researched and developed at the site-specific level. Five general categories of monitoring are cited: late-successional forest, species of concern, riparian species and habitat, human communities, and adaptive management. Each of these categories features a central issue with related questions posed. A list of monitoring variables is provided in association with each category. For example, late-successional forest issues include the lack of existing habitat to support associated species. Variables to be monitored include patch size, successional status, and understory composition.

25. Patience, N. and V.V. Klemas. 1993. Wetland functional health assessment using remote sensing and other techniques: literature search. NOAA Technical Memorandum NMFS-SEFSC-319, 114 pp.

Wetland functional health determination techniques are reviewed and analyzed in conjunction with remote sensing techniques. These techniques are relevant to NOAA's CoastWatch Change Analysis Program (C-CAP) as well as other evaluation methods, such as EPA's Environmental Monitoring and Assessment Program (EMAP). Remote sensing technology is rapidly advancing, allowing for finer scale mapping in the future. Wetland biomass evaluation is possible with the use of remote sensing, thereby reducing the need for conventional methods. Some indicators of wetland health such as extent and type, habitat structural, and vegetation component of wetland productivity can be surveyed by remote sensing alone. Other indicators still require the use of more conventional techniques.

26. Richardson, J.S. and M.C. Healey. 1996. A healthy Fraser River? How will we know when we achieve this state? *Journal of Aquatic Ecosystem Health* 5:107-115.

The large Fraser River network in British Columbia, Canada is presented as an example of the difficulty of monitoring a large ecosystem. For large-scale watersheds and environments, no single index of ecosystem health exists for simple assessment. Therefore, we are limited to methods that compare current ecosystem conditions against some nearby reference site or existing historical data.

The first method involves building a predictive model using multivariate characterization of "pristine" sites by environmental measures and structure of benthic assemblages. A second method is to use historical reconstruction to model ecosystem functioning in the past. Estimation of natural variation in species abundance and composition will assist in focusing in on ecosystem variation due to anthropogenic stresses. The major constraint is the inability to directly link environmental stressors to ecosystem changes. Reference sites are difficult if not impossible to ascertain for large-scale ecosystems. Caution must be exercised when extrapolating patterns of benthic assemblages from smaller ecosystems to larger watersheds. Despite these concerns, the diagnosis of ecosystem health is evolving and will be primarily based on expert opinion rather than experimental tests of cause and effect.

27. Richter, K.O. Criteria for the restoration and creation of wetland habitats of lentic-breeding amphibians of the Pacific Northwest. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. K.B. Macdonald and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

In order to achieve self-sustaining populations of breeding lentic amphibians in the Pacific Northwest, several watershed features and wetland characteristics need to be included in the design of wetland restoration and creation sites. Attributes considered include breeding, feeding and refuge habitat, as well as migration corridors and dispersal habitat. The criteria provided are based on landscape ecology and conservation biology literature, as well as the author's personal studies in the Puget Sound Basin. Quantified measures of habitat are suggested as design criteria for successful restoration. These measures include area, lengths, widths, and quality of refuge and movement habitats; wetland attributes such as current velocity, minimum water depths, water level fluctuations, open water and vegetation requirements for breeding. On a landscape scale, connectivity, wetland size, and buffers are discussed to enhance successful amphibian migration and spawning.

28. Rogers, C.S. Common (or is it uncommon?) sense about coral reef monitoring. In *A Coral Reef Symposium on Practical, Reliable, Low-Cost Monitoring Methods for Assessing the Biota and Habitat Conditions of Coral Reefs*, eds. Crosby, M.P., G.R. Gibson and K.W. Potts. Annapolis, MD, 26-27 Jan. 1995. 80 pp. EPA 904/R-95/016.

In order to design effective coral monitoring protocols, one must consider several factors including management objectives, who will perform monitoring, what methods will be used, sampling duration, frequency and intensity, and data analysis and accessibility. The objectives behind coral reef monitoring will determine what success criteria should be selected and what type of data gathered. Long-term assessment of coral reef health is central to any monitoring scheme. Repeated sampling at permanent sites over the long term is vital. Monitoring methods need to be dynamic and flexible enough to address future concerns.

Specific methods to measure coral reef structure (percent cover, species diversity, relative abundance) include quadrats, photo-quadrats, and chain transects; these monitoring methods are summarized and compared as well. Photography is essential in supplementing coral reef monitoring. Changes in reef structure may be correlated to physical and chemical measurements of the surrounding waters. A coral reef monitoring program will most likely involve a variety of methods and long-term monitoring at random sampling sites. Monthly observations are suggested for individual coral colonies, whereas quadrat and transect data should be collected every six months. These frequencies strike a balance between undersampling and destructive activity. Quality assurance/quality control is important for data quality. Standardization of sampling data on a nationwide or global level is recommended, although this goal is not realistically viable.

29. Schweitzer, C.J. What is restoring bottomland hardwood forests? A study from the lower Mississippi alluvial valley. In *Transactions of the 63rd North American Wildlife and Natural Resources conference*. Orlando, FL, 20-25 Mar. 1998. Washington, D.C.: Wildlife Management Institute.

Restoration of bottomland hardwood forests focuses on vegetation with no mention of restoring hydrologic, edaphic, or faunal components. A survey of 47 Wetland Reserve Program tracts was conducted in 1996, four years after planting, to evaluate reforestation success; soil and hydroperiod were not considered. Since vegetation has been the easiest and most common method of vegetation, the objective focused on attaining a goal of 125 trees per acre after three years. Admittedly, functions such as population dynamics, nutrient cycling, and hydrological cycling are difficult to monitor. Other problems with current reforestation practices include lack of long-term monitoring plots, failure to establish measurable goals, failure to initially restore hydroperiod to ensure planting success, and disregard for soil and faunal monitoring.

30. Simenstad, C.A. and R.M. Thom. 1996. Functional equivalency trajectories of the restored Gog-Le-Hi-Te estuarine wetland. *Ecological Applications* 6(1):38-56.

The ability to predict long-term trends in wetland restoration success was tested using seven years of monitoring data in the Gog-Le-Hi-Te wetland in Puget Sound, Washington. Sixteen ecosystem functional attributes were analyzed to gauge restoration progress and/or success. These measures included habitat and sediment structure, primary production, benthic and epibenthic invertebrates, fish, and birds. Experiments to assess function directly were also executed, such as monitoring juvenile salmon residence time, foraging, and growth. The results of seven years of monitoring indicated few predictable trends of system development and ecological function. Several ecological functions indicate that Gog-Le-Hi-Te is still in early stages of development, such as static or slow change in sediment organic content and infauna taxa richness and density. Natural variability in reference wetlands must be studied in order to select proper criteria for functional equivalency. Longer time frames for monitoring are needed to determine whether a restored wetland can withstand natural perturbations and variability. Furthermore, current monitoring mainly focuses on structural attributes rather than functional processes. These more costly measures of function are necessary to evaluate ecosystem functioning at both local and landscape scales, as well as identify "endpoints" of estuarine wetland development.

31. Streever, B. 1999. Performance standards for wetland creation and restoration under Section 404. *National Wetlands Newsletter* 21(3):10-13.

In 1998, the U.S. Army Corps of Engineers (Corps) reviewed over 300 section 404 permits to determine whether trends existed for wetland mitigation standards. Many of these 300 permits that required compensatory wetland did not include performance standards or success criteria. Nine examples of performance standards are excerpted from the permit review process; all of them considered vegetation community development to some extent. The 300 permits revealed the lack of a universally accepted set of success criteria for section 404 mitigation. The permit review did identify seven general approaches to how the Corps develops performance standards, i.e. use of indices to compress large amounts of information. Development of a universal set of criteria is complex since different wetlands provide difference functions and require slightly different restoration approaches.

32. Trexler, J.C. 1995. Restoration of the Kissimmee River: a conceptual model of past and present fish communities and its consequences for evaluating restoration success. *Restoration Ecology* 3(3):195-210.

Restoration of fish communities in the Kissimmee River requires selection of carefully defined criteria for assessing success. Two conceptual models were designed to predict the outcome of restoration of fish based on pre-channelization and current conditions. Both models compartmentalize the river into two broad habitat classifications. Three key ecosystem function criteria were cited as being critical to successful restoration of Kissimmee River fish communities. These elements include (1) availability of floodplain habitats to river fishes during summer highwater months; (2) seasonal draining of wetland marshes for export of detritus, invertebrates, and fish; and (3) continuous flow of water throughout the watershed to increase seasonal oxygen minima.

In order to assess the three ecosystem functions detailed, five types of information should be collected when assessing restoration in terms of fish monitoring. The five criteria include (1) export of organic matter, invertebrates, and fish from marshes to river-channel habitats during water recession, as well as low-water refuges for small fish, juveniles, and larvae on the floodplain; (2) movement of spawning adults onto marshes during highwater periods; (3) patterns of spatial variation in abundance by species; (4) systemwide oxygen levels and current velocities, with velocities recommended between 10 and 50 cms^{-1}; and (5) food-web analysis for all abundant fish taxa, conducted before and after restoration, including monitoring of response of indicator species to restoration progress. Criteria (1) and (2) measure key elements of ecosystem function and are considered critical to evaluating restoration success.

33. U.S. Army Corps of Engineers. 1996 Sep. *Planning and evaluating restoration of aquatic habitats from an ecological perspective*, eds. Yozzo, D., J. Titre and J. Sexton, Alexandria, VA: The Institute for Water Resources. 426 pp. IWR Report 96-EL-4.

The U.S. Army Corps of Engineers (Corps) addresses issues of ecological restoration planning and evaluation. The restoration planning process is detailed in several steps, including the selection of restoration objectives and monitoring criteria. Six ecosystem types are addressed: open coastline and near coastal waters, subtidal estuaries, estuarine and coastal wetlands, freshwater wetlands, streams and rivers, lakes and reservoirs. Each section provides information on the ecosystem such as key ecological processes, nutrient sources and distribution, functional values. Although specific quantifiable success criteria are not provided, key structural and functional characteristics are cited for each habitat. Monitoring plans should measure certain variables depending on the restoration objectives and goals. Brief case studies are provided for each habitat type as insight into how the Corps is conducting restoration and post-project evaluation.

34. U.S. Army Engineer Waterways Experiment Station. 1999. Case Study: Application of the HGM *Western Kentucky Low-Gradient Riverine Guidebook* to monitoring of wetland development, *WRP Technical Notes Collection* (TN WRP WG-EV-2.3). U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/wrp (9 Aug. 1999).

The hydrogeomorphic (HGM) approach for assessing wetland functions is a potential method of monitoring wetland restoration progress. Although the HGM method is designed to assess impacts of proposed projects on wetland functions, it can also be used to monitor wetland development following mitigation or restoration activities. This case study illustrates the potential uses of the HGM approach in the 15-year development of low-gradient riverine wetlands in western Kentucky. Ten variables associated with wetland vegetation development and functional capacity were measured. These included biomass, plant species composition, tree density, floodplain roughness, snag density, and woody debris and log biomass. Four wetland functions were selected that depended heavily on biotic variables measured at the sites: nutrient cycling, organic carbon export, maintenance of characteristic plant community, and wildlife habitat.

There was considerable variability in the field measures for each variable, although certain measures exhibited distinct trends over time. Average O-horizon biomass, site roughness, and similarity in species composition between assessed and reference wetlands all increased over time. Herbaceous ground cover generally declined as average density and basal area of trees increased. All four wetland functions increased in capacity over time, except for the oldest stand of trees. It was determined that performance standards for success should change with site age, rather than comparing restoration to a mature reference site. Unfortunately, Section 404 permit requirements for monitoring usually last for up to five years following mitigation. Development of certain structural characteristics can be engineered within a short time frame. Functional or biological characteristics may require many years to reach optimal levels; for instance, field measures of biological variables in the case study were well below reference standards even after 15 years.

35. Weinstein, M.P., J.H. Balletto, J.M. Teal, and D.F. Ludwig. 1997. Success criteria and adaptive management for a large-scale wetland restoration project. *Wetlands Ecology and Management* 4(2):111-127.

Two kinds of degraded salt marsh were restored in Delaware Bay, New Jersey, in order to mitigate losses of finfish populations from a local power plant. Two basic questions were asked to determine whether the project would be successful: how long would marsh restoration take, and what is the endpoint of restoration? In order to evaluate the success of these restoration efforts, three categories of performance criteria were developed: (1) percent coverage of the marsh by vegetation; (2) reduction in *Phragmites australis* coverage; and (3) percent open water. Three reference marshes were used to establish the "bound of expectation" in terms of measurable endpoints for restoration. Features including geomorphology and vegetation that represent the expected range of variability were monitored in the reference marshes, and these same variables were measured in the restoration sites.

In order to incorporate benefits to finfish in marshes, four structural and functional measures were identified: (1) geomorphology and hydrology; (2) low marsh; (3) hydroperiod; and (4) plant coverage and diversity. Three reasonable restoration endpoints were suggested, including open water coverage, *Phragmites* coverage, and desirable vegetation coverage. To ensure benefits for finfish, a composite evaluation system that merges marsh restoration and optimizes fisheries production was presented. A Habitat Value (HV) scoring method was used to ensure equal weight for each habitat component. For example, either a "lawnscape" of *Spartina* spp. with poor drainage features or an unvegetated, well-drained mud flat would yield an undesirable habitat.

An adaptive management process that can implement corrective actions is also presented. Three hydrology thresholds and two vegetation thresholds were established to gauge when corrective measures would be necessary. Other biological responses were also suggested, such as local herbicide application and planting *Spartina* species.

36. Wilcox, D.A. and T.H. Whillans. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. *Wetlands* 19(4):835-857.

Wetland restoration in large lake systems is a relatively new practice. This article compiled tested methods and developed additional potential methods to provide an overview of approaches for restoration. Rather than providing specific details of methods, the overview of restoration approaches focuses on four general fields of science: hydrology, sedimentology, chemistry, and biology. Some of these methods were used in three major wetland restoration projects and are illustrative of practical applications in the Great Lakes. Successful wetland restoration is usually determined by a set of measures that describe how closely the restored site resembles the structure of an undisturbed reference site. Such success criteria are usually selected through the regulatory process rather than by following ecological principles. Short-term regulatory measures of success are not indicative of long-term success as most wetland restoration projects need considerable time to develop proper ecological functioning. Measures of wetland structure and function are more meaningful targets for restoration efforts. Five measures are suggested: 1) sustainability, 2) productivity, 3) nutrient retention, 4) invasibility, and 5) biotic interactions.

37. Winfield, T.P., J. Florsheim, and P. Williams. Creating tidal marshes on dredged materials: design features and biological implications. In *Wetland and Riparian Restoration: Taking a Broader View, Proceedings of a Conference*, eds. Macdonald, K.B. and F. Weinmann. Society for Ecological Restoration International Conference, Seattle, WA, 14-16 Sep. 1995. 284 pp. EPA 910-R-97-007.

A set of general design criteria is needed to ensure structural and functional equivalency of created tidal marshes on dredged materials with natural tidal marshes. A study was performed on four tidal marshes in San Francisco Bay to investigate the biological and physical attributes of created tidal marshes and natural tidal marshes. Furthermore, the study identified important design features for consideration in future salt marsh creation projects on dredged material, to increase chances of success. Determination of success has been questionable due to lack of well-defined objectives and inadequate monitoring. Significant differences in vegetation percent cover between created and natural tidal marshes were found, and these were attributed to poor development of a tidal slough channel network at the constructed marshes. The initial elevation of dredged materials on the created tidal marsh is essential to development of slough channel density and morphology.

38. Zedler, J.B. Restoring cordgrass marshes in southern California. 1992. In Restoring the Nation's Marine Environment, ed. Thayer, G.W. College Park, MD: Maryland Sea Grant College, Publication UM-SG-TS-92-06. 716 pp.

Efforts to restore southern California cordgrass (*Spartina foliosa*) marshes have focused on revegetation, but full ecosystem functioning has yet to be documented. In an example in San Diego Bay, created marshes had not reached functional equivalency with natural reference marshes within five years. Other examples illustrate a less than 60 percent functional equivalency with an adjacent reference wetland. Research is needed to understand what causes functional inequivalency, and new methods are underway to improve restoration projects. Long-term studies of coastal restoration sites and development of new ecotechnological methods are needed to improve and accelerate wetland functional equivalency.

39. Zedler, J.B. 1995. Salt marsh restoration: lessons from California. In Rehabilitating Damaged Ecosystems, 2nd edition, ed. Cairns, J. Jr. Boca Raton, FL: CRC Press, Inc. 425 pp.

Mitigation of wetlands has become a justification for "quality replaces quantity". This has been propagated by the lack of documentation of restoration failures. In order to evaluate success, goals and objectives need to be specifically stated prior to any restoration activities. Several goals are presented as examples, including the need for regional coordination, maintaining native species communities that are uncommon in the region, maintaining the "natural variety" of communities rather than simply increasing "diversity", etc. Other goals for hydrological planning are discussed as well, such as the need to maintain natural variations in hydrologic conditions to manage native salt marsh communities.

Experimentation is the only way to refine the science of salt marsh restoration. Knowledge of both failures and successes through controlled, replicated field experiments, performed in conjunction with restoration will be extremely valuable. There are two reasons for assessing restoration success. The first is the need for resource agencies to keep track of how much regional wetland is being restored. The second is to determine whether mitigation has met contractual requirements. Two general criteria of success are whether the restoration project has met the preset objectives and what the restoration provided in comparison to the region's needs. Assessment must be performed over the long-term, from at least one to five years up to beyond 20 years. Detailed and frequent sampling is required to detect changes due to restoration as opposed to natural variation. Results of monitoring and restoration need to be published and peer-reviewed such that refinements can be made.

40. Zedler, J.B. 1996. *Tidal Wetland Restoration: A Scientific Perspective and Southern California Focus*. California Sea Grant College System, University of California, La Jolla, California. 129 pp. Report No. T-038.

Structural attributes are measured during monitoring as surrogates for functional processes. This is mainly due to the fact that basic ecosystem functioning is still being discovered, and monitoring structural criteria is cheaper than extensive functional assessments. Each monitoring program should have performance criteria that are tailored to that site. With respect to Southern California tidal salt marshes, frequency of monitoring is as follows: water quality is biweekly or monthly; vegetation in September; salinity of marsh soil in April and September; fishes and invertebrates on a quarterly basis; and special interest species during reproductive periods.

Three indicators of ecosystem functioning were selected as simple criteria. These included ability to support biodiversity, canopy architecture, and other indicators. Monitoring should be designed to track populations of sensitive and endangered species in order to support biodiversity. Canopy architecture needs to be monitoring such that the vegetation can support endangered birds. Other indicators such as water quality can be used to assess potential for support of fishes and invertebrates. Once these indicators have been selected, they must be reviewed and accepted by scientific peers. Agencies that manage endangered species must then test the cause-effect relationship between the indicator and the ecosystem function it represents.

☆ U.S. GOVERNMENT PRINTING OFFICE: 2000-592-123/16063