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Primer on Ecosystem Restoration

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Ecosystem restoration is generally defined as returning a system that has been altered, degraded, or destroyed to a state that closely mimics pre-disturbance conditions. The general term “restoration” can be used to describe many different approaches, and is a complex process that is being performed on numerous scales throughout the United States and abroad to combat damage that has been inflicted upon coastal ecosystems. Gulf of Mexico coastal ecosystems are vulnerable to anthropogenic effects ranging from coastal development to watershed inputs. It is the intention of many entities to restore systems throughout the Gulf that have been changed over time to help rebuild ecosystem functions and services. This primer on ecosystem restoration, within the context of ecosystem-based management, will describe the fundamentals of restoration including how the principles of landscape ecology help guide ecosystem restoration, components of a restoration project, and how to address uncertainty.

Restoration of coastal ecosystems can be conducted within the new paradigm of ecosystem-based management. The Pew Oceans Commission (2003) states that “*the goal of ecosystem-based management is to maintain the health of the whole as well as the parts. It acknowledges the connections among things.*” The Ecological Society of America (1995) identified eight critical elements of ecosystem-based management, as summarized below:

1. Managing ecosystems in a sustainable fashion.
2. Establishment of measurable goals essential for sustainability.
3. Ecological understanding and modeling through research performed on numerous levels.
4. Management that recognizes ecological complexity and connectedness necessary for resources to adapt to changes in the long run.
5. Recognizing that ecosystems are dynamic rather than static (change and evolution are inherent in ecosystem sustainability).
6. Understanding of spatial and temporal scales and how sites are influenced by their surroundings.
7. Humans are a major component of ecosystems.
8. Knowledge of ecosystem processes and functions are incomplete and that management should use scientific hypotheses, research, and monitoring as a foundation to make decisions.

The principles of ecosystem-based management outlined above can and are being used as the foundation for restoration science and incorporated into the process of coastal ecosystem restoration.

At the root of ecosystem restoration and within the framework of ecosystem-based management, there are fundamental components that help guide the restoration processes. These include restoration strategies, state of the ecosystem, and principles of landscape ecology. Johnson et al. (2003) describe five generic restoration strategies (Table 1) that may be used in isolation or in combination depending on project goals and

site conditions. All strategies outlined below except protection require some level of physical involvement if the environment no longer possesses the ability to uphold function and/or fix damage. Intervention is probably not warranted when the restoration manager believes that the environment has the capacity to naturally repair damage and meet restoration goals. Without intervention, the environment will either repair itself or continue to further degrade.

Table 1. Definitions of Restoration Strategies (modified from Johnson et al. 2003)

Restoration Strategy	Definition
Conservation	Maintenance of biodiversity (Meffe et al. 1994).
Creation	Bringing into being a new ecosystem that previously did not exist on the site (NRC 1992).
Enhancement	Any improvement of a structural or functional ecosystem attribute (NRC 1992).
Restoration	Return of an ecosystem to a close approximation of its previously existing condition (Lewis 1990, NRC 1992).
Protection	Formal exclusion of activities that may negatively affect the structure and/or functioning of habitats or ecosystems.

The second fundamental component of ecosystem restoration is the state of the environment. The main objective of restoration is to shift the condition of the environment from a generally unacceptable state to a more desirable condition in the least amount of time. Thus, an accurate assessment of the current condition of the environment and restoration goals is needed. Figure 1 illustrates a template to visualize the present (disturbed) and historical (undisturbed) conditions of the ecosystem (Thom 1997),

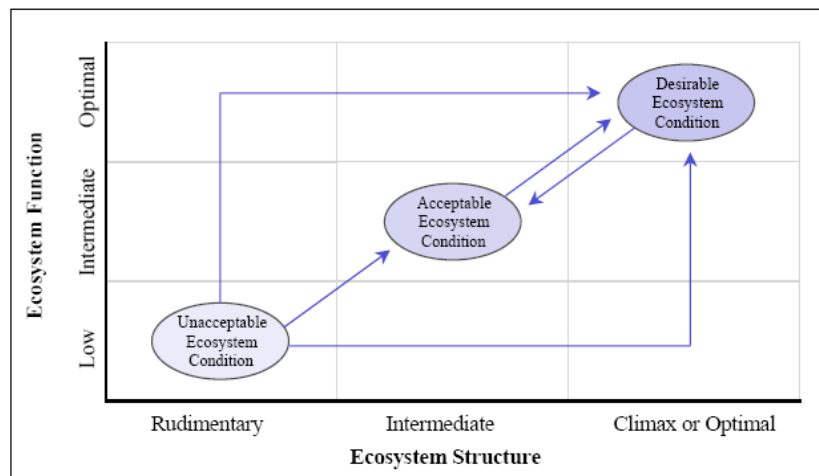


Figure 1. General Model of Ecosystem State. An ecosystem or habitat that is in rudimentary condition with low functioning develops into a system with optimal structure and functioning (after Thom 2000). Development can take several pathways and can oscillate between system states. (From Johnson et al. 2003).

and assumes that a positive relationship exists between ecosystem structure and function. The system state is divided into three groups on both axes (low, moderate, high or optimal), to address two main sources of uncertainty: 1) our lack of ability to measure the relationships and fully understand the intricacies between structural and functional ecosystem components, and 2) our lack of ability to forecast variability associated with structural and functional conditions based on periodic and stochastic events (Shreffler and Thom 1993, Hobbs and Norton 1996). The three stages on each axis represent qualitative indicator variables (e.g., acreage) which are connected to the structural condition (e.g., the size of the pond-wetland interface) and the functional conditions (e.g., the number of ducks nesting at this interface). For comparison of the different states an ecosystem can progress through (based on the arrows in the figure) the upper right hand box represents a habitat that is completely developed, quick to recover from disturbances, has achieved optimal biodiversity, and is self-sustaining. However, even an ecosystem under most favorable conditions of structure and function may vary over a range of values, and can be deemed a success if it hits a certain target within that range (Johnson et al. 2003).

Restoration ecologists are beginning to adapt the principles of landscape ecology into restoration projects and monitoring efforts. The fundamental concept of landscape ecology evaluates how factors within the environment affect the quantity and allocation of organisms. Johnson et al. (2003) further describe landscape ecology as, “*the effect of the spatial extent, heterogeneity, and geometry of elements (e.g. habitats) of the landscape on the flow of energy, animals, and materials through the landscape.*” Habitats are composed of smaller elements, each of which serves a function within the entire landscape. Removal or degradation of one or more elements may reduce or severely hinder the flow of energy, animals, or materials through the entire landscape causing landscape function to decrease. By understanding the fundamentals of landscape ecology, restoration practitioners can narrow their focus for restoration to the elements within the system that may be degraded or not functioning at natural capacity (Johnson et al. 2003).

The restoration process can be guided by the fundamental components described above. They also help to form the context of individual restoration projects. In the next section, descriptions are provided for five major components of a restoration project: planning, implementation, performance assessment, adaptive management, and dissemination of results (Diefenderfer et al. 2003).

The first step when conducting a restoration project is to chart a course during the planning phase. Figure 2 outlines the major steps in the process of project planning.

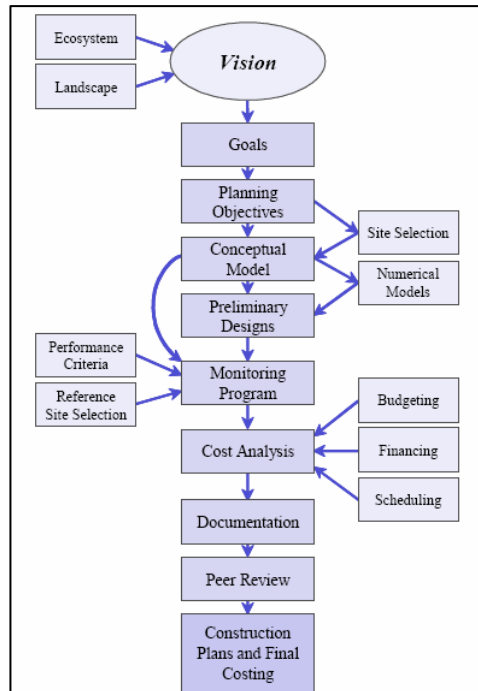


Figure 2. Planning process for coastal restoration (Diefenderfer et al. 2003).

Restoration project planning begins with a vision, an idea of the desired target state of the ecosystem based on ecological or biological requirements, and a path forward to achieve it. The vision can be transformed into the main goal(s) of the project, and is most useful when it can be converted into quantifiable units. Thus, during the monitoring phase of the program the goal will provide testable null hypotheses that can be measured and evaluated (Diefenderfer et al. 2003). Development of planning objectives or a strategy on how project goals will be achieved is the next step in the planning process. This requires input from the project team as well as local stakeholders. Another important piece is the development of a conceptual model. Conceptual models are useful to identify ecosystem stressors, controlling factors, ecosystem structures, and ecosystem functions and services provided by the habitat. They are an informative tool that provides the level of understanding about a particular habitat that will undergo some type of restoration (Diefenderfer et al. 2003). Performance criteria are quantifiable or observable measurements used to track the progress of a system in meeting the project goals. The measurements can be quantitative or qualitative based on the chosen site conditions. Finally, the establishment of a monitoring program that is best constructed early on in the planning process. The monitoring program is important for tracking the progress of project goals and is also a key element in adaptive management, or the capacity to make decisions “on the go” as new information is obtained during restoration. Other factors that should be considered in the planning phase are costing, scheduling, and contingency planning.

Site selection can be carried out using a systematic prioritization framework. For example, a suite of potential sites can be evaluated by their expected change in function, area of habitat, and probability of working in perpetuity.

The second part in the restoration process is project implementation. Before construction begins, it is beneficial to finalize project budgets and schedules and make sure that the contractor has all the site requirements including elevation, substrate requirements, planting requirements, and hydrological aspects. Once construction is initiated, it is essential that a restoration planner be involved in the process to ensure that project needs and goals are being met and that the right people, including engineers, are providing their expertise to project tasks (Diefenderfer et al. 2003). Different types of project construction include removal of dikes, vegetation planting, installation of culverts for fish passage, and stream bank stabilization for erosion control. Site monitoring after construction begins is critical to verify project goals are being met, plans and designs are being implemented according to specifications, and that the construction itself is not negatively impacting surrounding habitats.

After construction is completed a monitoring program is initiated to assess restoration site performance. It provides feedback on how the site is developing over time with respect to performance criteria by physically measuring environmental parameters outlined in the planning stage. A monitoring program should not only evaluate the trajectory of the restoration site, but should also measure parameters from a reference site so that restoration site variables can be compared to a site that has not been manipulated. This will provide the restoration planner with trends in the system over time (Diefenderfer et al. 2003).

Adaptively managing a restoration site provides opportunity to make adjustments to the site if the restoration is not following its planned trajectory of development. Information guided by site monitoring provides restoration planners with data on how well the site is meeting goals and performance criteria. Restoration managers are faced with three options: taking no action and allowing the site to develop without physical aid, maintaining the system, or modifying of project goals and taking appropriate action to meet the revised goals (Diefenderfer et al. 2003). Managing restoration projects in an adaptive matter can help combat uncertainties.

Thom et al. (2005), in the context of adaptive management, described uncertainties coastal restoration projects face. These include: lack of information on existing site conditions and/or historical site conditions, poor understanding of ecosystem controlling factors, funding, climate variability, offsite issues affecting habitat-forming processes, and social uncertainties. Uncertainty can be reduced, or at a minimum can be detected, by proper restoration planning, reviewing results of similar projects, and through adoption and exercise of adaptive management principles.

Finally, results of a coastal ecosystem restoration project should be provided to entities that have a stake or interest in the progress and outcome of a restoration project. Results can be disseminated through project reports, presentations, uploading information to various restoration websites, publication in a peer-reviewed journal, and technical meetings, scientific conferences, and workshops (Diefenderfer et al. 2003). The documentation of project progression and the subsequent dissemination of information can be used as a learning tool for future restoration efforts and to highlight aspects of a project that worked and those that did not.

In summary, coastal ecosystem restoration can be addressed adaptively using the principles of ecosystem-based management. These include managing the system as a whole as well as the parts, working in a sustainable fashion, recognizing that humans play

a major role in the ecosystem, and understanding that ecosystems and processes within are dynamic rather than static. This framework, along with an appreciation for the principles of landscape ecology and an understanding of the state of an ecosystem, can provide an overarching framework for shaping individual restoration projects.

Restoration projects can progress through five major stages: planning, implementation, performance assessment, adaptive management, and dissemination of results. With the increased pressure on coastal ecosystems there is a need to preserve and restore these habitats because of the numerous services they provide and the functions they undergo that ultimately support aquatic life.

REFERENCES

- Diefenderfer, H.L., Thom, R.M., and Adkins, J.E. 2003. Systematic approach to coastal ecosystem restoration. Battelle Report No. PNWD-3237. Prepared for National Oceanic and Atmospheric Administration, Coastal Services Center, September, 2003.
- Ecological Society of America (Ad hoc committee on ecosystem management). 1995. The report of the Ecological Society of America Committee on the scientific basis for ecosystem management. Available URL: <http://www.esa.org/pao/policyStatements/Papers/ReportOfSBEM.php>.
- Hobbs, R. J., and Norton, D. A. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology* 4: 93-110.
- Johnson, G.E., Thom, R.M., Whiting, A.H., Sutherland, G.B., Berquam, T., Ebberts, B.D., Ricci, N.M., Southard, J.A., and Wilcox, J.D. 2003. An ecosystem-based approach to habitat restoration projects with emphasis on salmonids in the Columbia River Estuary. Report No. PNNL-14412, September 30, 2003.
- Lewis, R. R., III. 1990. Wetland restoration/creation/enhancement terminology: suggestions for standardization. Pages 417-419 in Jon A. Kusler and Mary E. Kentula (eds). *Wetland creation and restoration the status of the science*. Island Press, Washington, D. C.
- Meffe, G. K., Carroll, C.R., and contributors. 1994. *Principles of Conservation Biology*. Sinauer Assoc., Inc., Sunderland, Mass.
- National Research Council. 1992. *Restoration of Aquatic Ecosystems*. National Academy Press, Washington, D.C.
- Pew Oceans Commission. 2003. *America's living oceans; charting a course for sea change. A report to the Nation, recommendations for a new ocean policy*, May, 2003.
- Shreffler, D. K., and Thom, R. M. 1993. *Restoration of urban estuaries: New approaches for site location and design by: Washington Department of Natural Resources: Battelle Pacific Northwest Laboratories; 1993107*.
- Thom, R. M. 1997. System-development matrix for adaptive management of coastal ecosystem restoration projects. *Ecological Engineering* 8: 19-232.
- Thom, R. M. 2000. Adaptive management of coastal ecosystem restoration projects. *Ecological Engineering* 15(3-4): 365-372.
- Thom, R.M., Williams, G., Borde, A., Southard, J., Sargeant, S., Woodruff, D., Laufle, J.C., and Glasoe, S. 2005. Adaptively addressing uncertainty in estuarine and near coastal restoration projects. *Journal of Coastal Research* 40: 94-108.