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Systematic Approach to Coastal Ecosystem Restoration

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ABSTRACT

This paper presents a systematic approach to coastal restoration projects in five phases: planning, implementation, performance assessment, adaptive management, and dissemination of results. Twenty features of the iterative planning process, applicable in a variety of coastal habitats, are synthesized from restoration project experience and the literature. The planning process starts with a *vision*, a description of the *ecosystem* and *landscape*, and *goals*. A *conceptual model* and *planning objectives* are developed, a *site is selected*, and *numerical models* contribute to *preliminary designs* as needed. *Performance criteria* and *reference sites* are selected and the *monitoring program* is designed. The monitoring program is emphasized as a tool to assess project performance and identify problems affecting progression toward project goals, in an adaptive management framework. Key approaches to aspects of the monitoring program are reviewed and detailed with project examples. Within the planning process, *cost analysis* involves *budgeting*, *scheduling*, and *financing*. Finally, *documentation* is *peer reviewed* prior to making *construction plans* and *final costing*.

Introduction

Objective

The goal of this paper is to present a framework that has proven to be effective and efficient in coastal restoration projects, providing a common approach for people working together for coastal restoration and helping to bridge the gap between scientists and the interested public. It is hoped that this framework will be useful to the partnerships that have proven to be important to many restoration projects, often involving local volunteers as well as personnel from governmental agencies and nongovernmental organizations (NGOs) with varying backgrounds in restoration ecology. It is intended as a review and guide for environmental planners, regulatory personnel, engineers, consultants, college students, and others involved in coastal restoration projects or planning. It may also be of interest to researchers in the field of restoration ecology and conservation biology.

This paper presents a systematic approach to coastal restoration projects in five phases: planning, implementation, performance assessment, adaptive management, and dissemination of results. It was developed in conjunction with a companion document, a *National Review of Innovative and Successful Coastal Habitat Restoration* (Borde *et al*. 2003), which focuses on methods. The systematic approach describes twenty aspects of the planning process that are important whether the project involves seagrass, coral, an estuary, kelp, salt marsh, mangrove, or other coastal habitat. The approach has been developed through direct experience in designing, implementing and monitoring restoration projects over the past 18 years, and informed by readings, discussions with colleagues, and the review of coastal restoration efforts across the United States (Borde *et al*. 2003). Special attention is given to monitoring, an often neglected component of restoration that is critical to the scientific process as well as to restoration success.

The lack of a systematic approach hinders the development of reliable restoration technologies, which affects our ability to design and implement successful restoration projects. Based on our restoration experience and review of projects and programs, we argue that a systematic approach will benefit most if not all types of restoration projects on all scales. There are few documented cases in which pre-project predictions of ecosystem functions and the timeline of development have been accurate (NRC 1992, 1994; Thayer 1992; Wilber *et al.* 2000). The National Research Council (NRC) (1992) concluded that restoration planning needs to be conducted in a more systematic and rigorous manner. The primary point of failure identified was the statement of goals for the project. Vague goals resulted in misdirected design and poorly functioning systems. Similarly, in reviewing over 200 restoration projects conducted over 15 years, Shreffler *et al.* (1995) identified an absence of standardized methods for establishing goals, performance criteria, and monitoring. The NRC (2001) again recommended that project goals and performance standards be made specific.

In developing this approach, we have relied heavily on recommendations from numerous sources. Key national syntheses include the National Oceanic and Atmospheric Administration (NOAA) Symposium on Habitat Restoration of 1990 (Thayer 1992), and the Goal Setting and Success Criteria for Coastal Habitat Restoration symposium in 1998 (Wilber *et al.* 2000). Recently, a special issue of the *Marine Pollution Bulletin* was also devoted to the topic (Edwards *et al.* 2000). Three NRC studies are particularly relevant: *Restoration of Aquatic Ecosystems* (1992), *Restoring and Protecting Marine Habitat: The Role of Engineering and Technology* (1994), and *Compensating for Wetland Losses under the Clean Water Act* (2001). Other key reports, specific to ecosystems or regions, are referenced throughout this paper.

While it may be argued that we should not try to restore ecosystems until we understand their components and long-term functioning, we maintain that the systematic planning, implementation and assessment of the restoration project is an important part of the learning process (Kusler and Kentula 1990a). Constructing a functioning system is perhaps the most complex experiment a scientist can undertake. It is analogous to engineering practices, in that the application of information gained by failed or imperfect designs will foster success.

Restoration Opportunities

Restoration opportunities are abundant in every coastal habitat type, whether nearshore or estuarine. Examples at various scales, many of which are associated with estuaries, include marine and tidal freshwater marshes; tidally-influenced river and stream corridors; unvegetated tidal flats; river deltas; deepwater swamps; coastal grasslands; maritime and riverine forests; coastal forested and unforested wetlands; coral reefs, seagrass meadows; mangroves; kelp beds or other macroalgae; marine and tidal freshwater submerged aquatic vegetation (SAV) in general; shellfish beds; the bottom and the water column; and rocky and soft shorelines. Innumerable local projects exist nationwide, supported to varying degrees by governmental agencies, NGOs and community volunteers. Several large-scale coastal restoration projects, each of which encompasses multiple habitats, have also been initiated in recent years: for example, Puget Sound, the Florida Everglades, the Columbia River estuary, Chesapeake Bay, and the Louisiana coastal wetlands.

The goal of the Estuary Restoration Act of 2000 (ERA) (33 USC 2901) is to restore one million acres of estuarine habitat by 2010 (Federal Register 2002). In contrast, less than 20 years ago, the restoration of a 10-acre wetland was considered a relatively large project (Simenstad and Thom 1996). Coastal America, a partnership for coastal protection, has to date helped restore 28,000 acres of wetlands (Vogt 2002). Other national programs, such as the NOAA Community Based Restoration Program, also support large networks of projects. Projects that are small in size can, of course, be of large significance within the landscape. *The systematic approach to coastal habitat restoration described in this paper is applicable to projects at all scales.*

Present Context of Coastal Restoration

Approximately half of the population of the United States, a growing number, lives in coastal areas (NOAA 2002; EPA 2002), and coastal ecosystems are under constant pressure from development and exploitation. Coastal ecosystems have been reduced by conversion to agriculture or other development, hydrologic alterations, water quality degradation, sedimentation, erosion, damage associated with vessels, and other factors. The coastal wetlands of Louisiana, for example, have been reduced by over 768,000 acres in the last 50 years (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2001). Short of drastically curbing population growth, we see that the main challenge to coastal restoration science in this century is to balance coastal development with the maintenance of clean and functional coastal ecosystems. Although the impetus for coastal restoration is often public concern about the state of the environment, it is justified by the monetary values of ecosystem goods and services (Costanza *et al.* 1997; Gosselink *et al.* 1974), and by non-resource values such as ecosystem stabilization and environmental baseline monitoring (Ehrenfeld 1976). Although major accounting systems still do not treat ecosystems as economic assets (Repetto 1990), the need for coastal restoration and mitigation is now enacted in federal laws such as the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) (16 U.S.C. 3951).

How can coastal development and exploitation be continued while *improving* coastal ecosystems? The answer is probably best captured by the concept of *sustainable development* (National Research Council 1999; Urbanska *et al.* 1997; World Commission on Environment and Development 1987). *Development* is the qualitative change in a system's complexity and configuration, as opposed to *growth,* which refers to a quantitative increase in the size of the system (Meffe *et al.* 1994). Sustainable development means that society conducts itself in a manner that preserves ecosystems for the future by encouraging actions that *conserve* what exists, and *restore* what has been damaged or lost (Meffe *et al.* 1994).

For example, it is becoming increasingly clear that the estuaries and nearshore areas of the Pacific Northwest provide critical feeding and rearing habitat for salmon populations (Simenstad and Cordell 2000; Williams *et al.* 2001). Salmon restoration efforts, once highly focused in the watersheds where salmon spawn, are now emphasizing the estuary and nearshore. However, it is common sense that any restoration of these latter habitats will only benefit a salmon population that is *conserved* through controls of stressors such as over-fishing. Conserved habitats, such as regulated marine protected areas (MPA), serve as *source areas* that can supply surplus recruits to a region (Hastings and Botsford 1999; Pulliam 1988; Roberts *et al.* 2001). To put it simply, if salmon have been totally lost from a watershed-estuarine-nearshore system, it makes little sense to *restore* habitats in that system without also reintroducing and protecting the salmon.

Sustainable development necessitates that restoration projects be considered in a landscape context. External influences may affect the performance of restored coastal ecosystems, even as changes brought about by restoration affect surrounding areas. Coral reefs, for example, may benefit from the restoration of nearby seagrasses or mangroves where reef species spend parts of their life cycles (Maragos 1992). The study of such interactions has intensified since the theory of island biogeography was formulated by MacArthur and Wilson (1963, 1967) and Preston (1962a, 1962b). Site-specific evaluation of the landscape in the planning phase of a restoration project is critical. Attributes such as size, shape, configuration, and connectedness, considered under the rubric of landscape ecology (Forman and Godron 1981), dramatically affect the net functional habitat provided by a coastal restoration project.

For sustainable development to succeed, the goal today must not be simple maintenance of the status quo, but a net improvement of the ecosystem. Coastal ecosystems, such as coral reefs, estuaries, mangroves, kelp forests, and eelgrass beds, are shrinking from pre-colonization levels or experiencing diminished functionality (Field 1998; Fonseca *et al.* 1998; Thayer 1992; Turgeon *et al.* 2002). The NRC (2001) has shown that the no-net-loss policy for wetlands is not working. Simply put, we have failed to constrain development to minimize damage; we do not compensate for damages immediately so as to offset any losses; and we do not have a high degree of predictability in the outcome of restoration efforts. This means that *the size, quality, location, and viability of a restoration project meant to compensate for development must overwhelmingly and obviously compensate for the expected losses*. This approach provides a cushion to account for uncertainties in the ability of combined conservation and restoration efforts to meet their goals. As the level of experience, body of knowledge, and record of success increases then the level of uncertainty decreases along with the magnitude of effort required to compensate for uncertainty.

Components of a Restoration Project

The five components of a systematic approach to a restoration project are planning, implementation, performance assessment, adaptive management, and dissemination of results (Figure 1). Specific features of each of these components are detailed throughout this paper. They are not new, but represent a convergence of techniques that is evident in a national coastal restoration strategy (RAE & NOAA 2002), guidelines of the Society for Ecological Restoration (Clewell *et al*. 2000), a national techniques manual (Sea Grant 2002), and major coastal restoration efforts across the country: Rhode Island (University of Rhode Island 2003), Chesapeake Bay (Batiuk *et al*. 2000, 1992), Florida Everglades (USACE & SFWMD 1999), Louisiana coastal wetlands (Louisiana Coastal Wetlands Conservation and Restoration Task Force 2001), Tijuana Estuary (Zedler 2001a), San Francisco Bay Delta (Josselyn and Buchholz 1984), and the more recent Columbia River estuary (Johnson *et al*. 2003) and Puget Sound nearshore ecosystem (Fresh *et al*. 2003), which are still in the planning stages. These techniques are applied to projects in large regional programs such as these, as well as to more isolated projects such as eelgrass restoration at the Clinton ferry terminal in Puget Sound (Southard *et al*. 2003). The eelgrass transplantation at Clinton, Washington is coordinated with ferry system operations and expansions, which provides opportunity for directed experimentation within a robust monitoring and management program (Borde *et al*. 2003). The Louisiana coastal wetlands and Clinton ferry terminal are examples of a large program and a relatively small project, respectively, in which those components that are often neglected in favor of implementation—planning, monitoring for performance assessment, and adaptive management–were included and funded early on.

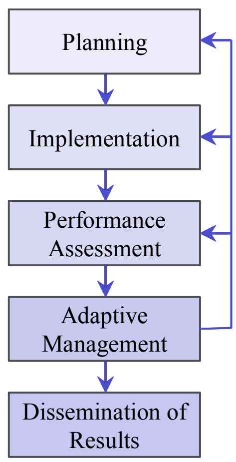

Figure 1. Five components of a coastal restoration project.

1. Planning
Planning includes the establishment of goals, objectives, and performance criteria for the project. Factors to consider in setting goals and performance criteria include time scale, spatial scale, structural conditions, functional conditions, self-maintenance, and the potential resilience of the system to disturbance. The type of system to be restored is determined, and the site is selected. Site selection involves examination of historical or predisturbance conditions, degree of present alteration, present ecological conditions, and other factors. Determining the level of physical effort, producing engineering designs, costing, scheduling, and producing contingency plans are all part of project planning. Stakeholders and the interested public should be identified and included in project planning.

2. Implementation
The implementation phase begins with any required assessments, such as an assessment of on-site contamination, though these may also be conducted in the planning phase. To avoid commonplace mistakes during construction, the operation must be monitored by someone who is aware of the project goals. As partners in the success of the project, engineers and contractors play a key role in ensuring that decisions during construction result in improvement of the system toward the goals. Also critical is the communication

of those engineering aspects of the program that might necessitate a revision of goals or performance criteria.

3. Performance Assessment: Development of the Monitoring Program
The monitoring program provides direct feedback on the development of the restored system with respect to performance criteria, using measurements of monitoring parameters. Field-sampling methods are selected for each parameter. The selection of appropriate reference or control sites in the vicinity of the restoration project is critical to analysis of monitoring data in order to identify trends that are not project-related.

4. Adaptive Management
The monitoring program is used as a tool to assess project success and identify any problems that might affect progression toward the project goals. Broadly speaking, the options available to the manager are no action, maintenance of the system, and modification of the project goals. If the monitoring program identifies deviation from the predicted trajectory of ecosystem development, adjustments can and should be made. Adaptive management of this kind has been recommended at a national level and is in use on many major restoration projects.

5. Dissemination of Results
It is important for complete information about the project to be disseminated as widely as possible (Hackney 2000). Yet, our national review of restoration projects (Shreffler *et al.* 1995) and a recent review of wetland mitigation projects in New England (Minkin 2003) indicated that record-keeping was given low priority in many projects. All aspects of the project should be documented, to show the effect of decisions, and progress toward goals. Planning for future projects requires such information to help minimize costs and maximize the probability of success.

Though the five components are displayed separately in Figure 1, in practice, coastal restoration is an iterative process, as represented by the arrows. Beginning in the planning phase, as new information is generated, it is incorporated into the conceptual model and plans are revised accordingly. Then during implementation, conditions on the ground may dictate reevaluation and possible alterations of plans. Through performance assessment and adaptive management, the development of the system is monitored and evaluated, and additional restoration measures are implemented as necessary. Management goals for the system may evolve based on information generated at the site or on the evolving state of the science. The dissemination of results facilitates information sharing by practitioners, which enables restoration practices to advance, makes restoration science more robust, and improves the chances of success at future projects.

Planning

In planning a coastal restoration project, sound ecological science and engineering and rigorous planning procedures are equally important. A failure in any area can lead to costly retrofitting during or after project implementation (Noble *et al.* 2000). No single planning approach or set of planning theories have gained wide acceptance among coastal resource managers (Kay and Adler 1999). Instead, a range of planning methods and theories are used, including, for example, rational, incremental, adaptive, and consensual approaches.

An example of the rational, or linear, planning approach is the six-step process outlined by the Water Resource Council for use by the US Army Corps of Engineers and other federal agencies in forming and evaluating plans for water and related land resource development projects (WRC 1983). Incremental planning considers only a few alternatives that represent limited deviation from the status quo. Adaptive planning methods are designed to allow managers to anticipate and take advantage of surprises by incorporating review and revision of already-implemented plans into the planning process. Consensual planning is designed to seek win-win solutions by involving all the stakeholders in a deliberative process that uses tools from dispute resolution, pragmatism, and education, and that often integrates elements of rational, incremental, and adaptive planning approaches.

Federal agencies have developed detailed project planning and engineering processes and have used them for decades. It is critical that tools and concepts from the science of ecological restoration be integrated with proven methods such as these (Thom *et al.* in press; Harrington and Feather 1996).

The planning approach that follows includes elements of rational and adaptive planning. The process and major components of this approach are illustrated in Figure 2 and detailed in the following sections, which correspond to the boxes in the Figure 2.

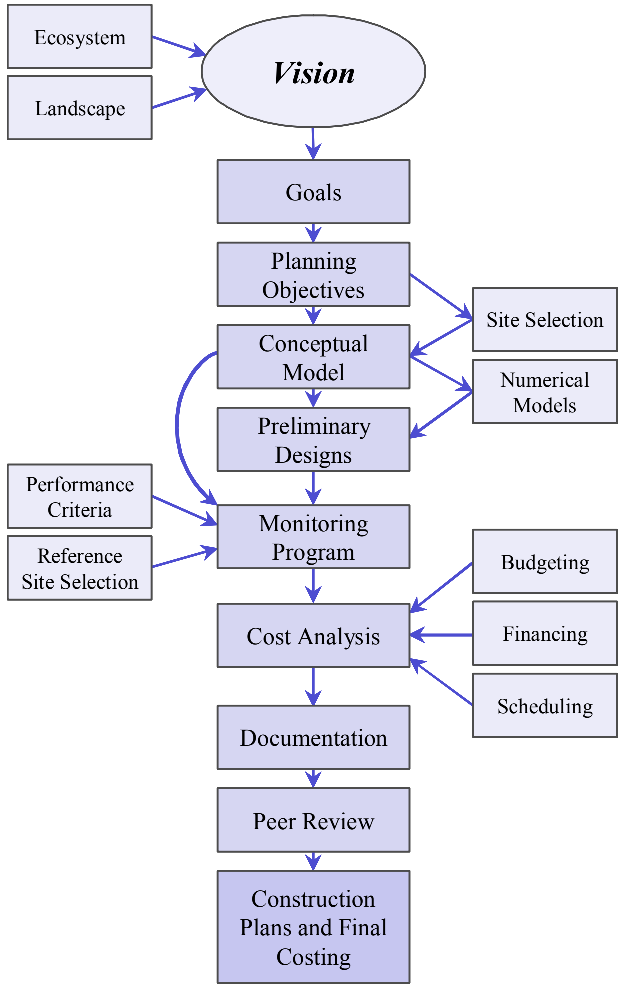

Figure 2. A coastal restoration project planning process.

The model of the planning process in Figure 2 is highly simplified and unified. In reality, the process is iterative and nonlinear, with complexities which cannot be adequately represented in a simple model such as this one. New information generated at any stage of the process may necessitate returning to an earlier stage or even to the beginning of the process. A good example of this is site selection: the project may begin with a known site, but the information generated in the planning process may recommend a different one. While the planning steps identified in Figure 2 may not always occur in the order presented, it is important that they all be incorporated in the decision process in order to develop sound recommendations in the final plan.

The Vision

A vision is the overarching idea from which a restored ecosystem is developed. A picture is refined and strengthened through interaction with individuals representing a variety of disciplines. At its core is an ecological or biological target. The environmental and planning contexts of the project are also incorporated. For example, how will the restored site function within the landscape? Will it complement other preservation or restoration efforts? How can the monitoring program support the project and help to further regional conservation goals?

Ecosystem

The vision statement highlights features at one or more scales, but if the scale of the threatened features does not encompass the ecosystem, then the ecosystem required to sustain the features is also identified. For example, if the vision includes specific benefits for one or more species, whether plant or animal, then the habitats required by these species are also included. Ecosystems, by definition, include the biota as well as abiotic features such as climate, physiography and soil. Examples of features that might form the heart of the vision include a mangrove forest, a fishery, a specific reef or estuary, or a single imperiled species. The ecological links and controlling factors that are critical to maintenance of the threatened structure or function, such as hydrology, must be identified to help scale the project. The conceptual model is critical to this task and to documenting any impairments to the controlling factors.

Landscape

The net contribution of a restoration project to conservation goals is directly related to its landscape context; therefore, the landscape is considered early in the planning phase when deciding whether a project is worthy of pursuit. Watershed-based or estuary-wide planning helps to prioritize projects (e.g. Johnson *et al*. 2003) and has been recommended and widely discussed (Foote-Smith 2002; Gersib 2002; Lewis 2000; Lewis *et al*. 1998; RAE-ERF 1999). The restoration project manager must also research the potential effects on system performance of countless factors such as adjacent land use, roads, off-road vehicles, boats, water diversion, air pollution, water-borne contamination, sewage discharge, dredging, human trampling (including diving), cyclic disturbances, wildlife, dogs, grazing animals, migratory birds and fish. These factors help to define the spatial extent of the landscape within which the project is evaluated, because they have the capacity to affect project performance. Whether a landscape element is included in the monitoring program depends on its potential effects relative to project goals.

Goals

The vision is formally stated as a goal or set of goals for the restoration project. These goals are most useful if they translate directly into measurable conditions. In this way, the goal leads to testable null hypotheses that are evaluated in the monitoring program. How to select measurable conditions or “parameters” is discussed under “Performance Criteria,” below. Above all, it is important to 1) make goals as simple and unambiguous as possible; 2) relate goals directly to the vision for the project; and 3) set goals that can be measured in the monitoring program (Thom and Wellman 1996). In the goal-setting process, the desired outcomes of the restoration project should be considered as alternatives to the future condition if no restorative action were taken, as well as being compared to existing conditions.

Planning Objectives

Once goals are stated and agreed to, specific planning objectives can be formulated that define more clearly what will be done to reach the goals. The identification and inclusion of stakeholders will strengthen the process by including local knowledge, reducing the chance that the project will be challenged later in its development and increasing its value to the public interest (Harrington and Feather 1996). For example, in 1992, the need for restoration of the Florida Everglades ecosystem was formalized into a goal statement that recommended modifying the federal project for "...improving the quality of the environment, improving protection of the aquifer, and improving the integrity, capability, and conservation of urban water supplies affected by the project or its operation" (Water Resources Development Act of 1992). Through a scientific working group and public involvement, these goals were refined into six planning objectives relative to concerns about the ecosystem, water quality, water supply, flood control, recreation, the economy, and social considerations (USACE 1994). Along with providing guidance for designing the project, these objectives form hypotheses against which performance of the restored system can be assessed:

1. increase the total spatial extent of wetlands;
2. increase habitat heterogeneity;
3. restore hydrologic structure and function;
4. restore water quality conditions;
5. improve the availability of water;
6. reduce flood damages on Seminole and Miccosukee tribal lands.

Site Selection

In cases where the site has not been predetermined for other reasons, the primary factors in site selection should be potential biological importance and likelihood of restoration success. Generally, consideration of these factors is closely followed by an assessment of the complexity of the task and the investment required to achieve restoration success at a variety of sites using a variety of means. In particular, the feasibility of returning the controlling factors identified in the conceptual model to a condition that is conducive to meeting the project goals is assessed. Such factors may include sediment deposition patterns, currents, hydrology, soil or sediment types, temperature, or any other parameter controlling the establishment of desired vegetation, fish or wildlife. Knowledge of specific systems guides the gathering of important information such as whether propagules are present in nearby mangroves, or whether debris is present on a coral reef. In New Hampshire, for example, a model in geographic information systems (GIS) synthesizes data to determine good locations to plant eelgrass (Short *et al*. 2002). Sites where success is improbable or requires extremely complex or expensive methods are better rejected in favor of sites where success is more likely to be worth the investment, unless the site is critical to a key species or to conservation of a habitat or ecosystem at a landscape level, or to other overriding conservation goals. Disturbance regimes, which will influence the development and sustainability of the restored site, must also be considered in the assessment of the likelihood of success. Three general steps in site selection and prioritization are described in Borde *et al* (2003): assessment and characterization of the study area, development of site selection criteria, and prioritization of potential sites.

Conceptual Model

The principal factors that control the development and maintenance of the habitat structure, the major habitat characteristics of importance, and the functions for which the habitat is restored are identified in the model. Conceptual models are used to develop performance criteria from goals and objectives. The Chesapeake Bay Program restoration plan for submerged aquatic vegetation provides an excellent, comprehensive example of how to relate performance criteria to goals through a conceptual model (Batiuk *et al*. 2000, 1992). Conceptual models (Figure 3) illustrate the direct and indirect connections (represented as arrows) among the physical, chemical, and biological components (represented as boxes) of the ecosystem. In this way, they highlight the specific requirements of target components. If a review of existing models and data finds important gaps, baseline studies may be required to develop data on which to build the conceptual model. If a baseline study is needed, it can be designed to provide information that later contributes to judging the success of the project. Conceptual models help to forecast the effects of restoration actions relative to expected changes if no action is taken. If an adequate conceptual model cannot be developed, the project may need to be abandoned because the lack of understanding makes it unlikely to succeed.

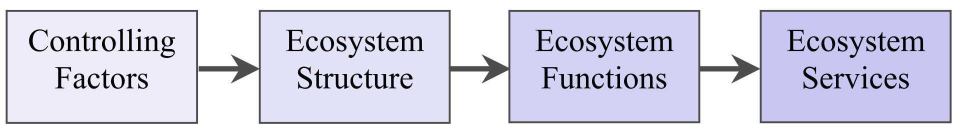

Figure 3. Structure of a conceptual model for ecosystem restoration.

Numerical Models

Because hydrology is of critical importance to water resource projects and the science is well developed, hydrological modeling is frequently conducted during restoration project planning. The restoration of the Florida Everglades is one example (Fitz *et al*. 1996). Numerical models can help in the planning process by facilitating sensitivity analysis of aspects of the system such as basin morphology, and prediction of conditions such as hydroperiod. They can also be used to help select performance criteria. Numerical ecological models are much less frequently employed because the relationships among ecological parameters and the physical-chemical environment often are not well understood and models for this purpose generally are not available. In some systems, however, ecological models have provided tools to describe predicted trajectories of ecosystem development under variable conditions. Twilley *et al*. (1998), for example, in a mangrove restoration case study, show that using such models can support the development of realistic goals and time frames and the selection of critical monitoring variables. Improving the understanding of the relative effects of processes operating at different scales through modeling complements field studies, and helps to improve project design, implementation and adaptive management (Twilley at al. 1998).

Preliminary Designs

The conceptual model and numerical models are used in the development of a preliminary series of alternative designs, each of which would implement a different set of management actions with different associated costs to meet the objectives. One alternative is “no action.” It is critical that landscape-level variables such as size, shape, connectivity and configuration be considered in the development of these designs (Shreffler and Thom 1993; Thom *et al.* in press). Designs should be developed systematically, to ensure that all reasonable approaches have been considered (USACE 2000). The effect of each design is forecasted and compared to other designs and the no-action alternative. In the Corps process, the designs are appraised against four criteria: completeness, effectiveness, efficiency, and acceptability (USACE 2000; USACE 1999). Relative costs, ability to meet the objectives, and acceptability to the stakeholders are considered. In most cases, more detailed feasibility designs are required for peer review and cost estimation. Designs may be weighted for comparison, but value judgments are made as well (Harrington and Feather 1996; Thom *et al.* in press). By developing the designs iteratively, those that don’t meet relevant ecological, engineering and economic criteria can be dismissed early in the process, while those with more merit receive detailed analysis, forecasting and comparison (Thom *et al.* in press).

Monitoring Program

It is best to develop the monitoring program during the planning phase, so that early discussion of project goals considers the types of information required to evaluate whether the goals are met. Evaluating the progress of a restored system through monitoring is critical to adaptive management, yet it is rare that adequate monitoring is carried out to support the decision framework. Goals such as “we will restore the genetic composition of the system to predisturbance conditions,” although theoretically achievable, would be very difficult to evaluate because of the data-intensive requirements of genetic research relative to the level of the ecosystem and because of the lack of predisturbance genetic data. Similarly, a goal to “restore historical biodiversity to the site” can be interpreted in various ways, and measuring “biodiversity” can become problematic. Larger restored ecosystems tend to have greater habitat heterogeneity as well as to abut a greater number of habitats, which can increase the uncertainties and complexity of the monitoring program. When the monitoring program is developed early, it can be considered as one criterion during development of preliminary plans, ensuring that alternatives without straightforward and feasible monitoring procedures do not go forward in the process.

Performance Criteria

Performance criteria are measurable or otherwise observable aspects of the restored system that indicate the progress of the system toward meeting the goals (Thom and Wellman 1996). They are more specific than the planning objectives. Most performance criteria are controlling factors or ecological response parameters. Acceptable bounds or limit values for the criteria are specified, and may be quantitative or qualitative. The relevance of evaluation criteria depends highly on the system type, region, and question under consideration. Development of criteria is often accomplished by a small group of individuals with system expertise. Larger groups may provide useful information and input but may also devise monitoring programs that are too complex or elaborate. Criteria are usually developed through an iterative process to determine the most efficient and relevant set of performance measures relative to goals. The primary purposes of the monitoring program must be kept in mind: to assess progress and to determine the steps necessary to fix any systems that are not meeting expectations. Approaches to developing performance criteria are further discussed in the "Performance Assessment" section of this paper.

Reference Site Selection
Although comparisons of the system pre- and post-implementation are useful in documenting the effect of the project, the level of performance can best be judged relative to reference systems. Monitoring sites established in reference systems serve three primary functions: 1) they can be used as models for developing restoration actions for another site; 2) they provide a target from which performance goals can be derived and against which progress toward these goals can be compared; and 3) they provide a control system by which "natural" fluctuations, unrelated to the restoration action, can be assessed. Alternatively, degraded reference sites can be used to show progress of the restored system away from the degraded condition (NRC 1992). Criteria for the identification of reference sites are examined in the "Performance Assessment" section of this paper.

Cost Analysis
Researchers for the U.S. Army Corps of Engineers (Corps) Institute for Water Resources have made advances in the evaluation of alternative restoration project plans using cost effectiveness and incremental cost analysis without monetizing the benefits of ecosystem restoration (Brandreth and Skaggs 2002; Thom *et al.* in press). Even with this level of rigor, actual project costs often differ substantially from estimated costs because of uncertainties about the site condition and implementation (Noble *et al.* 2000). Other restoration projects often lack rigorous cost analysis and associated documentation (Shreffler *et al.* 1995). The costs of coastal restoration projects vary widely both within and between ecosystem types, and depend on many factors including the location and condition of the site and the goals and methods of the restoration (Spurgeon 1998). According to Gunion (1989), factors affecting final wetland restoration costs are 1) economies of scale, 2) type of restoration; 3) restoration design; 4) restoration site quality; 5) adjacent site quality; 6) appropriate technology; 7) simultaneous construction/multiple use; and 8) project management. Costs are summarized and reported by different methods (US DOI 1991; Guinon 1989; NOAA 1992; Shreffler *et al.* 1995), making the comparison of projects a challenge. Some formats in which costs have been analyzed include the cost per acre; costs for specific restoration tasks; costs for construction stage; cost for restoration phase (*e.g.,* design, construction, monitoring); costs for input (*e.g.,* labor, equipment, materials); and costs by funding source. The costs of every restoration project are significantly influenced by unique factors such as site access, preparation requirements, controlling factors, and weather.

Budgeting
The economic issues of importance to the systematic approach to coastal restoration are pragmatic: cost analysis, financing, and budgeting. All five components of a restoration project are critical to success, but construction or planting activities often receive the most attention, while a complete planning process, post-restoration monitoring and the

dissemination of results are frequently underfunded (NRC 2001). Contingency funds should be available in case the evaluation of monitoring data determines that additional steps are required for the ecosystem to develop as planned. Funding for annual reports during the adaptive management phase supports decision-makers and provides the basis for publishing results. The budget integrates the project schedule, including seasonal requirements, with the availability of funds on unrelated cycles such as the fiscal year.

Financing

In many cases, coastal restoration projects are creatively financed through partnerships that secure funds from multiple sources. Sources may include state, federal, local, tribal, private, and nonprofit. The matching funds required by some grants may be provided in part using a per-hour equivalency for community volunteer time on the project. NOAA supports the restoration of coastal habitats important to any fisheries resources, and the Natural Resources Conservation Service (NRCS) and Corps emphasize coastal wetlands and estuaries. Increasingly, funds for some wetlands restoration projects, such as the Florida Wetlands Bank, are provided by corporations through mitigation banking systems designed to provide "credits" to developers whose plans involve the degradation of wetlands (Marsh *et al.* 1996). Available funding depends in part on the organization behind the restoration project, for instance, whether it is a multi-agency partnership or a single nonprofit organization. Funding is often difficult to secure for long-term monitoring, particularly in light of institutional barriers such as annual or biennial funding cycles, but funding for monitoring and adaptive management is critical to the success of the project. If funding can be secured, long-term monitoring also contributes to the state of restoration science. As a practical consideration, an initial round of monitoring and project modification as necessary may be included in the construction budget.

Scheduling

The four major considerations in scheduling a project are biological, engineering, funding, and legal. Ideally, scheduling would be based on a combination of biological considerations, such as germination, and engineering feasibility factors, like flood regime. In the case of a dike breach for estuarine restoration, for example, optimal timing can minimize downstream sedimentation. Furthermore, permits will likely prohibit in-water construction activities in certain seasons to avoid adverse impacts to fish. However, the schedule of many restoration projects is to a large degree dictated by the availability of funding and the procurement of required permits. The Corps administers the regulatory program for activities in coastal waters such as restoration under legislative authorities including the Rivers and Harbors Acts of 1899 (33 USC 401), Federal Water Pollution Control Act ("Clean Water Act," CWA) (33U.S.C. 1251), and Marine Protection, Research, and Sanctuaries Act of 1972 (MPRSA) (16 USC 1431 and 33 USC 1401) (USACE 2003). In general, applicants consult with the Corps prior to preparing the permit application. When the application is submitted, the Corps initiates key coordinating functions including public notice, notification of NOAA Fisheries and the U.S. Fish and Wildlife Service (USFWS) for consultation under the Endangered Species Act (ESA) (16 U.S.C. 1531-1544), and notification of the state agency that is responsible for regulation under the CWA. A biological evaluation (BE) is likely to be required, and an environmental impact statement (EIS) may be required under the National Environmental Policy Act (NEPA) (42 U.S.C. 4321-4370c). Applicants are required to certify that the project complies with an approved State Coastal Zone Management Program and receives state concurrence under the Coastal Zone Management Act of 1972 (CZMA) (16 USC 1451 et seq.). Some states also require a hydraulic project approval permit, and local jurisdictions may have other permit requirements.

Documentation

Shreffler *et al.* (1995) found that the best-documented restoration projects provided sufficient information for both project-specific and broader purposes. Three simple concepts were common among the best-documented projects: 1) a single file was developed that was the repository of all project information; 2) project events were recorded chronologically in a systematic manner; and 3) well-written documents such as engineering plans, legal documents and monitoring reports were produced and distributed widely enough to become part of the regional or national awareness of the project. Shreffler *et al.* (1995) found it difficult to access information on over 200 non-Corps restoration projects in a national review; reasonable documentation was available on only 39 of the projects. Kentula *et al.* (1992b), in a review of project mitigation permits issued under Section 404 of the Clean Water Act, found that the quality of documentation was inadequate to allow reliable descriptions of trends in the status of the wetland or to evaluate the success of mitigation or management strategies. Project completion dates were inadequately reported, and, therefore, it was unclear whether mitigation had been completed. In a review of mangrove restoration, Field (1998) found that documentation on the many projects conducted worldwide was scarce. A simple, systematic documentation and reporting protocol containing minimum requirements for the project would remedy the problems encountered in these reviews.

Peer Review

In large restoration projects, a team of experts should be hired to review the plan. Required expertise includes engineering, ecological, funding, management, and in some cases, modeling or the biology of a target species. When agencies or large organizations are involved in the project, such expertise may be found on staff. Ideally, the project team that develops plans and selects the best alternative is itself interdisciplinary. A review by the best available outside experts is a good way to strengthen the plan and ensure success.

Construction Plans and Final Costing

Projects of any complexity generally require a formal set of construction plans and specifications for implementation by the contractor (Hammer 1996; Shreffler *et al.* 1995). This is especially true for projects involving manipulations of land or water, or placement or manipulation of underwater structures. Conceptual plans precede detailed plans. Often the design will be refined through several iterations, for example, the 35%, 80% and 95% design, prior to the final design. The engineering drawings of the site are a useful tool to visualize the physical structure of the project and locate features such as species plantings and monitoring stations. Specifications include details such as elevation, slope, erosion protection, substrata composition, and schedule. Design engineers must understand unusual critical features, such as tolerances for elevation and hydrology, which, if not met, would jeopardize the development of the system with an inappropriate duration of flooding for the selected plant community. If planned features are infeasible, they are dropped or modified. Following construction, the drawings can be compared with post-construction “as built” drawings to evaluate how closely the construction followed the design. In the course of most construction projects, adjustments must be made to deal with unknown features, such as previously-unknown cables or sources of contamination, which also may require modifications to the plans. These changes can be recorded in the field and documented on the as-built surveys. Finally, the construction plans provide the basis for determining the costs and schedule of project implementation.

Implementation: Making the Vision a Real Project

The primary aspects of project implementation are preparation for construction, construction, and construction monitoring. The term “construction” is used broadly to include plantings and other restoration techniques.

Preparation for Construction
The planner should seek advice from knowledgeable individuals in regulatory agencies regarding the permits described in the planning section, above. Although the intent of restoration projects is to have a net benefit on the ecosystem, regulators may request specific changes in the project design to minimize environmental impacts that may occur during or after construction. In preparing for construction, the construction budget and schedule are finalized, funding is secured, and contractors are hired as needed. Plans and specifications, which provide legally binding language describing the recommended plan, are provided to the site construction contractor. All details defining the site, including the elevations, slopes, substrata requirements, seeding and planting requirements, and hydrology, must be communicated to the contractor. It is particularly important to convey features of the restoration plans and specifications that may be unusual in a contractor’s experience, such as the limited hydrological tolerances associated with wetlands.

Construction
There are many forms of construction “actions”. Shreffler *et al.* (1995) list common actions including ground enhancement, rip rap installation, culvert installation, culvert cleanout and removal, channel cleaning, erosion control, vegetation planting, dike removal, dike/dam/levee building, and cattle fencing. In a national review of innovative coastal restoration methods, Borde *et al*. (2003) describe restoration methods in habitats including coral reefs, mangroves, salt marshes, and intertidal zones (seagrasses), including the placement of reef balls and other underwater structures.

Several excellent references on constructing projects are available (*e.g.,* Galatowitsch and van deer Valk 1994; Hammer 1996; Marble 1992). Although most of these references deal primarily with wetland restoration and construction, they provide a set of detailed steps that are applicable to other systems. Because restoration projects run the gamut from a simple marsh planting to complex projects involving multiple habitat types and intricate engineering requirements, a restoration planner needs to identify the expertise required to get the project built. In all but the simplest projects, an engineer needs to be involved from the planning phase onward, particularly when physical alterations such as dike removal, grading, altering hydrology, or sealing of the site are required.

The implementation may or may not involve the introduction of plants and/or animals into the system. In a majority of wetland restoration projects, for example, plantings are done to enhance the rate of development of the desired habitat. Extensive information on selection of species and planting methods is available. For instance, Sullivan (2001) provides a primer on the establishment of vegetation in coastal wetlands, and Fonseca *et al*. (1998) provide guidelines for seagrasses. Though the use of transplantation methods versus natural recovery is debated for mangroves and coral reefs (Edwards and Clark 1998, Lewis and Streever 2000), methods and species are discussed in these resources and others (e.g. Epstein *et al*. 2001; Field 1998; Gilliam *et al*. 2003; Glynn *et al*., 2003; Lugo 1998; Quinn *et al*. 2003; Rinkevich 1995).

A common cause of plant loss in wetland projects is grazing by waterfowl (Calloway and Sullivan 2001). Likewise, sea urchins are known to graze on young kelp plants (North *et al.* 1986). Fencing and other techniques have been used effectively to exclude grazers during the period of initial development of plants.

Monitoring Construction
The primary goals of monitoring during construction are to ensure that the restoration plans are correctly implemented, and that the natural habitats and other properties surrounding the site are not unduly damaged. The implementation phase often begins with assessments such as on-site contamination, which may be permit requirements. Monitoring of the construction process by the project manager is very important. In wetland systems, for example, where a few centimeters may mean the difference in success or failure of the project, site inspections are essential for ensuring that the site is constructed to specifications (Raynie and Visser 2002).

Problems frequently arise during implementation of large and complex projects. During construction of the Gog-Le-Hi-Te wetland in Washington State, for example, several problems arose that needed immediate attention (Simenstad and Thom 1996). First, a pipeline used for oil transport was uncovered during excavation and required rerouting before construction could continue. In addition, just before final breaching of the river dike that would open the new system to tidal inundation, an oily material containing polychlorinated biphenyls (PCBs) was discovered near the breach site and cleanup operations halted construction for two weeks. Years after construction, it was also discovered that the system was excavated to incorrect depths; although the system functioned acceptably, correct depths may have improved wetland functions (Simenstad and Thom 1996).

As with any construction project, monitoring should ensure that the project is built according to plans, but in a restoration project, special attention should also be given to aspects of the construction that may affect performance of the system. Any variations or unusual occurrences or findings should be documented as part of the overall monitoring program. This information may become useful in interpreting the data.

Immediately following construction, surveys of elevation and other relevant data should be collected to verify that the construction met the specifications for the project. These as-built surveys provide the best indicator of the starting conditions for fundamental aspects of the systems such as elevation and soil type. As-built surveys may reveal that the conceptual design produced by the restoration planners was imperfectly built.

Performance Assessment: Development of the Monitoring Program

A monitoring program does not need to be complex and expensive to be effective (Kentula *et al.* 1992a). How much monitoring is required? The answer to this question is dependent on the goals and performance criteria for the project as well as on the type of ecological system being restored. A well-designed, systematic program that targets key parameters tied to goals, objectives and performance criteria should be sufficient to produce concise and informative results.

The NRC (1992) recommended that to assess the equivalency of the restored system to the antecedent one, wetland restoration monitoring programs should observe the following conditions, which we suggest are generally applicable to coastal restoration projects:

- assessment criteria should include structural and functional attributes
- criteria should be based on known antecedent conditions of the target or reference ecosystem
- criteria should be established before the assessment takes place, with an indication of the expected degree of similarity between restored and reference sites
- criteria should be linked to the objectives of the project
- measurements should account for temporal variation and spatial heterogeneity
- multiple criteria should be used for evaluation
- a range of reference sites and long-term data sets should be available
- criteria may need to be regionally specific
- the time frame for reaching the criteria should be established *a priori* and the site should be monitored for this period
- assessment criteria and methods should stand up to peer review.

These recommendations are elaborated in the following sections: Approaches to Establishing Performance Criteria; Identifying Reference Sites; Selection of Monitoring Parameters; Sampling Methods; and Timing, Frequency and Duration.

Approaches to Establishing Performance Criteria

Performance criteria describe the expected structure and function of the system. Monitoring parameters are measured to assess the system's structure and function relative to the performance criteria. Erwin (1990) stated that criteria for performance must be established prior to the evaluation effort and must be "fundamental to the existence, functions, and contributions of the wetland system and its surrounding landscape." Reference to the conceptual model identifies the linkages among critical physical, chemical, biological, and sociological aspects of the system.

Criteria development must be based on a thorough knowledge of the system under consideration. For example, good summaries of the physical and chemical requirements of many fisheries and wildlife species are available in the "species profiles" series (USGS 2002). Similarly, the "community and estuarine profile" series covers fundamental physical, chemical, and biological knowledge about larger systems.

A target time frame for meeting functional performance criteria should be a prescribed criterion. However, basic predictive capabilities, such as how long it takes for a restored or created system to reach full functional performance, remain limited. True functional equivalency with a reference system may take decades or longer (Zedler and Callaway 1999). Therefore, to make the time-frame criterion more meaningful, performance criteria should be stated in terms of trends as well as target ranges.

Trends can indicate that the system is on its way to being restored and meeting the goals of the project, and the rate at which this is occurring. Identification of trends is a powerful tool in assessing the need for midcourse corrections. The trends analysis can be plotted as performance curves (Kentula *et al.* 1992a). Kentula *et al.* (1992a) shows that performance curves can take many different shapes (*e.g.,* asymptotic, s-shaped), and that the shapes will vary depending upon the parameter. Shapes of these curves are often referred to as trajectories of development (Simenstad and Thom 1996). Though the development of sites with characteristics such as high levels of environmental pulsing may not smoothly follow predicted trajectories (Zedler and Callaway 1999), many restoration sites have been shown to follow nonlinear trajectories, eventually reaching reference conditions (Morgan and Short 2002). The duration of performance once goals are met, should also be stated in the planning phase. Because systems change naturally over time, an in-perpetuity criterion may not be realistic (Zedler 2000).

Performance criteria are distinctive to a region and a system. A special issue of *Ecological* Engineering was recently devoted to "Goal Setting and Success Criteria for Coastal Habitat Restoration" (Wilber *et al*. 2000). Regionalized and system-specific parameters have been developed for restoration projects such as the southern California coastal wetlands (PERL 1990), estuarine habitats in the Pacific Northwest (Simenstad *et al.* 1991), Louisiana coastal marshes (Steyer and Stewart 1992), Florida salt marshes and mangroves (Redmond 2000), and seagrass systems (Fonseca *et al.* 1998). Three of these are reviewed below.

1) PERL (1990), drawing on over a decade of research on constructed wetlands in southern California's coastal zone, considered the following functions essential for effective restoration in southern California coastal wetlands:

- provision of habitat for wetland-dependent species
- support for food chains
- transformation of nutrients
- maintenance of plant populations
- resilience (ability to recover from disturbances)
- resistance to invasive species (plant or animal)
- resistance to herbivore outbreaks
- pollination
- maintenance of local genetic diversity
- access to refuges during high water
- accommodation of rising sea level.

Because this list was developed specifically for the region and system type, it could be used in the planning process to define the vision and goals for the project. The monitoring program could then develop performance criteria and measurable parameters with confidence that they are highly relevant and sensitive indicators of the progress of the system. A recent compilation includes updated methods to assess the functions of these coastal wetlands, in several categories: hydrology and topography, water quality, soils (substrate qualities and nutrient dynamics), vegetation, invertebrates, and fishes (Callaway *et al.* 2001).

2) Simenstad *et al.* (1991) developed the Estuarine Habitat Assessment Protocol (EHAP) to provide a standardized approach for assessing the performance of restored or constructed estuarine systems in the Pacific Northwest. The EHAP sampling protocols emphasize attributes of estuarine habitats that promote functions such as fish and wildlife utilization and fitness, and provide design criteria for habitat restoration. Attributes selected were based on a comprehensive survey of approximately 200 estuarine scientists in the region, and supported by published information. A total of 105 "protocol" species were identified, including fish, invertebrates, birds and mammals. The occurrence of the species in each major habitat type was shown, and the use of the habitat (*e.g.,* feeding, rearing, reproduction, resting) provided. The EHAP further identifies three levels of sampling complexity: minimum, recommended and preferred.

3) In a comprehensive review of the literature and of practical seagrass restoration methods, Fonseca *et al.* (1998) identified a large number of criteria that have been used to evaluate the success of seagrass planting projects. In an effort to identify parameters that are economical to monitor and provide reasonable assurance of functional equivalency, these researchers offered the following criterion for seagrass planting success: "the unassisted persistence of the required acreage of seagrass coverage for a prescribed period of time (suggested minimum of 5 years)." Such a criterion would require only that three parameters be monitored: number of surviving planting units (minimum one shoot),

the number of shoots per planting unit, and the area coverage of seagrass per planting unit (Fonseca *et al.* 1998).

4) A program begun in 1980 to restore tidal action to marshes off Long Island Sound in Connecticut, which did not establish specific restoration targets, recently was evaluated through the comparison of nine of the restored sites to reference sites (Brawley *et al.* 1998; Swamy *et al.* 2002; Warren *et al.* 2002). Although specific criteria had not been formulated at the inception of the project, parameters were selected to evaluate characteristics of fully functioning tidal salt marshes: vegetation, macroinvertebrates, use by fish and birds, soil salinity, elevation and tidal flooding, and soil water table depth. The studies found that the recovery of animal populations took up to two or more decades, with highly variable rates of recovery within and among marshes.

In addition to regional or system-specific performance criteria, various efforts to assess or index ecological systems may also provide valuable references for restoration efforts. Examples include the EPA Environmental Monitoring and Assessment Program (EMAP) (Hunsaker and Carpenter 1990) and the EPA biological criteria for water quality assessments (EPA 1991a, 1991b).

In a recent review of wetland mitigation, however, the NRC (2001) concluded that a gap remains between the large array of functional assessment procedures, including the hydrogeomorphic (HGM) approach adopted by the Corps (Brinson 1993; Shafer *et al*. 2001), and the kind of specific guidance required to functionally assess mitigation wetlands. In its report, the NRC called for the *replacement of best professional judgment with science-based procedures* that

- effectively assess goals of wetland mitigation projects
- assess all recognized functions
- incorporate effects of position in landscape
- reliably indicate important wetland processes, or at least scientifically established structural surrogates of those processes
- scale assessment results to results from reference sites
- are sensitive to changes in performance over a dynamic range
- are integrative over space and time
- generate parametric and dimensioned units, rather than non-parametric rank.

These principles for the assessment of ecosystem function are generally applicable to coastal restoration projects.

Identifying Reference Sites

Appropriate reference sites are often as critical to a restoration monitoring program as they are difficult to find. This is particularly true in urban settings, where restoration actions are most frequent. Brinson (1993) defines a "reference wetland" as follows:

> A wetland or one of a group of wetlands within a relatively homogeneous biogeographical region that represents typical,

representative, or common examples of a particular hydrogeomorphic wetland type, or examples of altered states.

Brinson's system groups wetlands according to their hydrology, soils, and geomorphology, which are the main factors controlling wetland functions. Further, his definition includes the need to choose reference wetlands within the region where the restoration will take place. Although this system was developed in the context of the Corps' permit review process to assess the effect of a project on wetland functions, it is useful in the context of coastal restoration and this definition is generally applicable to other aquatic systems.

The value of reference sites is illustrated by the example of a Grays Harbor, Washington, eelgrass transplant project (Thom 1993). The inclusion of several reference sites in the monitoring program provided information about the natural range of values for the parameters used in the monitoring program, and showed the annual variation in these parameters. The reference plots also documented the physically driven morphology of the natural eelgrass patches, information which could be used to bound the design of later transplant patches.

An example of the types of information that should be considered when evaluating the suitability of a wetland reference site is provided by Horner and Radaeke (1989). The authors identified the following features that should be assessed for degree of similarity between the reference site and the potential conditions at the mitigation site:

- functional similarity
- climatological and hydrological similarity
- similarity in influences of human access, habitation, and economic activities, and in the quantity and quality of water runoff from these activities to the wetland
- similarity in the history of and potential for such activities as grazing, mowing, and burning
- similarity in size, morphology, water depth, wetland zones and their proportions, and general vegetation types
- similarity in soils and nonsoil substrates
- similarity in access by fish and wildlife.

These criteria are broadly applicable for reference site selection for most wetland types as well as for aquatic habitats in general. Good information on potential target parameters within the reference systems generally exists. In some cases, studies are needed to develop a database on functions of reference systems relative to the goals for the restoration site. These studies provide boundaries for design and performance for the restoration action.

Boesch *et al.* (1994) points out that it is often difficult or impossible to find appropriate reference sites, especially for large-scale restoration projects in landscapes as complex as coastal Louisiana. This lack of replication in both reference sites and restored systems prevents the use of inferential statistics. They recommend that nonparametric and regression approaches be considered in lieu of analysis of variance (ANOVA) designs for evaluating restoration performance against reference sites; parametric units can be used in nonparametric approaches. This means that reference sites do not need to meet unrealistic assumptions necessary for the use of classical analyses.

Boesch *et al.* (1994) also recommended that a two-tiered approach be taken, in which a limited number of restoration sites be monitored intensively as a representative "class" of restoration sites. A "class" might mean those sites where the same restoration strategy has been applied in the same habitat type, or a "class" of reference sites with similar features. Other sites could be monitored less intensively. The two-tiered approach effectively reduces the size and cost of the monitoring program in situations where a large number of projects are planned and implemented within a defined geographic region.

This concept is incorporated in the coast-wide reference monitoring system being implemented to evaluate wetland restoration trajectories in Louisiana (Steyer *et al.* 2003). The system addresses the problem of identifying paired reference and project areas by providing an array of reference sites, which will be used to evaluate project effectiveness as well as the cumulative effects of multiple restoration projects (Steyer *et al.* 2003). Some 200 reference sites will be monitored annually and another 500 will be monitored every three years, to provide efficiency and data for long-term trend analysis. According to Steyer *et al.* (2003), the design will involve assigning the coastal wetlands to classes, selecting reference sites that span the range of ecological response characteristics of each class, and identifying "reference standards," or those sites that "most closely approach the sustainable functional potential of each class." On this basis, the trajectories of project sites can be compared with all reference sites, with functionally equivalent reference sites, and with reference standards.

There is a general need to establish, protect, and study reference systems of the common types of ecosystems (Brinson 1993; NRC 1992). The National Estuarine Research Reserve (NERR) sites of NOAA, the Long Term Ecological Research (LTER) sites and Land Margin Ecosystem Research (LMER) sites of the National Science Foundation, marine protected areas, national parks, and wildlife refuges are places where suitable reference sites and ecosystems can be established, maintained, and investigated. Systematic databases on representative ecosystems form a basis of information for establishing goals for restoration site design and monitoring.

Selection of Monitoring Parameters

A scientifically-based and relatively easily measured set of monitoring parameters are selected to provide direct feedback on the performance of a system with respect to the goals. There is an overwhelming array of parameters for monitoring aquatic systems (*e.g.,* Erwin 1990). The NRC (1992) recommended that for aquatic systems at least three parameters be selected and that they include physical, hydrological, and ecological measures; too few parameters may provide insufficient information to evaluate performance or may provide information that is difficult to interpret. With an increase in the number of parameters, both the robustness of the monitoring assessment, and the confidence in conclusions about performance increase, but the costs increase as well. The monitoring of key controlling factors is recommended to better understand why a system is or is not meeting performance criteria.

Erwin (1990) suggested that a quantitative wetland evaluation plan should be implemented "when the construction technique is unproven, where the ability to successfully create or restore a habitat is unproven, or when success criteria are related to obtaining specific thresholds of plant cover, diversity, and wildlife utilization." The quantitative wetland evaluation should include hydrological monitoring and vegetation analysis. In situations where there is more certainty of success, and where performance is not tied to specific quantitative criteria, qualitative evaluations are appropriate. As an example of qualitative evaluations used for wetlands, Erwin (1990) recommended the following:

- plan view map of sampling points
- baseline vegetation survey
- fixed point panoramic photographs
- rainfall and water level data
- wildlife utilization observations
- fish and macroinvertebrate (species list; qualitative abundance estimates)
- annual reporting for 5 years.

The use of high-resolution multi-spectral imagery and other remote sensing is another method being tested and implemented for qualitative evaluation of wetlands, oyster reefs and other features of habitat restoration sites (Callaway *et al.* 2001; Finkbeiner 2003).

The most specific national guidance on the selection of restored wetland monitoring parameters comes from the NRC (1992, 2001) and EPA (Kentula *et al.* 1992a; Kusler and Kentula 1990b). The NRC developed a list of seven wetland functions that should be considered in assessing equivalency between natural and constructed wetland systems based upon experiences in coastal salt marshes. For each function, the NRC suggested measures that could be used for quantification. Kentula *et al.* (1992a) presented a list of 26 wetland system variables, justification for selection, suggested uses, and general procedures. The variables are divided into categories of general information, morphometry, hydrology, substrate, vegetation, fauna, water quality, and additional information. These variables are well justified in the scientific literature, and many have been investigated directly by the EPA Wetland Research Program (WRP).

As part of the effort under the CWPPRA, monitoring protocols were developed to provide guidance on minimum monitoring standards to assess performance of restored systems relative to goals, and to provide information for developing costs for restoration programs (Steyer and Stewart 1992). The CWPPRA was established to provide guidance and means to implement projects that stop further loss of Louisiana's coastal wetlands and that restore coastal wetlands in the region. Subgroups of technical experts developed protocols in seven categories: water quality, hydrology, soils and sediment, vegetative health, habitat mapping, wildlife, and fisheries. Monitoring plans were developed for nine project types: freshwater introductions and diversions, sediment diversions, marsh management, hydrologic restoration, beneficial use of dredged material, shoreline protection, barrier island restoration, vegetative planting, and sediment and nutrient trapping. Variables were developed for each monitoring category and prioritized for each project type. Priorities range from a primary objective (Priority 1) through lower-priority, long-term evaluation (Priority 4), with an additional priority of as-needed, unique to a specific project (Priority N). Methods are provided in varying degrees of detail for the variables, and costs are provided for instrumentation, analysis and related items.

Batiuk *et al*. (2000) have analyzed monitoring data to refine the habitat requirements for submerged aquatic vegetation (SAV) on the Chesapeake Bay. This effort provided an improved approach for testing shallow water sites for suitability for SAV restoration. It incorporates an indicator that had previously not been addressed, the availability of light at the leaf surface, by developing an algorithm integrating the previous water quality habitat requirements: dissolved inorganic nitrogen, dissolved inorganic phosphorus, water-column light attenuation coefficient, chlorophyll *a* and total suspended solids.

Monitoring Methods

Monitoring methods include sampling design, sampling methods, and sample handling and processing. Monitoring methods used on restoration projects in the United States have been extremely varied (Shreffler *et al.* 1995). Calloway *et al*. (2001) represent one of a number of texts that provide excellent guidance on monitoring methods. Three basic questions to ask when selecting methods for monitoring are: 1) does the method efficiently provide accurate data on the parameters; 2) is the method repeatable; and 3) is the method feasible within time and cost constraints? Any method used for sampling a parameter should have a documented protocol. This documentation often consists of peer-reviewed technical articles in which the method is well described. In general, this means that the method has been reliably implemented under diverse conditions. New and poorly documented methods can open questions of accuracy and repeatability.

It is highly desirable to choose sampling methods that provide for collection of data on more than one parameter. For example, a sediment core sample can provide information on rhizome development, hydrology, and invertebrate communities. Some of the information (*e.g.,* odor, composition) can be taken directly in the field, whereas information such as particle size would be assessed through use of appropriate laboratory methods. Collecting concordant data is efficient and allows for robust analysis.

The project manager should be aware of available information that is not part of the monitoring program. Consultation with agency personnel, local universities, consultants, citizen environmental groups, and landowners in the area can reveal information of this type. Data on parameters that do not relate directly to the assessment of performance may help interpret other results. Ongoing monitoring programs provide useful data, such as state hunting and fishing reports, U.S. Geological Survey hydrological data and topographic maps, Audubon Society bird counts, NRCS soils maps, U.S. Weather

Service data, and air quality data. Many agencies and volunteer groups want to see their data used and are willing to cooperate with restoration programs, but a systematic and equitable method of data transfer should be planned.

A fundamental decision on whether the monitoring must show highly quantifiable results or whether the program only needs to illustrate general changes will influence the choice of monitoring methods. Quantitative and qualitative methods can be employed effectively in the same monitoring program. Quantitative methods develop numerical data sets from measurements taken at the site or from collected samples. In most cases in which performance goals and criteria are quantitative, quantitative methods must be employed. For example, if performance criteria state that the stream system will have a midsummer mean temperature between 15°C and 17°C, then temperature must be measured to develop an accurate and repeatable estimate.

Methods have been developed to rank the performance of habitats for certain functions. Three examples are the Habitat Evaluation Procedure (HEP) (USFWS 1980), the Wetland Evaluation Technique (WET) (Adamus 1983), and the Hydrogeomorphic (HGM) Approach (Brinson 1993; Shafer and Yozzo 1998). These methods are similar; they use scores of various features of the system to arrive at a numeric value for each function assigned to the system. HEP focuses on fish and wildlife and not on vegetation, soils, and hydrology. In contrast, WET is highly directed toward assessing the latter qualities. The HGM system, which is regionally specific, is based on geomorphic setting, water source, and hydrodynamics.

Timing, Frequency, and Duration
The monitoring program should be carried out according to a systematic schedule. The plan should include a start date, the time of the year during which field studies should take place, the frequency of field studies, and the end date for the program. Timing, frequency, and duration are dependent on the system type and complexity, and uncertainty. In addition, controversy over the project can force a higher degree of scrutiny and may increase the level of monitoring effort.

Timing. The monitoring program should be designed prior to conducting any baseline studies, so that the pre- and post-construction sampling and analysis methods are the same. Baseline studies are used to complete the initial database and are important in understanding existing conditions, planning restoration, and analyzing the effects of restoration activities. Post-construction performance monitoring should commence as soon as the major restorative actions have taken place and the system is left to develop more or less on its own. One primary objective of the initial post-construction sampling is to document "as-built" conditions of the system as the starting point from which development can be documented. Post-construction data are also compared with baseline data to assess the effect of the construction.

Seasonality is often a concern, and data from the ecoregion can help. For example, migratory bird populations should be studied during the month(s) when they are typically found in greatest abundance in the region; water temperatures in midsummer; juvenile salmonid use of estuarine systems, during the spring outmigration; and wetland hydrology, during the spring growing season. Seasons of sampling can change, however, depending on the question being addressed. For example, if the goal were flood protection, then hydrology would be monitored year round. If implementation is completed during a season that is inappropriate for the sampling parameters, it is best to wait. However, data that are independent of season, such as the number and distribution of vegetation units planted, can be gathered immediately after implementation. These data are important because large physical changes often occur shortly after implementation while the system adjusts to physical conditions. Information acquired during off-seasons, when physical factors such as floods and freezes can have effects of high magnitude, may also help in the interpretation of changes identified during regular monitoring.

Well-timed sampling minimizes the number of sampling efforts and thereby reduces the cost of the program. Because weather varies from year to year, it is wise to "bracket" the season. For example, sampling temperature four times during the midsummer would be better than a single sampling in the middle of the season. Concentrated bracketing is typical in hydrological monitoring. The monitoring protocols for tidal wetland restoration in the Gulf of Maine, for example, call for monitoring up to three spring and three neap tides to track the pattern of water level change (Neckles and Dionne 2000).

According to Horner and Radaeke (1989), monitoring of wetland mitigation sites and associated reference sites can be performed in two ways: 1) by concentrating all tasks during a single site visit, or 2) by carrying out one task or a similar set of tasks at several sites in a single day. The latter strategy is preferable because it minimizes seasonal effects and variability in conditions from day to day, and repeating the same task on the same day may be more efficient. Sampling of specific parameters in reference areas should take place during the same time of year as sampling in restored areas. For example, to accurately compare herbaceous vegetation communities in restored and reference sites, sampling needs to occur during the same season as herbaceous vegetation changes throughout the year. This is true also for invertebrate sampling, migratory fish and birds, temperature, algae, and zooplankton.

Frequency. Frequency of sampling can vary within a year as well as among years. In general, "new" systems change rapidly and should be monitored more often than older systems. This is especially true for systems in which success is highly uncertain. Deviations from the predicted trajectory of development, if detected early, may be corrected more easily than those allowed to progress further. For example, if erosion is greater than expected, shoreline modifications can be made before the entire restored area is lost. As the system becomes established, it is generally less vulnerable to disturbances. Hence, monitoring can be less frequent.

Frequent monitoring in the early stages also is necessary to understand major processes that can affect the system. Annual monitoring may provide a good indication of development, but it cannot document damages caused by winter storms. A simple visit to a new site after a major storm event may be useful in documenting the exact cause of loss or malfunctioning in the system seen the next summer. The project manager needs to understand the vulnerabilities of the restored system to natural or anthropogenic events and to document the effects, if possible. Often the most efficient documentation in these cases is photographs, videotapes, and field notes.

Duration. The duration of the monitoring program is a controversial issue. The monitoring program should extend long enough to provide reasonable assurance that the system has met its performance criteria, will meet them, or will not likely meet them. A restored system should be reasonably self-maintaining after a certain period of time, though fluctuations on an annual basis in some parameters of the system will occur even in mature systems. It is important for the program to extend beyond the period of most rapid change and into the period of stabilization of the system.

A growing body of evidence on constructed systems shows that most aquatic systems do not reach stability in less than 5 years (*e.g.,* Kentula 2000; Simenstad and Thom 1996). Ecosystems of the size of most restoration projects take decades or centuries to develop (Boumans *et al.* 2002; Crooks *et al.* 2002; Frenkel and Morlan 1990; Thom *et al.* 2002). Hence, we cannot expect restored systems to be stable in a year. The period of development is dependent on the initial conditions and the type of habitat being restored. If the system is what Cairns (1989) terms a "new ecosystem" (*i.e.,* a system is constructed that is new for the site), that starts with no vegetation and for which hydrology must be established, development will take a long time. In contrast, systems that are minor adjustments of existing aquatic habitats will require less time.

The Chehalis Slough mitigation project is an example of a long-term, post-restoration monitoring program in a new system with a high degree of uncertainty regarding functional performance. In 1990, the Corps, in conjunction with the local sponsor (Port of Grays Harbor), constructed a tidal slough adjacent to the Chehalis River in Grays Harbor, Washington. The slough was intended to serve as mitigation for loss of juvenile salmonid habitat caused by navigation channel improvements. Because the slough was essentially dug out of upland habitat, it represented an entirely new ecosystem for the site. The monitoring program, which focuses on vegetation, fish prey, and fish use of the system, was conducted annually in spring and summer during the first 2 years (Simenstad *et al.* 1993). Vegetation (sedges) was monitored annually for 4 years, and fish annually for 2 years, then in Years 4, 7 and 9. Sedimentation, site stability, and retention of large organic debris were scheduled to be monitored in Year 10. The Corps committed to post-construction monitoring over 50 years to ensure that the mitigation effectively fulfilled its objectives, but the frequency of monitoring was not specified beyond the initial 10-year period (Simenstad *et al*. 1997).

The frequency and duration of the Chehalis River slough monitoring typifies the present strategy for monitoring restoration projects. Ten years of monitoring is not unreasonable for most projects of a significant size. An attenuated frequency of sampling from an annual basis initially to every 2 to 4 years later is considered adequate and appropriate for documenting major changes in the system. If the system is not going to "work," this will often become apparent in 1 to 3 years. If the system is going to develop into a functioning system but may not meet expectations in the long-term, this will be apparent in later years. This strategy for attenuating sampling allows for adaptive management of the system while minimizing monitoring effort and cost.

Statistical Framework

The monitoring study design needs to include statistical considerations such as sample location and number of replicates. These decisions should be made based on an understanding of the accuracy and precision required for the data as identified in the protocol. Many scientists view restoration projects fundamentally as experiments that can be set up to test hypotheses. Performance goals and criteria could be considered informal statements of testable hypotheses. The NRC (1992) recommended that at least some part of the restoration action incorporate experiments that will evaluate aspects of restoration actions. The result of these experiments will then add to the technology of restoring ecosystems. In contrast, the goal of a restoration action is generally to improve the system function. Although accurate quantification of some functions of aquatic systems is possible, overall ecosystem “performance” is much more complex and difficult to evaluate.

A rigorous experimental design that evaluates one or more null hypotheses is appropriate on a limited basis for most restoration efforts, but less rigorous analyses are more appropriate for supplying evidence for the development of the ecosystem. Yoccuz (1991) argued that ecological studies often use statistical “overkill,” when simple bar graphs with error bars are sufficient to interpret trends. The analysis of the results should be driven by an understanding of the ecosystem rather than by statistics. Although rigorous statistical testing documents statistical significance at an *a priori* level of confidence, this type of study requires intensive sampling, and many of the assumptions of true replication and appropriate controls are not easily met (Boesch *et al.* 1994; Hurlbert 1984).

Simply relying on statistical tests can result in misinterpretation of project results. For example, if strong trends in the trajectory of development of the site are evident, but statistical tests indicate non-significance, the true ecological significance of the trends might be discounted. Statistical test results, if used, should be tempered by critical and objective assessment so as to not miss actual ecological change.

An example of a study in which useful results were attained without a rigorous experimental design is the examination by Short *et al.* (1995) of the effectiveness of reducing the number of eelgrass shoots during restoration planting. This study showed that using planting bundles of two eelgrass shoots rather than the standard 10 shoots per bundle resulted in similar survival, development rates, and patterns for the eelgrass patches. This significant reduction in planting stock not only saves expense, but reduces impact to donor stocks. Short *et al.*’s (1995) experiment was not set up with a rigorous statistical design yet was carried out on a scale large enough to provide convincing and valid results that improve restoration technology.

Adaptive Management

Background and Principles
Perhaps one of the most significant developments in aquatic system restoration has been the trend toward the use of adaptive management principles in managing projects (*e.g.,* Boesch *et al.* 1994). Ecosystem monitoring is at the heart of adaptive management (USACE 2000). Simply put, in adaptive management, the restored system is monitored, the data are assessed against existing knowledge and, if necessary, a remedy is prescribed. Monitoring helps determine the remedy, evaluate its effectiveness, and prescribe new ones if needed. In a special report by the Forest Ecosystem Management Assessment Team (FEMAT 1993), which recommended adaptive management as a critical element in the management and restoration of Pacific Northwest forest ecosystems, the adaptive management process was defined as involving planning, action, monitoring, evaluation, and adjustment. Goals are revised based on monitoring, new knowledge, inventories, research, and new technologies. The adaptive approach provides a method to reduce project failures through cause-and-effect input to the management process, and a means to make decisions despite the existence of uncertainty (Thom 2000; Thom 1997).

To ensure success, restored systems often require midcourse corrections and management. Cairns (1990) stated that "whatever restoration measures we take, the outcome is highly uncertain." The success of wetland restoration and creation, for instance, often depends on long-term management, protection, and manipulation of both wetlands and adjacent buffer areas (Shreffler and Thom 1993). The NRC (1992) recommended that individual restoration projects be designed and executed according to the principles of adaptive planning and management. The NRC report suggests that rather than relying on a fixed goal for restoration and an inflexible plan to achieve the goal, adaptive management recognizes the imperfect knowledge of interdependencies within and among natural and social systems. This uncertainty requires that plans be modified as technical knowledge improves and social preferences change.

The use of adaptive management in the restoration of damaged coastal ecosystems has been recommended in major programs such as the following:

- Louisiana wetland restoration: A review panel recommended the use of adaptive management in the evaluation of restoration projects in this region (Boesch *et al.* 1994), adaptive management was implemented programmatically (Steyer and Llewellyn 2000), and a large-scale adaptive management review of implemented projects has been completed (Raynie and Visser 2002)
- Chesapeake Bay restoration: An adaptive management approach has been followed in developing restoration actions, assessing performance, and adjusting the program (Hennessey 1994)
- Gulf of Maine restoration: A comprehensive monitoring program with adaptive management components was recommended to the Gulf of Maine Council on the Marine Environment (Cornelisen 1998)

- Florida Everglades restoration: An adaptive assessment program including system-wide monitoring is developed in the Comprehensive Everglades Restoration Plan (USACE & SFWMD 1999)
- Tijuana Estuary restoration: The term *adaptive restoration* is used to describe projects at the Tijuana Estuary that were designed to make the restoration itself an experiment that tests alternative actions (Zedler 2001b)
- U.S. Army Corps of Engineers restoration projects: The Corps recommends that adaptive management be considered for restoration projects with potential uncertainty in achieving restoration objectives (USACE 2000).

Walters (1986) has outlined three ways to structure adaptive management: 1) evolutionary or "trial and error," 2) passive adaptive, and 3) active adaptive. Under the evolutionary method, early choices are made in a haphazard manner and later choices are made from a subset of choices that may give more desirable results (Walters and Holling 1990). Passive adaptive management is employed when, using the best available information, a single response model is selected and decisions are made based upon this model. It is assumed, but not always rightly so, that the model is correct. Likely response models should be developed in the planning phase, and these should be evaluated through small experiments or through large-scale manipulations during the monitoring and adaptive management phase. Finally, active adaptive management means that manipulations to the restored system are made to evaluate which model is best, for both developing an understanding and enhancing the performance of the system. Most theoretical literature on resource management uses the passive adaptive approach. The active approach is most often applied in studies such as agricultural field tests, but evaluations in tidal systems have been carried out (Zedler 1996).

Although very rarely applied to date in coastal ecosystem restoration, the active adaptive method may provide the most meaningful information for making decisions that ensure the success of the project, and to contribute to the design of future projects. However, this method may also be the most costly and, initially, the most potentially harmful to the system, depending on the size and complexity of the experiments conducted. Designing the experiments may not be trivial when managers require statistically significant results, and may require a high degree of replication at the restoration site and reference site (Walters and Holling 1990).

Under adaptive management, the knowledge gained through project monitoring and social policies must be translated into restoration policy and program redesign. The WRP of the EPA uses adaptive management as its strategy for improving design guidelines for wetland restoration projects (Kentula *et al.* 1992a).

Specifics on development of adaptive management for Corps restoration projects are provided in Yozzo *et al.* (1996). This document recommends annual assessments of the progress of the system, at which time decisions can be made regarding any midcourse corrections or other alternative actions, including modification of goals. The annual assessments use monitoring data and may require additional data or expertise from outside the project. Because the ultimate goal is to make the project "work" and not to waste funds adhering to inflexible and unrealistic goals, managers will need to evaluate both corrective actions and goal adjustments to achieve success of the overall project.

Adaptive Management Example: Marsh Restoration
Marshes generally present a complex problem of physical and chemical adjustment and succession for a restoration scenario. Although performance criteria are often established for functions that are not closely linked to structural measures, structural parameters of a restored system are typically monitored. For example, the goal of the Gog-Le-Hi-Te tidal wetland system in the Puyallup River estuary in Washington State was to support juvenile salmon, shorebirds, waterfowl, small mammals, and raptors (Simenstad and Thom 1996). The performance objectives included specific allocations of area for each group: 50% of the area for juvenile salmon, 20% for waterfowl, and 10% each for shorebirds, raptors, and small mammals.

When the project was planned in the early 1980s, relatively little was known about the specific habitats required for each of the target groups nor of the associated critical functions of the restored system. Further complicating the planning process was the fact that no natural systems remained in the heavily industrialized and developed estuary to serve as a reference system for design and monitoring. Using the best available information, scientists provided guidance on habitat types that should be included in the system to support the target species. Accordingly, a 2.2-ha tidal wetland was designed and constructed, which included intertidal sedge, cattail, unvegetated mudflats, and tidal channels. To enhance the development of the sedge marsh, approximately 49,000 shoots of sedge were planted on the intertidal flats. In addition, 1.7 ha of upland grassland was constructed with a small freshwater marsh, as well as shrub and forested riparian habitats. The premise was that the diverse system provided a landscape that accommodated all of the target species groups.

Monitoring of the system between 1986 and 1993 showed that the sedge marsh rapidly developed to a maximum extent between 1986 and 1987, then declined to a very small area by 1993. Cattails grew to dominate much of the space originally occupied by the sedge. In addition, more bare mudflat was exposed as a result of the loss of the marsh, and channels rapidly filled with sediment transported by the Puyallup River. The channels narrowed considerably over the first 7 years, and a new system of braided channels developed through natural hydrological processes. Hence, the system looked very different from that envisaged by the planners. The upland areas, which were largely in existence when the system was constructed, remained unchanged.

Despite the unexpected structural results, monitoring of fish and birds showed that the restored system was used from its early stages of development. Juvenile salmon were present in the system during the first year. Subsequent experimental studies proved that the fish were eating prey resources and were growing while resident in the system (Shreffler *et al.* 1990, 1992). Birds were observed in densities far greater than those in other areas in the estuary, and some species were feeding, resting, reproducing, and rearing in the system. Clearly, the system was meeting the goals.

Using a system development matrix for this project to characterize outcomes (Thom 1997) could have more clearly organized the performance criteria for target resources (Figure 4). This matrix can form the framework for adaptive management of a restoration project. The matrix acknowledges that structure and function are correlated, and that, by dividing each axis into three sections, one can quantify this relationship only within a wide range of variation. Establishing high, moderate and low categories acknowledges the uncertainties about the system and system development predictions. Within each of the nine boxes, or system states, is placed an explanation of why the system may be in that state.

The structure of the habitat (*e.g.,* sedge marsh) would be placed along the x-axis and the function of the habitat for target species on the y-axis. For example, in an early stage of the project, the sedge would have a low density, and the corresponding densities of prey resource species for salmon would be within the known, typical range on the left side of the matrix. The ranges of sedge densities and prey densities in fully developed sedge marshes would be represented in the upper right box. The intermediate stage could be identified through field studies or experimental investigations. If an intermediate stage were not definable, then the matrix would reduce to 2 x 2.

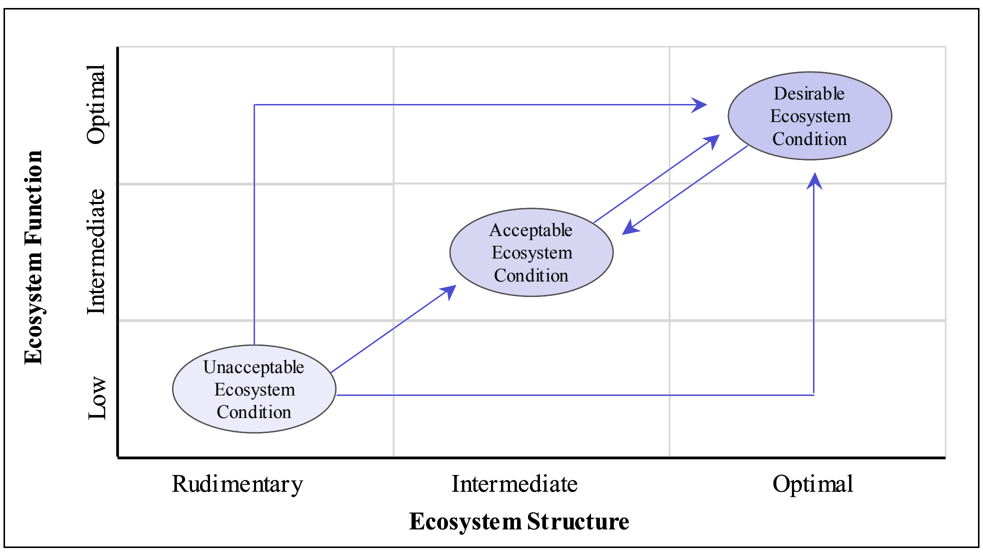

Figure 4. System development matrix (redrawn from Thom 1997).

Post-restoration monitoring at Gog-Le-Hi-Te indicated that the system existed in the upper left box in the matrix. That is, the sedge marsh was only poorly developed, but the system contained high densities of prey resources. The target community did not meet predictions, but the system did meet functional criteria. Further analysis showed that the poor development of sedge and the massive increase in cattail may have been due to variations in salinity and elevation. Based on this information, the project manager could develop alternative actions including no action, modification of the vegetation, and changing the goal. In the latter case, the structural target of sedge could be changed because the system was meeting optimal ecosystem functions of a desirable ecosystem condition.

At Gog-Le-Hi-Te, monitoring has shown that the functional performance of the system for juvenile salmonids is very complex. Prey production probably occurs in the marsh as well as in the channels and mudflat. In addition, prey are transported into the system from upstream sources. Trapped in the system, they provide a concentrated food resource for salmon. Monitoring has thereby served a primary function of adaptive management: increasing knowledge that will contribute to the design and assessment of this and other systems. Monitoring indicated that both the conceptual model and system development matrix needed to be adjusted to fit the empirical results. Clearly, modeling (both conceptual and numerical) can be a powerful tool in sorting out this complexity and defining the most favorable structural attributes to provide optimal functional performance.

Dissemination of Results

Considerations in regard to disseminating the results of a coastal restoration project include the purpose, audience, timing, and appropriate venues.

Purpose and Audience
There are several key reasons to ensure that the results of coastal restoration projects are made available. The coastal restoration and scientific community learns by sharing information and improves coastal restoration methods on that basis. Coastal restoration projects also affect the interests of various stakeholders who need to understand the outcomes. Good reporting is also critical to informed long-term adaptive management of the project itself.

The NRC (1990) pointed out the importance of recognizing the audience interested in the results of a restoration project. This audience may include beach-goers, birders and amateur naturalists, fishermen, sportsmen and recreationists, developers, industry representatives, engineers, government environmental managers, politicians, scientists, and others. Hence, a restoration monitoring program must often meet many needs. Some examples of the audience and the reasons for their interest are as follows:

Project developers and managers
- Is the project responding?
- How do we need to adjust the project?
- How can we minimize cost and maximize performance?

Scientists and Planners
- What can we learn to do things better?
- How does performance fit predictions?

Resource Users

- Is the resource benefiting?
- Is the public benefiting?
- Are adjacent areas affected?

Understanding the audience and its needs is critical. Disseminating information about a restoration project can lead to an increase in public involvement in and acceptance of the project (Harrington and Feather 1996). It is helpful to compile a list of known and potentially interested parties, along with a statement about the use that each party may make of the information. This list is often easy to make based on meetings held during restoration project planning, and it can later serve as a mailing list for documents produced by the project. State and federal agencies with permitting responsibility are, by definition, interested parties. The general public is often interested in coastal restoration projects as well. Volunteer monitors and others in the region want to hear about the progress of the system.

Venues and Timing
Recipients of the monitoring reports and other information should include all interested parties and those who by regulation must get copies (*i.e.,* all state and federal agencies involved in a permit action). If appropriate, a meeting with interested parties can be held to present the results of the monitoring effort and to discuss the future of the project. The project manager can also develop special summary reports of one to two pages that present the fundamental findings from the monitoring program in nontechnical terms. These reports can be published as articles in the periodicals of involved agencies or organizations, posted on websites, or formatted as press releases for the local news media.

Relevant information can also be added to the restoration project databases maintained by the EPA (http://yosemite.epa.gov/water/restorat.nsf/rpd-2a.htm) and under development by NOAA. The publicly-accessible program databases increasingly available on the web provide good models (e.g. www.dep.state.fl.us/water/wetlands/fwric/, www.gulfofmaine.org, www.evergladesplan.org/pub/restudy_eis.cfm, eureka.regis.berkeley.edu/wrpinfo/, www.cacoastkeeper.org/cacoast/, www.lcrep.org/, www.galvbay.org, www.prism.washington.edu/lc/PSNERP/). The Rhode Island Habitat Restoration portal, for example, provides information for seagrass, salt marsh, and anadromous fish habitat restoration, spanning projects from planning to monitoring, and serving many program coordination functions such as volunteer recruitment and opportunities for the public to recommend projects to the coordinating team (http://www.edc.uri.edu/restoration/).

It is strongly recommended that the results of the monitoring program be published in a peer-reviewed journal, and that the restoration project be presented at technical meetings and workshops where the project manager can discuss problematic aspects with colleagues. The sharing of fundamental information is integral to developing the technology of coastal ecosystem restoration. Although large, complex, and controversial projects are always of interest, small, well-conceived and well-implemented projects can also be worthy of publication. Publication is often reserved for completed projects, but for projects with longer monitoring programs, a report summarizing early results may be appropriate. Preliminary results and project descriptions are often welcome at conferences and workshops. The results of the monitoring program can be of great use to others in the field. Once a project has been presented to a professional audience, the members look forward to periodic updates on its progress. Professional societies that feature aquatic habitat restoration in meetings include the American Fisheries Society, Estuarine Research Federation, Ecological Society of America, Society for Ecological Restoration, Society of Wetland Scientists, and American Society of Civil Engineers.

Keys to Successful Restoration

The five key components of a complete and successful restoration project covered in this paper are planning, implementation, performance assessment, adaptive management, and the dissemination of results (Figure 1). In the past, implementation has typically received the most investment. However, the examples discussed here and in a companion document, *National Review of Innovative and Successful Coastal Habitat Restoration* (Borde *et al*. 2003), show that the other four components are now being integrated in programs throughout the country. The monitoring program is central to project success as a tool to assess project performance and identify problems affecting progression toward project goals, in an adaptive management framework.

Twenty features of the iterative planning process, applicable in a variety of coastal habitats, were synthesized from restoration project experience and the literature (Figure 2). The planning process starts with a *vision*, a description of the *ecosystem* and *landscape*, and *goals*. A *conceptual model* and *planning objectives* are developed, a *site is selected*, and *numerical models* contribute to *preliminary designs* as needed. *Performance criteria* and *reference sites* are selected and the *monitoring program* is designed. *Cost analysis* involves *budgeting*, *scheduling*, and *financing*. Finally, *documentation* is *peer reviewed* prior to making *construction plans* and *final costing*.

Restoration may require a multitude of strategies developed from several scientific and technical disciplines. For example, restoring seagrasses or mangroves may help enhance a fish population. Full restoration of the population, however, may require protection of the adjacent coral reef upon which the fish also depend (*e.g.,* Nagelkerken *et al.* 2002). This example demonstrates the synthesis of at least three distinct scientific disciplines: restoration ecology, landscape ecology, and fisheries biology. Other highly specialized disciplines that can serve to influence and assist in restoration and restoration monitoring include plant and animal community ecology, reproductive biology, biodiversity ecology, population genetics, soils science, hydrology, ecotoxicology, island biogeography, disturbance ecology, geospatial analysis, remote sensing, and ecological modeling. The list can grow very long.

The trick for the restoration planner is the effective synthesis and application of relevant information from these myriad disciplines to the practical problem of project design. To accomplish this task, the planner should first seek help from knowledgeable experts;

second, think of restoration from the landscape to the site; third, keep the goals of the project paramount; and fourth, during and following implementation, evaluate the results against the theoretical basis by using monitoring to determine whether the design is working as predicted. When a project does not develop according to the theoretical basis, improvements may be made to the design, the monitoring program, or the theory. Regardless, the discovery of information can be used to improve project success through adaptive management and to strengthen the science of restoration ecology.

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