Using Conceptual Models to Select Ecological Indicators for Monitoring, Restoration, and Management of Estuarine Ecosystems

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2.0 Introduction

When restoration and management of ecosystems are successful, everyone wins and even failure provides an opportunity to learn how ecosystems work (Ewel 1987). A frequently asked important question is: How can one determine success? Ecosystem restoration and management seeks to repair, improve, or maintain a suite of desired environmental conditions for a specific ecosystem. Ecological monitoring is essential for evaluating ecosystem condition over time. Because it is not feasible to measure, much less monitor, all conditions of an estuarine ecosystem, scientists and managers heavily rely on the concept of ecological indicators to reveal information about their ecosystems (Szaro et al. 1999). As a result, monitoring programs focus on indicators that maximize information on ecosystem patterns and processes while minimizing cost and effort.

After goals and objectives have been established, ecosystem monitoring programs contain three vital components: (1) selection of ecosystem attributes to be used as indicators of overall ecosystem response; (2) design of a sampling program, including methods of data collection and management, quality assurance and control, and statistical protocols; and (3) a method of implementing results of the monitoring program in the decision-making process as desired conditions are met, or not.

The first phase of selecting indicators for monitoring should begin with understanding and describing key components and processes of the ecosystem. Information on these components subsequently allows an assessment of the management actions that may affect them. Conceptual models used in the context of the criteria described above can be used to portray the current status of knowledge about an ecosystem and can be used to determine which components of an ecosystem are most critical for monitoring. This chapter discusses the application of conceptual ecological models in selecting indicators for estuarine ecosystem monitoring programs in Southwest Florida.

2.1 Conceptual Ecological Models

Conceptual ecological models can be used to identify which biological attributes or indicators should be monitored to best interpret ecosystem conditions, changes, and trends (Rosen et al. 1995, Gentile 1996, Chow-Fraser 1998, Twilley 2000). Conceptual ecological models are simple, nonquantitative models, represented by a diagram that shows a set of relationships between major anthropogenic and natural stressors, biological indicators, and target conditions for the indicators. The development and application of conceptual models may provide benefits to the scientists who create the models and the environmental managers and general public who use them to guide, implement, and understand resource policy (Gentile 1996, Ogden et al. 1997, Gentile et al. 2001). They are a means of: (1) simplifying complex ecological relationships by organizing information and clearly depicting system components and interactions; (2) integrating to more comprehensively implicit ecosystem dynamics; (3) identifying which species will show ecosystem response; (4) interpreting and tracking changes in targets; and (5) communicating with environmental managers. It has also been suggested that researchers can improve interdisciplinary science through the use of conceptual models as a communication tool (Heemskerk et al. 2003).

Conceptual ecological models have been widely used in other regions of North America in planning several large-scale restoration projects (Rosen et al. 1995, Gentile 1996, Chow-Fraser 1998, Twilley 2000). In South Florida, they are being used to give direction to performance-based ecological monitoring and research plans as part of the Comprehensive Everglades

Restoration (CERP) and are currently being created as part of the Southwest Florida Feasibility Study (SWFFS) to identify attributes or indicators for modeling and monitoring.

2.2 Methods

The creation of a conceptual ecological model is an interactive and iterative process. A conceptual ecological model can be an effective instrument for developing consensus regarding a set of working hypotheses that explain changes that have occurred within an estuary and identify indicators that are representative of the overall ecological conditions of the ecosystem. Prior to creation of a model, a model coordinator should review existing information on the ecosystem. The next step is to use informal workshops to identify and discuss causal hypotheses that best explain both natural and key anthropogenically driven alterations in the estuary. Workshop attendees should include regional and local experts from multiple disciplines. From these discussions, participants create lists of the appropriate stressors, ecological effects, and attributes (indicators) in the estuarine system. The objective is to identify physical and biological components and linkages in each landscape, that best characterize the changes described by the hypotheses. Preparers (modeling team leaders) use hypotheses and lists of components to lay out an initial draft of the model and to prepare a supporting narrative document to explain the organization of the model and science supporting the hypotheses. Drafts of narratives should be reviewed and revised in subsequent workshops.

The South Florida conceptual ecological models follow a top-down hierarchy of information with the following components (Ogden and Davis 1999):

Drivers/Sources — Major external driving forces that have large-scale influences on natural systems. Drivers can be natural forces (e.g., sea level rise) or anthropogenic (e.g., regional land use changes).

Stressors — Physical or chemical changes that occur within natural systems, which are brought about by drivers and are directly responsible for significant changes in biological components, patterns, and relationships in natural systems

Ecological Effects — Biological responses caused by stressors. The links in conceptual ecological models between one or more stressors and ecological effects and attributes are diagrammatic representations of working hypotheses that explain changes that have occurred in ecosystems.

Attributes — Also known as indicators or end points and defined as a frugal subset of all potential biological elements or components of natural systems representative of overall ecological conditions. Attributes typically are populations, species, guilds, communities, or processes. Attributes are selected to represent known or hypothesized affects of stressors (e.g., numbers of nesting wading birds) and elements of systems that have important human values (e.g., endangered species, sport fish). Performance measures and restoration objectives are set for each attribute. Status and trends among attributes are measured by a system wide monitoring and assessment program as a means of determining success of a program in reducing or eliminating adverse effects of stressors. Measuring both stressors and their attributes also provides a means for evaluating working hypotheses and for better understanding cause-and-effect relationships in natural systems.

Measures — Specific features of each attribute to be monitored to determine how well that attribute is responding to projects designed to correct adverse effects of stressors (i.e., to determine success of the project).

As one connects stressors to indicators, a link is established with a working hypothesis, recognizing that these relationships have different levels of certainty. Knowing this level of certainty allows indicators to be organized into monitoring components and research questions.

A conceptual ecological model should be presented in both graphic and narrative form (Suter 1996). Each model narrative should include (from Ogden and Davis 1999):

1. A brief introduction to the dynamics and problems of the landscape

2. Descriptions of specific ecological stressors or external drivers, as well as ecological attributes

3. Ecological effects, including descriptions of major ecological linkages (working hypotheses) affected by stressors, and levels of certainty of the hypotheses

4. Research questions developed from working hypotheses

5. Recommended performance measures and restoration targets for attributes

A good conceptual ecological model will not attempt to explain all possible relationships or include all possible factors influencing the performance measure targets. Instead, it will simplify ecosystem function by containing only information most relevant to ecosystem monitoring goals. Following these criteria, chosen attributes must be measurable and historical patterns, relationships, and functions well enough understood to interpret their responses (Ogden et al. 2003).

2.3 Case Study

The Southwest Florida Feasibility Study is a component of the Comprehensive Everglades Restoration Plan. The Southwest Florida Feasibility Study will result in an independent but integrated implementation plan for Comprehensive Everglades Restoration Plan projects. The Southwest Florida Feasibility Study will provide a framework to address the health and sustainability of aquatic systems. This includes water quantity and quality, flood protection, and ecological integrity. A Southwest Florida Feasibility Study system-wide monitoring and assessment plan will be developed from a minimal set of attributes and performance measures considered by the Southwest Florida Feasibility Study Team as necessary to understand system responses. To identify attributes (indicators) to be measured, the Southwest Florida Feasibility Study Team has developed a set of conceptual ecological models for both inland and coastal systems. The performance measures in the resulting monitoring and assessment plan are arranged into packages describing each performance measure, key uncertainties, related research questions, and monitoring protocol. Three coastal models have been developed. Included here is a conceptual ecological model created for the Ten Thousand Islands region of Southwest Florida (Figure 2.1)

The Ten Thousand Islands region is a shallow, marine-dominated system characterized by mangroves and open-water habitats with areas of coastal strands, saltwater marshes, mudflats, oyster reefs, and seagrasses. The salinity gradient varies spatially with topography and location, and temporally by season (Popowski and Burke 2003). Because of its location in the downstream portion of the East Collier drainage basin, the Ten Thousand Islands region is affected by seasonal freshwater input and upstream water management practices that alter freshwater flows that drive salinity gradients (Popowski and Burke 2003).

Altered hydrology, habitat, and changes in water quality are the predominate stressors of the system and have affected distribution and abundance of species historically found within the system. Alterations include conversion of wetlands, dredging of channels and spoil disposal, changes in shoreline, snagging of streams for navigation, and decrease in spatial extent of the estuaries. Increase in nutrients and dissolved organics entering the system as a result of anthropogenic activities in the watershed also have caused changes in water quality (USGS 1998). Non-native flora and fauna, such as Brazilian pepper *(Schinus terebinthifolius)* and the Mayan cichlid *(Cichlasoma urophthalmus)*, and an increase in boating and fishing pressure were identified as stressors on this ecosystem. Use of personal watercraft, airboats, and similar shallow-draft vessels has increased significantly, providing motorized access to previously inaccessible shallow waters. These stressors are the result of three major sources or drivers: water management practices, changes in land use, and natural phenomena (such as hurricanes and sea level rise).

Eight attributes were identified as indicators of ecosystem response for the Ten Thousand Islands (Figure 2.1, Table 2.1). These indicators also were evaluated by other criteria. A general checklist of criteria for evaluating potential indicators was established by the National Research Council (2000). A modified subset applied to this study included the following:

General Importance — Does the indicator provide information about changes in important ecological processes? Does the indicator show us something about major environmental changes that affect significant areas? Is the indicator sensitive to stress? Is it biologically or socially relevant?

Reliability — What experiences or other evidence demonstrate the indicator's reliability?

Temporal and Spatial Scales — Does the indicator inform us about ecosystem, community, or species specific conditions, processes, and products? Are the changes measured by the indicator likely to be short term or long term? Can the indicator detect changes at the appropriate temporal and spatial scales without being overwhelmed by variability?

Statistical Properties — Has the indicator been shown to serve its intended purpose in the areas of accuracy, sensitivity, precision, and robustness? Is the indicator sensitive enough to detect important changes but not so sensitive that signals are masked by natural variability? Are its statistical properties understood well enough that changes in its values will have clear and unambiguous meaning?

Data — Are they easily measured? How much and what kinds of data are required for the indicator to show a measurable trend? Are the data integrative?

In addition to a distinct linkage to a stressor, each selected attribute had additional significance, such as being ecologically important for endangered species, or providing habitat for other species (Table 2.1). This final set of attributes allows monitoring to track ecosystem response at different temporal and spatial scales and at different taxonomic levels. Each indicator has at least one performance measure allowing evaluation of changes in response to management manipulations (Table 2.1).

2.4 Discussion

Conceptual ecological models can be used as tools for identifying biologically and socially relevant indicators for monitoring (Rosen et al. 1995, Gentile 1996, Chow-Fraser 1998, Twilley 2000). When properly developed, a model can effectively capture important ecosystem processes, and when carefully chosen, indicators can give important information on the overall health of that ecosystem. The model creation process is simple but is often time-consuming because several iterations may be necessary to correctly portray the ecosystem and its subsequent consensus from the working group. Consensus building, through the workshop process, helps assure managers that the indicators have been selected using the best professional knowledge and available information on the ecosystem of interest and its significant attributes.

Once a model has been created and indicators have been selected, it is very important to take each indicator through an additional checklist of criteria, such as that above, to assure its applicability and usefulness to project specific goals and management needs. It is important to remember throughout the process of identifying indicators that no single indicator can provide a comprehensive picture of the system and that a suite of indicators, at different spatial or temporal scale and biological levels, should be included (Franklin 1993, Lambeck 1997).

Because ecological monitoring is such a critical factor in understanding ecosystem and landscape response to change, it is very important to select high-quality indicators (Szaro et al. 1999). In South Florida, indicators have been identified through the conceptual ecological process discussed previously and are being incorporated into system wide and project-specific monitoring plans. In addition, conceptual ecological models have been used to identify the critical linkages between ecosystem stressors, indicators, and performance measures, and the uncertainties associated with the linkages.

The creation of conceptual ecological models has become a crucial part of the adaptive assessment process required for all of the Comprehensive Everglades Restoration projects as part of the Water Resources Development Act of 2000. Adaptive management can be described as a learning process to guide management in the face of uncertainty (Stankey et al. 2003). In Southwest Florida, conceptual ecological models have been used as the foundation for developing an integrated process for adaptive management (Figure 2.2). Regional hydrological and ecological models, such as habitat suitability models or stressor response models, are used to evaluate alternative scenarios and the results used to modify alternatives in the study. These models forecast future conditions and provide an understanding of the potential magnitude of management and restoration alternatives. Models relating output of hydrological models and potential changes in the landscape to amount and location of potential habitat for individual species or habitats give both a visual and a quantitative picture of effects of restoration on selected attributes.

The SWFFS conceptual ecological models show how scientists think the natural areas of Southwest Florida have been stressed, and present the working hypotheses used to explain current ecological conditions in these altered systems. These hypotheses are separated by their level of certainty into research or monitoring. Research or experimentation tests the certainty of linkages and provides calibration for models. This provides a process for active adaptive management. Monitoring evaluates the *in situ* system response and evaluates the success or failure of a project. This creates an iterative or passive adaptive management loop. Despite the potential of adaptive management there are serious concerns regarding the ability to incorporate scientific knowledge into the decision-making process (Walters 1997). Ecosystem management decisions are frequently complex and uncertain, precluding the structure needed for adaptive management to work (Stankey et al. 2003).

Decision support systems are broadly defined as computer-based systems used to aid environmental manager using data and models to solve unstructured problems (Sprague and Carlson 1982, Rauscher 1999, Mowrer 2000). They do not make decisions or set policy; rather they help decision makers to organize, sort, and display decision variables and parameters, and to appreciate impacts of potential policy actions. Decision support systems will provide critical linkage between science and management in the SWFFS.

This approach will enable the SWFFS and other restoration projects to conduct tasks of formulation, evaluation, and modification of alternatives. These alternatives are necessary to develop an effective and feasible plan. In addition, this approach will supply information required by the SWFFS to meet its objectives of conserving and protecting water resources to ensure sustainability of natural resources; improving and protecting quality, heterogeneity, and natural biodiversity in freshwater, upland, estuarine, and marine ecosystems; and protecting and recovering "listed" species.

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Table 2.1. Ten Thousand Islands Conceptual Ecological Model: Summary of Attributes, Linkages, and Performance Measures.

Attribute	Criteria, Scale, and Organization Level	Linkages	Performance Measures
Algal blooms	Criteria - Indicator of Water Quality Spatial – Landscape Temporal Response– days to weeks Level of organization - species	- Altered hydrology through harmful algal blooms - Altered hydrology through altered salinity regime - Changes in water quality through harmful algal blooms	Algal bloom frequency, duration, identity, concentration and size
Fish community structure and function	Criteria - Valued ecosystem component Spatial Scale – Ecosystem Temporal Response– less than 1 year Level of Organization Community	- Changes in water quality through harmful algal blooms - Changes in water quality through loss of SAV - Altered hydrology through altered salinity regime - altered hydrology through loss of mangroves - Habitat alteration and loss through loss of SAV - Habitat alteration and loss through loss of mangroves - Habitat alteration and loss through increase in non-native fish - Exotics through loss of mangroves - Exotics through increase in non-native fish - Boating and fishing pressure through loss of SAV - Boating and fishing pressure through loss of mangroves Boating and fishing pressure through increased fish	Juvenile community structure and composition

		harvesting	
Oyster structure and function	Criteria - Provides estuarine habitat and structure Spatial Scale – Ecosystem Temporal Response– less than 1 year Level of Organization Species	- Altered hydrology through altered salinity regime	Oyster growth, disease, mortality, and recruitment
SAV community structure and composition	Provides estuarine habitat and structure Spatial Scale – Ecosystem Temporal Response– multiple growing seasons Level of Organization Community	- Changes in water quality through loss of SAV - Altered hydrology through altered salinity regime - Altered hydrology through loss of SAV - Habitat alteration and loss through loss of SAV - Boating and fishing pressure through loss of SAV	SAV distribution, density, and abundance
Shoreline vegetation community structure and composition	Provides information on the terrestrial/aquatic transition zone Spatial Scale – Ecosystem Temporal Response– years Level of Organization Community	- Altered hydrology through loss of mangroves - Habitat alteration and loss through loss of mangroves - Exotics through loss of mangroves - Boating and fishing pressure through loss of mangroves	Composition and percent cover
Alligator distribution and abundance	Keystone Species Spatial Scale – Ecosystem	- Altered hydrology through altered salinity regime - Altered hydrology through	Relative distribution and abundance

	Temporal Response– years Level of Organization Species	loss of mangroves - Habitat alteration and loss through loss of mangroves - Exotics through loss of mangroves - Boating and fishing pressure through loss of mangroves	
Manatee distribution and abundance	Endangered Species Spatial Scale – Ecosystem Temporal Response– years Level of Organization Species	- Changes in water quality through loss of SAV - Altered hydrology through altered salinity regime - Habitat alteration and loss through loss of SAV - Boating and fishing pressure through loss of SAV - Boating and Fishing Pressure through increased manatee mortality	Relative distribution, and abundance
Wading Bird Community Structure and Function	Valued ecosystem component Spatial Scale – Ecosystem Temporal Response– multiple nesting seasons Level of Organization Community	- Altered hydrology through loss of mangroves - Habitat alteration and loss through loss of mangroves - Exotics through loss of mangroves - Boating and fishing pressure through loss of mangroves	Number of nesting pairs

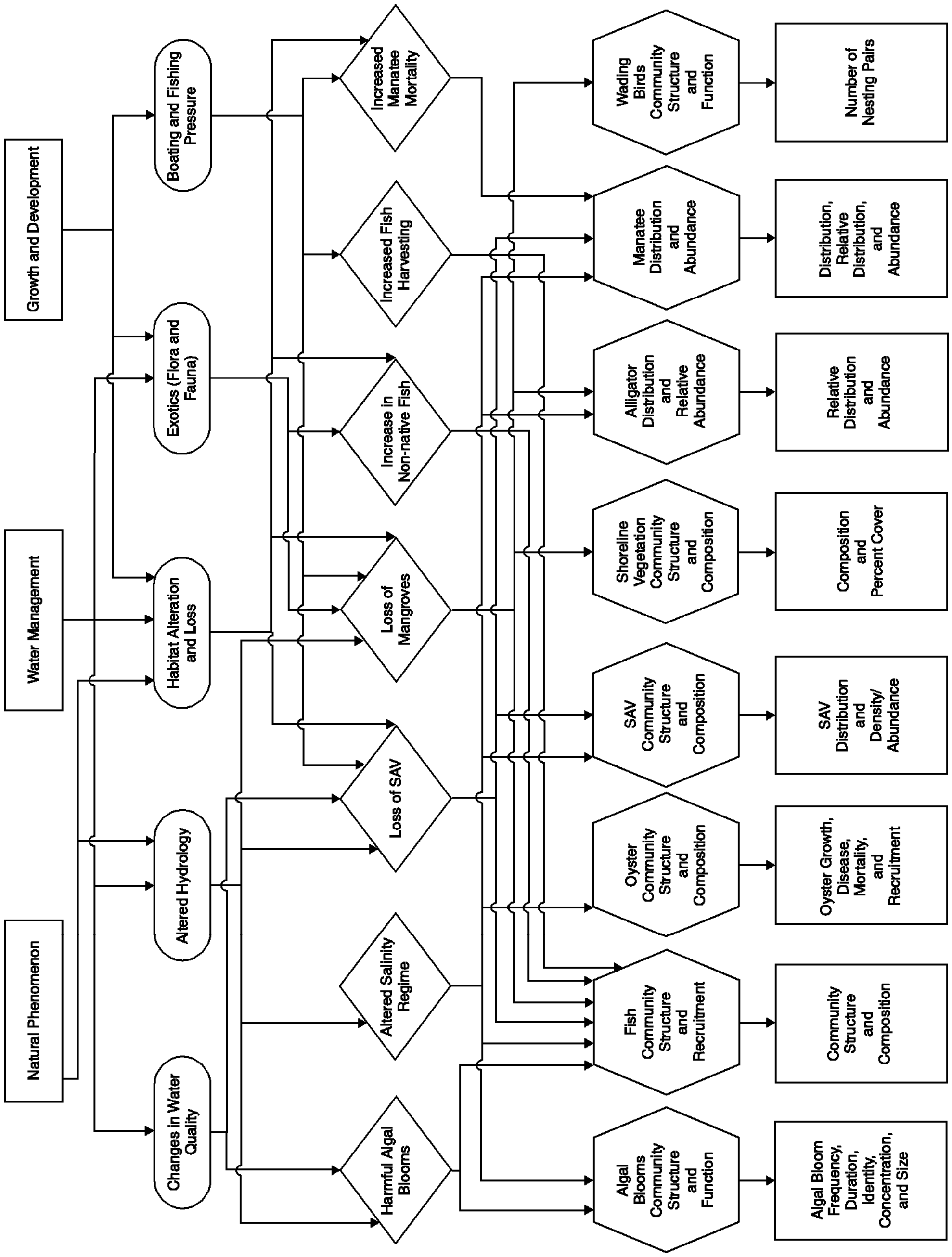

Figure 2.1. Ten Thousand Islands conceptual ecosystem model.

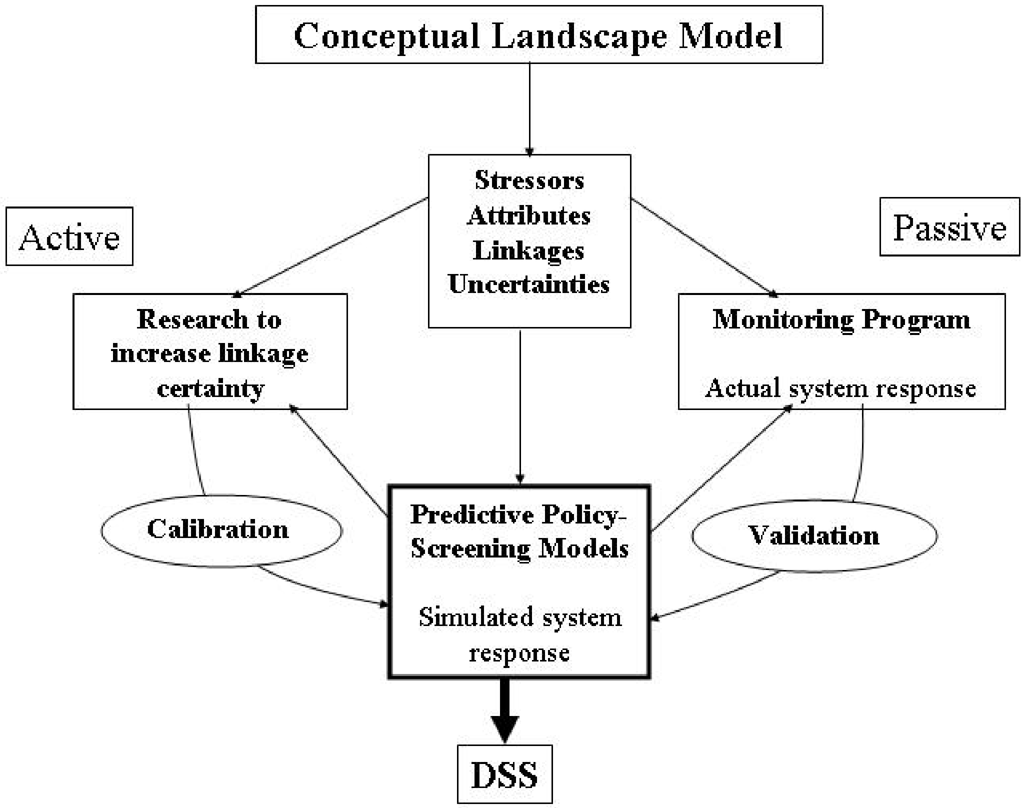

Figure 2.2. Conceptual ecological models form the basis for an integrated approach to adaptive ecosystem management and restoration.