CHAPTER 1: INTRODUCTION TO VOLUME TWO

INTRODUCTION

Coastal habitats provide ecological, cultural, and economic value. They act as critical habitat for thousands of species, including numerous threatened and endangered species, by providing shelter, spawning grounds, and food (Mitsch and Gosselink 2000). They often act as natural buffers, providing ecological, social, and economic benefits by filtering sediment and pollution from upland drainage thereby improving water quality, reducing the effects of floodwaters and storm surges, and preventing erosion. In addition to these ecosystem services, healthy coastal habitats provide many human values including opportunities for:

- Outdoor recreation and tourism

- Education

- Traditional use and subsistence lifestyles

- Healthy fishing communities, and

- Obtaining other marketable goods

Therefore, healthy functioning coastal habitats are not only important ecologically, they also support healthy coastal communities and, more generally, improve the quality of human lives. Despite these benefits, coastal habitats have been modified, degraded, and removed throughout the United States and its protectorates beginning with European colonization (Dahl 1990). Thus, many coastal habitats around the United States are in desperate need of restoration and subsequent monitoring of restoration projects.

WHAT IS RESTORATION MONITORING?

The science of restoration requires two basic tools: the ability to manipulate ecosystems to recreate a desired community and the ability to evaluate whether the manipulation has produced the desired change (Keddy 2000). The latter is often referred to as restoration monitoring.

For this manual, restoration monitoring is defined as follows:

"The systematic collection and analysis of data that provides information useful for measuring project performance at a variety of scales (locally, regionally, and nationally), determining when modification of efforts are necessary, and building long-term public support for habitat protection and restoration."

Restoration monitoring contributes to the understanding of complex ecological systems (Meeker et al. 1996) and is essential in documenting restoration performance and adapting project and program approaches when needs arise. If results of monitoring restored coastal areas are disseminated, they can provide tools for planning management strategies and help improve future restoration practices and projects (Washington et al. 2000). Restoration monitoring can be used to determine whether project goals are being met and if mid-course corrections are necessary. It provides information on whether selected project goals are good measures for future projects and how to perform routine maintenance in restored areas (NOAA et al. 2002). Monitoring also provides the basis for a rigorous review of the pre-construction project planning and engineering.

Restoration monitoring is closely tied to and directly derived from restoration project goals. The monitoring plan (i.e., what is measured, how often, when, and where) should be developed with project goals in mind. If, for example, the goal of a restoration project is to increase the amount of fish utilizing a coastal marsh, then measurements should be selected that can quantify progress toward that goal. A variety of questions about sampling techniques

and protocols need to be answered before monitoring can begin. For the fish utilization example, these may include:

- Will active or passive capture techniques be used (e.g., beach seines vs. fyke nets)?

- Where and when will samples be taken?

- Who will conduct the sampling?

- What level of identification will be required?

- What structural characteristics such as water level fluctuation or water chemistry will also be monitored and how?

- Who is responsible for housing and analyzing the data?

- How will results of the monitoring be disseminated?

Each of these questions, as well as many others, will be answered with the goals of the restoration project in mind. These questions need to be addressed before any measurements are taken in the field. In addition, although restoration monitoring is typically thought of as a 'post-restoration' activity, practitioners will find it beneficial to collect some data before and during project implementation. Pre-implementation monitoring provides baseline information to compare with post-implementation data to see if the restoration is having the desired effect. It also allows practitioners to refine sampling procedures if necessary. Monitoring during implementation helps insure that the project is being implemented as planned or if modifications need to be made.

Monitoring is an essential component of all restoration efforts. Without effective monitoring, restoration projects are exposed to several risks. For example, it may not be possible to obtain early warnings indicating that a restoration project is not on track. Without sound scientific monitoring, it is difficult to gauge how well a restoration site is functioning ecologically both

before and after implementation. Monitoring is necessary to assess whether specific project goals and objectives (both ecological and human dimensions) are being met, and to determine what measures might need to be taken to better achieve those goals. In addition, the lack of monitoring may lead to poor project coordination and decreased efficiency.

Sharing of data and protocols with others working in the same area is also encouraged. If multiple projects in the same watershed or ecosystem are not designed and evaluated using a complementary set of protocols, a disjointed effort may produce a patchwork of restoration sites with varying degrees of success (Galatowitsch et al. 1998-1999) and no way to assess system-wide progress. This would result in a decreased ability to compare results or approaches among projects.

CONTEXT AND ORGANIZATION OF INFORMATION

In 2000, Congress passed the *Estuary Restoration Act (ERA), Title I of the Estuaries and Clean Waters Act of 2000*. The ERA establishes a goal of one million acres of coastal habitats (including those of the Great Lakes) to be restored by 2010. The ERA also declares that anyone seeking funds for a restoration project needs to have a monitoring plan to show how the progress of the restoration will be tracked over time. The National Oceanic and Atmospheric Administration (NOAA) was tasked with developing monitoring guidance for coastal restoration practitioners whether they be academics, private consultants, members of state, Tribal or local government, non-governmental organizations (NGOs), or private citizens, regardless of their level of expertise.

To accomplish this task, NOAA has provided guidance to the public in two volumes. The first, *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework*

for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457) was released in 2003. It outlines the steps necessary to develop a monitoring plan for any coastal habitat restoration project. *Volume One* briefly describes each of the habitats covered and provides three matrices to help practitioners choose which habitat characteristics may be most appropriate to monitor for their project. Experienced restoration practitioners, biologists, and ecologists as well as those new to coastal habitat restoration and ecology can benefit from the step-by-step approach to designing a monitoring plan outlined in *Volume One*.

Volume Two, *Tools for Monitoring Coastal Habitats* expands upon the information in *Volume One* and is divided into two sections **Monitoring Progress Toward Goals** (Chapters 2-14) and **Context for Restoration** (Chapters 15-18). The first section, Monitoring Progress Toward Goals includes:

- Detailed information on the structural and functional characteristics of each habitat that may be of use in restoration monitoring

- Annotated bibliographies, by habitat, of restoration-related literature and technical methods manuals, and

- A chapter discussing many of the human dimensions aspects of restoration monitoring

The second section, Context for Restoration includes:

- A review of methods to select reference conditions

- A sample list of costs associated with restoration and restoration monitoring

- An overview of an online, searchable database of coastal monitoring projects from around the United States, and

- A review of federal legislation that supports restoration and restoration monitoring

The Audience

Volumes One and *Two* of *Science-Based Restoration Monitoring of Coastal Habitats* are written for those involved in developing and implementing restoration monitoring plans, both scientists and non-scientists alike. The intended audience includes restoration professionals in academia and private industry, as well as those in Federal, state, local, and Tribal governments. Volunteer groups, non-governmental organizations, environmental advocates, and individuals participating in restoration monitoring planning will also find this information valuable. Whereas *Volume One* is designed to be usable by any restoration practitioner, regardless of their level of expertise, *Volume Two* is designed more for practitioners who do not have extensive experience in coastal ecology. Seasoned veterans in coastal habitat ecology, however, may also benefit from the annotated bibliographies, literature review, and other tools provided.

The information presented in *Volume Two* is not intended as a 'how to' or methods manual: many of these are already available on a regional or habitat-specific basis. *Volume Two* does not provide detailed procedures that practitioners can directly use in the field to monitor habitat characteristics. The tremendous diversity of coastal habitats across the United States, the types and levels of impact to them, the differing scales of restoration activities, and variety of techniques used in restoration and restoration monitoring prevent the development of universal protocols. Thus, the authors have taken the approach of explaining *what one can measure during restoration monitoring, why it is important*, and *what information it provides* about the progress of the restoration effort. The authors of each chapter also believe that monitoring plans must be derived from the goals of the restoration project itself. Thus, each monitoring effort has the potential to be

unique. The authors suggest, however, that restoration practitioners seek out the advice of regional experts, share data, and use similar data collection techniques with others in their area to increase the knowledge and understanding of their local and regional habitats. The online database of monitoring projects described in Chapter 17 is intended to facilitate this exchange of information.

The authors do not expect that every characteristic and parameter described herein will be measured, in fact, very few of them will be as part of any particular monitoring effort. A comprehensive discussion of all potential characteristics is, however, necessary so that practitioners may choose those that are most appropriate for their monitoring program. In addition, although the language used in *Volume Two* is geared toward restoration monitoring, the characteristics and parameters discussed could also be used in ecological monitoring and in the selection of reference conditions as well.

MONITORING PROGRESS TOWARDS GOALS

The progress of a restoration project can be monitored through the use of traditional ecological characteristics (Chapters 2 - 13) and/or emerging techniques that incorporate human dimensions (Chapter 14).

THE HABITAT CHAPTERS

Thirteen coastal habitats are discussed in twelve chapters. Each chapter follows a format that allows users to move directly to the information needed, rather than reading the whole text as one would a novel. There is, however, substantial variation in the level of detail among the chapters. The depth of information presented reflects the extent of restoration, monitoring, and general ecological literature associated with that habitat. That is, some habitats such as marshes, SAV, and oyster reefs have been the subject of extensive restoration efforts, while others such as rocky intertidal and rock bottom habitats have not. Even within habitats there can be considerable differences in the amount of information available on various structural and functional characteristics and guidance on selecting parameters to measure them. The information presented for each habitat has been derived from extensive literature reviews of restoration and ecological monitoring studies. Each habitat chapter was then reviewed by experts for content to ensure that the information provided represented the most current scientific understanding of the ecology of these systems as it relates to restoration monitoring.

Habitat characteristics are divided into two types: structural and functional. Structural habitat characteristics define the physical composition of a habitat. Examples of structural characteristics include:

- Sediment grain size
- Water source and velocity
- Depth and timing of flooding, and
- Topography and bathymetry

Structural characteristics such as these are often manipulated during restoration efforts to bring about changes in function. Functional characteristics are the ecological services a habitat provides. Examples include:

- Primary productivity
- Providing spawning, nursery, and feeding grounds
- Nutrient cycling, and
- Floodwater storage

Structural characteristics determine whether or not a particular habitat is able to exist in a given area. They will often be the first ones monitored during a restoration project. Once the proper set of structural characteristics is in place and the biological components of the habitat begin to become established, functional characteristics may be added to the monitoring program. Although structural characteristics have historically been more commonly monitored during restoration efforts, measurements of functional characteristics provide a better estimate of whether or not a restored area is truly performing the economic and ecological services desired. Therefore, incorporating measurements of functional characteristics in restoration monitoring plans is strongly encouraged.

When developing a restoration monitoring plan, practitioners should follow the twelve-step process presented in *Volume One* and refer to the appropriate chapters in *Volume Two* (habitat and human dimensions) to assist them in selecting characteristics to monitor. The information presented in the habitat chapters is derived from and expands upon the *Volume One* matrices (*Volume One* Appendix II).

Organization of Information

Each of the habitat chapters is structured as follows:

1. Introduction
   a. Habitat description and distribution
   b. General ecology
   c. Human impacts to the habitat
2. Structural and functional characteristics
   a. Each structural and functional characteristic identified for the habitat in the *Volume One* matrices is explained in detail. Structural and functional characteristics have generally been discussed in separate sections of each chapter. Occasionally, some functions are so intertwined with structural characteristics that the two are discussed together.
   b. Whenever possible, potential methods to measure, sample, and/or monitor each characteristic are introduced or readers are directed to more thorough sources of information. In some cases, not enough information was found while reviewing the literature to make specific recommendations. In these cases, readers are encouraged to use the primary literature cited within the text for methods and additional information.
3. Matrices of the structural and functional characteristics and parameters suggested for use in restoration monitoring
   a. These two matrices are habitat-specific distillations of the *Volume One* matrices
   b. Habitat characteristics are cross-walked with parameters appropriate for monitoring change in that characteristic. Parameters include both those that are direct measures of a particular characteristic as well as those that are indirectly related and may influence a particular characteristic or related parameter. Tables 1 and 2 can be used to illustrate an example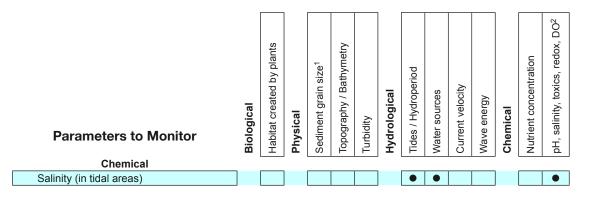. The parameter of salinity in submerged aquatic vegetation is a direct measure of a structural characteristic (salinity, Table 1). In addition, salinity is related to other structural characteristics such as tides and water source. Salinity is also related to functional characteristics such as biodiversity and nutrient cycling and may be appropriate to include in the monitoring of these functions as well (Table 2). Experienced practitioners will note that many characteristics and parameters may be related to one another but are not shown as such in a particular matrix. The matrices are not intended to be all inclusive of each and every possible interaction. The matrices provided and the linkages illustrated are only intended as starting points in the process of developing lists of parameters that may be useful in measuring particular characteristics and understanding some of their interrelationships.
   c. Some parameters and characteristics are noted as being highly recommended for any and all monitoring efforts as they represent critical components of the habitat while others may or may not be appropriate for use depending on the goals of the individual restoration project.
4. Acknowledgement of reviewers
5. Literature Cited

Three appendices are also provided for each habitat chapter. In the online form of *Volume Two,* these appendices download with the rest of the habitat chapter text. In the printed versions of *Volume Two*, each chapter's appendices are provided on a searchable CD-ROM located inside the back cover. Each appendix is organized as follows:
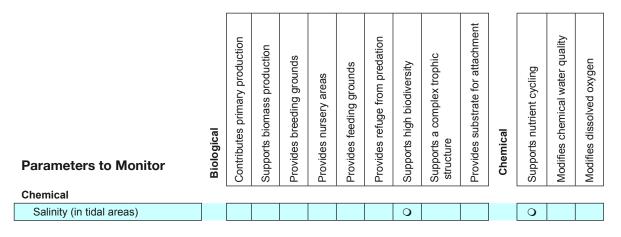
Appendix I - An Annotated Bibliography
a. Overview of case studies of restoration monitoring and general ecological studies pertinent to restoration monitoring
b. Entries are alphabetized by author

Parameters to Monitor the Structural Characteristics of SAV (excerpt)

Parameters to Monitor	Biological	Habitat created by plants	Physical	Sediment grain size[1]	Topography / Bathymetry	Turbidity	Hydrological	Tides / Hydroperiod	Water sources	Current velocity	Wave energy	Chemical	Nutrient concentration	pH, salinity, toxics, redox, DO[2]
Chemical														
Salinity (in tidal areas)								●	●					●

Table 1. Salinity is a parameter that can be used to directly measure a structural component of submerged aquatic vegetation habitats (Chemical/salinity). It is shown with a closed circle indicating that it highly recommended as part of any restoration monitoring program, regardless of project goals. A circle for salinity is also shown under the **Tides/Hydroperiod** and **Water source** columns as salinity levels are related to these structural characteristics as well. (Entire table can be found on page 9.39.)

Parameters to Monitor the Functional Characteristics of SAV (excerpt)

Parameters to Monitor	Biological	Contributes primary production	Supports biomass production	Provides breeding grounds	Provides nursery areas	Provides feeding grounds	Provides refuge from predation	Supports high biodiversity	Supports a complex trophic structure	Provides substrate for attachment	Chemical	Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Chemical														
Salinity (in tidal areas)								○				○		

Table 2. Salinity is related to the functions of **Supporting high biodiversity** and **Supporting nutrient cycling**. It is shown here with an open circle, denoting that it may be useful to monitor if monitoring of these functions is important to the goals of the restoration project. (Entire table can be found on page 9.40.)

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[1] Including organic matter content.
[2] Dissolved oxygen.

Appendix II - Review of Technical and Methods Manuals
    These include reviews of:
    a. Restoration manuals
    b. Volunteer monitoring protocols
    c. Lab methods
    d. Identification keys, and
    e. Sampling methods manuals

Whenever possible, web addresses where these resources can be found free of charge are provided.

Appendix III - Contact information for experts who have agreed to be contacted with questions from practitioners

As extensive as these resources are, it is inevitable that some examples, articles, reports, and methods manuals have been omitted. Therefore, these chapters should not be used in isolation. Instead, they should be used as a supplement to and extension of:

• The material presented in *Volume One*

• Resources provided in the appendices

• The advice of regional habitat experts, and

• Research on the local habitat to be restored

WHAT ARE THE HABITATS?

The number and type of habitats available in any given estuary is a product of a complex mixture of the local physical and hydrological characteristics of the water body and the organisms living there. The ERA Estuary Habitat Restoration Strategy (Federal Register 2002) dictates that the Cowardin et al. (1979) classification system should be followed in organizing this restoration monitoring information. The Cowardin system is a national standard for wetland mapping, monitoring, and data reporting, and contains 64 different categories of estuarine and tidally influenced habitats. Definitions, terminology, and the list of habitat types continue to increase in number as the system is modified. Discussion of such a large number of habitat types would be unwieldy. The habitat types presented in this document, therefore, needed to be smaller in number, broad in scope, and flexible in definition. The 13 habitats described in this document are, however, generally based on that of Cowardin et al. (1979).

Restoration practitioners should consider local conditions within their project area to select which general habitat types are present and which monitoring measures might apply. In many cases, a project area will contain more than one habitat type. To appropriately determine the habitats within a project area, the practitioner should gather surveys and aerial photographs of the project area. From this information, he or she will be able to break down the project area into a number of smaller areas that share basic structural characteristics. The practitioner should then determine the habitat type for each of these smaller areas. For example, a practitioner working in a riparian area may find a project area contains a *water column, riverine forest, rocky shoreline*, and *rock bottom*. Similarly, someone working to restore an area associated with a tidal creek or stream may find the project area contains *water column, marshes, soft shoreline, soft bottom*, and *oyster beds*. Virtually all estuary restoration projects will incorporate characteristics of the water column. Therefore, all practitioners should read *Chapter 2: Restoration Monitoring of the Water Column* in addition to any additional chapters necessary.

Habitat Decision Tree

A Habitat Decision Tree has been developed to assist in the easy differentiation among the habitats included in this manual. The decision tree allows readers to overcome the restraints of varying habitat related terminology in deciding which habitat definitions best describe those in their project area. Brief definitions of each habitat are provided at the end of the key.

1. a. Habitat consists of open water and does not include substrate (**Water Column**)
    b. Habitat includes substrate (go to 2)
2. a. Habitat is continually submerged under most conditions (go to 3)
    b. Habitat substrate is exposed to air as a regular part of its hydroperiod (go to 8)
3. a. Habitat is largely unvegetated (go to 4)
    b. Habitat is dominated by vegetation (go to 7)
4. a. Substrate is composed primarily of soft materials, such as mud, silt, sand, or clay (**Soft Bottom**)
    b. Substrate is composed primarily of hard materials, either of biological or geological origin (go to 5)
5. a. Substrate is composed of geologic material, such as boulders, bedrock outcrops, gravel, or cobble (**Rock Bottom**)
    b. Substrate is biological in origin (go to 6)
6. a. Substrate was built primarily by oysters, such as *Crassostrea virginica* (**Oyster Reefs**)
    b. Substrate was built primarily by corals (**Coral Reefs**)
7. a. Habitat is dominated by macroalgae (**Kelp and Other Macroalgae**)
    b. Habitat is dominated by rooted vascular plants (**Submerged Aquatic Vegetation - SAV**)
8. a. Habitat is not predominantly vegetated (go to 9)
    b. Habitat is dominated by vegetation (go to 10)
9. a. Substrate is hard, made up materials such as bedrock outcrops, boulders, and cobble (**Rocky Shoreline**)
    b. Substrate is soft, made up of materials such as sand or mud (**Soft Shoreline**)
10. a. Habitat is dominated by herbaceous, emergent, vascular plants. The water table is at or near the soil surface or the area is shallowly flooded (**Marshes**)
    b. Habitat is dominated by woody plants (go to 11)
11. a. The dominant woody plants present are mangroves, including the genera *Avicennia*, *Rhizophora*, and *Laguncularia* (**Mangrove Swamps**)
    b. The dominant woody plants are other than mangroves (go to 12)
12. a. Forested habitat experiencing prolonged flooding, such as in areas along lakes, rivers, and in large coastal wetland complexes. Typical dominant vegetation includes bald cypress (*Taxodium distichum*), black gum (*Nyssa sylvatica*), and water tupelo (*Nyssa aquatica*). (**Deepwater Swamps**)
    b. Forested habitat along streams and in floodplains that do not experience prolonged flooding (**Riverine Forests**)

Water column - A conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Rock bottom - Includes all wetlands and deepwater habitats with substrates having an aerial cover of stones, boulders, or bedrock 75% or greater and vegetative cover of less than 30% (Cowardin et al. 1979). Water regimes are restricted to subtidal, permanently flooded, intermittently exposed, and semi-permanently flooded. The rock bottom habitats addressed in *Volume Two* include bedrock and rubble.

Coral reefs - Highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Oyster reefs - Dense, highly structured communities of individual oysters growing on the shells of dead oysters.

Soft bottom - Loose, unconsolidated substrate characterized by fine to coarse-grained sediment.

Kelp and other macroalgae - Relatively shallow (less than 50 m deep) subtidal and intertidal algal communities dominated by very large brown algae. Kelp and other macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous plant and animal communities.

Rocky shoreline - Extensive littoral habitats on high-energy coasts (i.e., subject to erosion from waves) characterized by bedrock, stones, or boulders with a cover of 75% or more and less than 30% cover of vegetation. The substrate is, however, stable enough to permit the attachment and growth of sessile or sedentary invertebrates and attached algae or lichens.

Soft shoreline - Unconsolidated shore includes all habitats having three characteristics: (1) unconsolidated substrates with less than 75% aerial cover of stones, boulders, or bedrock; (2) less than 30% aerial cover of vegetation other than pioneering plants; and (3) any of the following water regimes: irregularly exposed, regularly flooded, irregularly flooded, seasonally flooded, temporarily flooded, intermittently flooded, saturated, or artificially flooded (Cowardin et al. 1979). This definition includes cobble-gravel, sand, and mud. However, for the purpose of this document, cobble-gravel is not addressed.

Submerged aquatic vegetation (SAV; includes marine, brackish, and freshwater) - Seagrasses and other rooted aquatic plants growing on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, rivers, and lakes. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Marshes (marine, brackish, and freshwater) - Transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mangrove swamps - Swamps dominated by shrubs (*Avicenna, Rhizophora*, and *Laguncularia*) that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C; this limits their northern distribution.

Deepwater swamps - Forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley.

They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Riverine forests - Forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the southeastern United States, riverine forests are found throughout the United States in areas that do not have prolonged flooding.

THE HUMAN DIMENSIONS CHAPTER

The discussion of human dimensions helps restoration practitioners better understand how to select measurable objectives that allow for the appropriate assessment of the benefits of coastal restoration projects to human communities and economies. Traditionally, consideration of human dimensions issues has not been included as a standard component of most coastal restoration projects. Most restoration programs do not currently integrate social or economic factors into restoration monitoring, and few restoration projects have implemented full-scale human dimensions monitoring. Although some restoration plans are developed in an institutional setting that require more deliberate consideration of human dimensions impacts and goals, this does not generally extend to the monitoring stage. It is becoming increasingly evident, however, that decisions regarding restoration cannot be made solely by using ecological parameters alone but should also involve considerations of impacts on and benefits to human populations, as well. Local communities have a vested interest in coastal restoration and are directly impacted by the outcome of restoration projects in terms of aesthetics, economics, or culture. Human dimensions goals and objectives whether currently available or yet to be developed should reflect societal uses and values of the resource to be restored. Establishing these types of parameters will increase the public's understanding of the potential benefits of a restoration project and will increase public support for restoration activities.

While ecologists work to monitor the restoration of biological, physical, and chemical functional characteristics of coastal ecosystems, human dimensions professionals identify and describe how people value, utilize, and benefit from the restoration of coastal habitats. The monitoring and observation of coastal resource stakeholders allows us to determine who cares about coastal restoration, why coastal restoration is important to them, and how coastal restoration changes people's lives. The human dimensions chapter will help restoration practitioners identify:

1) Human dimensions goals and objectives of a project

2) Measurable parameters that can be monitored to determine if those goals are being met, and

3) Social science research methods, techniques, and data sources available for monitoring these parameters

This chapter includes a discussion of the diverse and dynamic social values that people place on natural resources, and the role these values play in natural resource policy and management. Additionally, some of the general factors to consider in the selection and monitoring of human dimensions goals/objectives of coastal restoration are presented, followed by a discussion of some specific human dimensions goals, objectives, and measurable parameters that may be included in a coastal restoration project. An annotated bibliography of key references and a matrix of human dimensions goals and measurable parameters are provided as appendices at the end of this chapter. Also included, as an appendix, is a list of human dimensions research experts (and their areas of expertise) that you may contact for additional information or advice.

CONTEXT FOR RESTORATION

The final four chapters of this manual are designed to provide readers with additional information that should enhance their ability to develop and carry out strong restoration monitoring plans. Chapter 15 reviews methods available for choosing areas or conditions to which a restoration site may be compared both for the purpose of setting goals during project planning and for monitoring the development of the restored site over time. Chapter 16 is a listing of generalized costs of personnel, labor, and equipment to assist in the development of planning preliminary cost estimates of restoration monitoring activities. Some of this information will also be pertinent to estimating costs of implementing a restoration project as well. Chapter 17 provides a brief description of the online review of monitoring programs in the United States. The database can be accessed though the NOAA Restoration Portal (http://restoration.noaa.gov/). This database will allow interested parties to search by parameters and methodologies used in monitoring, find and contact responsible persons, and provide examples that could serve as models for establishment or improvement of their own monitoring efforts. Chapter 18 is a summary of the major United States Acts that support restoration monitoring. This information will provide material important in the development of a monitoring plan. A Glossary of many scientific terms is also provided at the end of the document.

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CHAPTER 11: RESTORATION MONITORING OF MANGROVES

Felicity Burrows, NOAA National Centers for Coastal Ocean Science[1]
Perry Gayaldo, NOAA National Marine Fisheries Service[2]

INTRODUCTION

Mangroves are woody plants found in tropical and subtropical regions in brackish and saltwater conditions along the margins between the ocean and land. There are nearly 70 species of mangroves worldwide. These species include trees and shrubs (Chapman 1976; Teas 1984) and cover approximately 240,000 km^2 of sheltered coastlines (Lugo et al. 1990). In the United States and its protectorates, they are distributed primarily along the Atlantic and Gulf coasts of Florida as well as Puerto Rico, the US Virgin Islands, Hawaii, and the Pacific Trust Territories (Hoff et al. 2002). Species of mangroves commonly found in these areas include:

Red mangroves *(Rhizophora mangle,* Figure 1)

Black mangroves *(Avicennia germinans,* Figure 2)

White mangroves *(Laguncularia racemosa*) (Massaut 1999), and

Button-mangrove or buttonwood (*Conocarpus erectus* is also found in the warmer climates of the Gulf of Mexico and Caribbean). Button-mangrove, however, is not always considered a true mangrove (Hoff et al. 2002)

In more northern areas along Texas, Louisiana, and Mississippi where temperatures are cooler, black and button-mangroves dominate along the coastline because they have the ability to withstand relatively low temperatures (Markley et al. 1982; Sherrod et al. 1986), whereas red, white, and black mangroves generally dominate more tropical areas.

Species of mangroves are often found in association with coral reefs and seagrasses (Ogden 1988; Yáñez-Arancibia et al. 1993; Nagelkerken 2001; Mumby et al. 2004) and therefore function as an integrated system that supports many species such as birds, fishes, invertebrates, and crustaceans. Juvenile coral reef fish, for example, commonly inhabit mangroves (Mumby et al. 2004) and utilize these habitats as nursery grounds (Nagelkerken

Figure 1. Red Mangroves along the Anne Kolb Nature Center. Photo courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Sciences.

[1] 1305 East West Highway, Silver Spring, MD 20910.
[2] 1315 East-West Highway 9th Floor F/CS, Silver Spring, MD 20910.

Figure 2. Black mangroves. Photo courtesy of the South Florida, United States Geological Survey. http://sofia.usgs.gov/virtual_tour/images/photos/wlak/ak_blackmang.jpg

Figure 3. Kayakers enjoying a day on the water amongst mangrove communities in Thailand. Photo courtesy of the Mangrove Action Project, Port Angeles, WA. http://www.earthisland.org/map/mngim_thailand_sn.htm

2001). The distribution and abundance of organisms that occupy mangroves may be used as indicators of mangrove health.

There are over 500 species of animals associated with mangrove habitats in the United States including 200 species of fish. Not only are mangroves used by many organisms, but they are also harvested to produce paper and textiles, as well as for fuel wood (Novelli and Cintron-Molero 1991; Bandaranayake 1998; Shunula 2001; Fast and Menasveta 2003). In some cultures (European, African, and Caribbean),

the wood of mangrove trees is used to build boats and community houses (Bandaranayake 1998; Dahdouh-Guebas et al. 2000; Shunula 2001). Mangrove communities also provide an environment that is enjoyed by persons fishing, kayaking, or canoeing (Figure 3) along the coastline.

Despite their tremendous economic, ecological, and cultural importance, mangroves are threatened by a number of human activities that deteriorate the habitat's structural and functional characteristics (Spalding et al. 1997). These

human impacts include coastal development, shrimp farming and aquaculture practices, and coastal pollution (sewage, nutrient pollution, chemical discharge, and oil spills). Detailed information on how such pressures affect mangrove communities is discussed in the following section.

HUMAN IMPACTS TO MANGROVES

Coastal Development

Mangroves are threatened by a number of human activities that deteriorate the structural and functional characteristics of these complex ecosystems (Spalding et al. 1997). One of the leading threats to mangroves is coastal development and channel construction. In Florida, a residential project eliminated approximately 24% of mangrove cover (Twilley 1998). In Ecuador, along the El Oro River, approximately 45-63% of mangrove habitat was lost due to mariculture pond construction (Twilley 1989). Mangroves are also removed and replaced by dredged channels, seawalls, pond development, and other commercial and residential construction (Burchmore 1993; Primavera 1993; Thompson 2003). Also associated with such development is the diversion of freshwater with the use of dams to control river flows. If mangrove communities do not receive freshwater inflow, the salinity

levels in the water may increase significantly decreasing mangrove productivity (Harrison et al. 1994; McIvor et al. 1994; Kulkarni 2002).

Cultural Practices

Deforestation of mangroves for cultural purposes is also a concern. For many years, mangrove harvesting practices have been sustained, but over time, increasing human populations along the coast have led to unsustainable practices (Twilley 1998). In some countries such as Africa, Sundarbans (India, Bangladesh), Indonesia, Peninsular Malaysia, and Thailand, red mangroves are considered a valuable commodity and are a primary source of firewood and charcoal sold locally and commercially. Mangrove wood is also relied on as fuel wood for cooking and heating; used to construct houses (Figure 4), furniture, and small boats to perform local fishing, and create pulp to produce paper and paper products (Snedaker 1978; Bandaranayake 1998). Mangroves may also be used in agriculture and as pastures for livestock.

Shrimp Farming and Aquaculture

Shrimp farming and aquaculture practices that use ponds also threaten mangrove communities by polluting waters or by removal of mangroves in order to create areas suitable for shrimp

Figure 4. Community houses in Indonesia using wood of mangrove trees. Photo courtesy of the Mangrove Action Project, Port Angeles, WA 98362-0279 USA. http://www.earthisland.org/map/mngim.htm

farming and aquaculture (Boyd 2001; Fast and Menasveta 2003). In addition to direct habitat loss due to the conversion of forests to shrimp ponds, effluents from ponds enter the remaining mangrove areas, altering environmental conditions and affecting mangrove growth (Rajendran and Kathiresan 1996). During shrimp farming, channels are created to control the supply of freshwater and seawater to the ponds. Diverting the natural water flow may negatively affect mangrove establishment and growth as seeds cannot be properly dispersed, seedlings cannot establish themselves, and changes in salinity levels decrease mangrove growth (Chapman 1976; McIvor et al. 1994). Animal communities may also change as a result. In some cases, fertilizers used in shrimp farming contaminate the mangrove water supply (Figure 5), affecting mangrove growth as well as impacting animal communities by reducing species composition, abundance, and diversity (Paez-Osuna et al. 2003).

Pollution

Coastal pollution in mangrove communities from human activities includes thermal pollution (hot-water outflows), nutrient pollution (including sewage), heavy metals, industrial chemicals, and oil spills.

Thermal pollution

One source of pollution that may affect mangroves by reducing leaf area, causing partial defoliation (loss of leaves on a plant or tree), or dwarfed seedlings is thermal pollution. This refers to significantly high water temperatures in marine, fresh, and brackish water systems as a result of discharge of hot effluents from thermal generating plants and heated water during industrial processes. Mangrove seedlings are more vulnerable to thermal discharges and show close to 100% mortality once water temperatures elevate between 7 and 9 °C (Hogarth 1999). Although thermal discharges are a threat to mangroves in some areas, it is not very common in the tropics.

Nutrient pollution

In some cases, sewage discharge when managed correctly, adds nutrients such as nitrogen and phosphorous to the water column, promoting mangrove growth and productivity (Twilley 1998). If the rate of discharge, however, is more than the uptake rate of the mangrove, excess nutrients will accumulate in mangrove

Figure 5. Polluted sludge waste discharged from shrimp pond next to mangroves - southwest coast of Thailand. Photo courtesy of the Mangrove Action Project, Port Angeles, WA. http://www.earthisland.org/map/mngim_thailand.htm

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[3] Specialized roots formed on several species of plants occurring frequently in inundated habitats; the root is erect and protrudes above the soil surface.

communities causing reduced water quality and increased algal growth that can block mangrove pneumatophores[3] and reduce oxygen exchange. Excessive algal growth may also obstruct growth of mangrove seedlings (Hogarth 1999). For example, in sheltered mangroves, located in two aquatic reserves in Australia, nutrient loads increased as a result of the Bolivar Sewage Treatment Works causing increased growth of sea lettuce (*Ulva*). Increased sea lettuce growth resulted in high mortalities in young mangrove seedlings by smothering seeds and reducing photosynthetic ability (Edyvane 1991). In addition, microbes may become present because of excess nutrients and reduce dissolved oxygen content in the water, also negatively affecting mangrove fauna (Hoff et al. 2002).

Heavy metals and agriculture chemicals

Metals (such as mercury, lead, cadmium, zinc, and copper) from mining and industrial wastes can affect mangroves. Once heavy metals enter mangrove ecosystems, they have the potential to decrease mangrove growth and respiration rates and negatively impact the animal community. High concentrations of mercury, cadmium, and zinc can be toxic or cause physiological stress to invertebrate and fish larvae (Hoff et al. 2002). Pesticides, also used on farms, may runoff into surface waters and may be taken up and absorbed by animals such as fish, shrimp, and mollusks that use mangroves and affect their growth and development (Hoff et al. 2002).

Oil spills

Hazardous spills such as oil spills may also contribute to the loss of mangrove habitats. If high concentrations of oil or any other pollutant enter the soil or water supply within mangrove forests, the results may include death in plant species, change in normal development, reduced functional ability, and mortality in birds that use mangrove habitats for feeding and breeding grounds (Lewis 1980; Samarasekara 1994; Hoff et al. 2002). Following the 1986 Bahía las Minas (Galeta) oil spill in Panama, investigators

observed that oil in mangrove sediments affected root survival, canopy condition, and growth rates of mangrove seedlings. Six years after the oil spill event, surviving fringing forest near deforested areas continued to display canopy leaf biomass deterioration (Burns et al. 1993). Thus, the detrimental effects of oil spills on mangroves can be both serious and long lasting. Some researchers, however, may have contrasting views in regards to oil effects on mangroves (Snedaker 1997). There is some evidence to suggest that mangrove tolerance and sensitivity to oil spills varies by species, and that some species are able to tolerate exposure to moderate levels of oil on their roots (Snedaker 1997).

RESTORATION AND MONITORING EFFORTS

Mangrove restoration projects aim to restore the habitat's physical structure and functional capacity so that it can continue to support many species of plants, fish, and wildlife (Hamilton and Snedaker 1984, Lewis et al. 1985). Planting of propagules or transplanting of mangroves is not always necessary when restoring mangroves. This is because they have the ability to repair themselves once normal tidal hydrology and the availability of waterborne seeds or seedlings (propagules) of mangroves from adjacent areas is restored (Lewis 1982a, Cintron-Molero 1992). Mangrove planting is only necessary if:

- Natural recruitment is not likely to occur due to lack of propagules
- Soil conditions prohibit natural establishment
- Waterborne seeds or seedlings (propagules) cannot reach the restoration site under normal hydrological conditions (Lewis et al. 2000)

Mangrove propagules can be planted bare or with the use of PVC pipes (Figure 6). When using PVC pipes, small holes are cut along the

Figure 6. One year after mangrove seedlings were placed in PVC pipes. Photo courtesy of Mike Devany and Marine Resource Council, NOAA Restoration Center. Publication of the National Oceanic & Atmospheric Administration (NOAA), NOAA Central Library. http://www.photolib.noaa.gov/habrest/r0008735.htm

length of each pipe to allow water flow and then filled with muddy sediment. The propagules are then planted in sediment at the top of the pipe where they are left to grow.

NOAA's Community-Based Restoration Program in partnership with other Federal agencies, states, local governments, non-governmental, and non-profit organizations provides financial and technical assistance for restoration of mangrove and other coastal habitats throughout the United States and its protectorates. To find out additional information pertaining to NOAA-related mangrove restoration projects and possible funding opportunities for coastal restoration efforts, contact the NOAA Community-Based Restoration Program, NOAA Fisheries, Office of Habitat Conservation (F/HC3), 1315 East West Highway, Silver Spring, MD 20910.

Monitoring mangrove's structural and functional characteristics will help restoration practitioners understand their ecological and economical value, and determine what management actions need to be performed (Ellison 2000). Monitoring mangrove productivity and associated physical, biological, and chemical characteristics provides insight into which combination of factors may be influencing mangrove development. When monitoring mangrove areas, a survey and an inventory of the vegetation is performed, and site characteristics are identified and measured (Lewis and Streever 2000). These include:

- Species diversity and abundance
- Height and density
- Community structure
- Soil texture
- Salinity
- Moisture
- pH, and
- Overall mangrove health (Lewis and Streever 2000)

Monitoring is encouraged before implementing a restoration project to establish a baseline, during the project, and after the restoration effort is implemented to determine whether or not it is progressing as expected. Monitoring allows the practitioner to modify the restoration design to increase the project's effectiveness. Other factors that influence the planning of a good and feasible restoration monitoring project are sufficient funds, equipment, adequate labor, and suitable methods. It has been suggested that practitioners organize a priority list where, at a minimum, documentation is made of ground level photography from fixed photo stations, percent cover by all species of plants, percent

and density of mangrove seedlings, and later mangrove trees (Lewis per comm. 2004). Monitoring begins with a Time Zero report and then typically continues quarterly the first year, then semi-annually, then annually up to 5-years post implementation. This can provide a series of 10 monitoring reports as follows:

Time Zero
Time Zero + 3 months
Time Zero + 6 months
Time Zero + 9 months
Time Zero + 12 months
Time Zero + 18 months
Time Zero + 24 months
Time Zero + 36 months
Time Zero + 48 months
Time Zero + 60 months + final report

Methods used for monitoring restoration success may, however, be costly depending on selected parameters. Fish sampling, for example, needs to be performed more than once a year, at one location. Obtaining a good representation of the habitat's fish community may involve multiple sampling measures, daylight and night-time sampling, and sampling various locations (e.g., fringe mangrove, tidal creeks, and black mangrove basin areas) using quadrats as a basic sampling unit. Not only is this type of sampling costly but can also be time consuming. Identifying invertebrate species and measuring their abundance, on the other hand, is considered very cost effective. Practitioners should therefore establish project goals and objectives that will fit budgetary limits and still produce efficient monitoring results over time.

In some cases, researchers may have to prioritize sampling measures based on factors such as cost, time restraints, and availability of funds or labor (Lewis per comm. 2004), while considering the goals of the project. The matrices presented at the end of this chapter provide structural and functional parameters that can be measured to track restoration success, and help prioritize the measures to be performed.

STRUCTURAL CHARACTERISTICS OF MANGROVES

This section presents the structural characteristics of mangroves that are applicable to restoration monitoring. The characteristics described in this section refer to the biological, physical, hydrological, and chemical features of the habitat that may be potential parameters used to gather baseline information and for monitoring restoration efforts and abiotic factors that may influence the restoration process. Not all structural characteristics described, however, are expected to be measured or monitored in every restoration project. Additional information provided is intended to help educate the reader on the ecology of mangroves such as the role each characteristic plays in supporting the structure of the habitat and plant and animal life.

The structural characteristics described in this section include:

Biological
- Habitat created by plants (i.e., mangroves)
  - Root structure
  - Community types
  - Invasives

Physical
- Turbidity/Light availability
- Sediment type and grain size
- Topography/Bathymetry

Hydrological
- Tides/Hydroperiods
- Water sources

Chemical
- Salinity

Since these structural characteristics can influence mangrove growth and productivity, practitioners should first conduct monitoring of these characteristics before project implementation to ensure conditions are favorable for successful restoration. After restoration efforts, monitoring may be performed to track the success of the project by comparing the restoration site to reference sites. Also presented are methods that can be used to sample, measure, and monitor each parameter whenever possible before, during, and after restoration.

BIOLOGICAL

Habitat Created by Plants

There are three types of mangrove species found in the United States: red, black, and white mangroves. Red mangrove leaves are 1-5 inches long, broad, shiny, deep green on top, and pale green on the underside of the leaf (Jimenez and Lugo 1985). Black mangroves leaves are oblong, shiny green on top, with hairy structures on the underside of the leaves. They are found in areas that are elevated and grow closer inland to the shore (Jimenez and Lugo 1985). The unique characteristic of white mangroves is their leaves, which are elliptical, yellowish in color, and have two well-defined glands at the base of each petiole. These glands regulate salt concentration (Elias 1980). White mangroves commonly grow at relatively higher land elevations compared to red and black mangroves. Some other vegetative species present within mangrove communities include:

> Perennial glasswort (*Salicornia virginica)*,
> Giant wild pine (*Tillandsia fasciculate),* and
> Black needle rush (*Juncus roemerianus)*

Macrophytes (herbaceous aquatic plants) such as these serve as an important food source for fish and invertebrate species that directly graze on them. They are also an important link in the detrital food chain. Macrophytes are very sensitive to nutrients, light, temperature, contaminants, turbidity, salinity, and water level change (Crowder and Painter 1991). They are therefore considered good indicators of coastal

ecosystem health and should be studied and monitored during restoration.

Root Structure

Roots act as anchors for mangroves growing in soft sediment as well as ensuring sufficient transportation of oxygen to belowground meristematic tissue responsible for the formation of new cells (Hogarth 1999). The aboveground portion of the root system (Figure 7) is comprised of porous tissues that help aerate the plant. Red mangroves develop aerial or prop stilt roots that arch from the main trunk in various directions until they reach bottom sediments. The prop root system also aids in dispersing wave energy, increasing surface area suitable for attachment of some organisms, such as sponges (Figure 8) and molluscs, and providing shelter for numerous other marine organisms such as fishes (Thayer et al. 1987; Thayer and Sheridan 1999).

Black mangroves do not possess prop roots but have an underground system of horizontal radiating roots that produce upward growing terminal branches called pneumatophores or breathing roots. White mangroves, however, have no prop roots or pneumatophores. There are also some organisms that actually live within each mangrove, such as *Sphaeroma,* an isopod that bores into the roots of mangroves. Although these boring crustaceans leave holes that may appear to be a sign of mangrove deterioration, they are actually indicators of mangrove health because they are found primarily in healthy mangroves. Mangrove root structures are very complex and therefore can be difficult to assess. Practitioners. however, can generally evaluate root communities and health primarily by visual assessment.

Community Types

Various mangrove community types develop due to hydrological and geological processes. These include: fringing, riverine, scrub or dwarf, overwash, basin, and hammock.

Fringing forests exist as a relatively thin fringe along coastal water bodies where elevations are higher than mean high tide. These forest types experience periodic flooding. Zonation patterns are from seaward to landward, typically red-black-white mangroves respectively (Odum et al. 1985).

Figure 7. Red mangroves in Florida showing above-ground root system. Photo courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Sciences, Silver Spring, MD.

Figure 8. Sponges attach to mangrove roots. Photo courtesy of NOAA Center for Coastal Monitoring and Assessment.

Riverine mangrove forests consist of tall floodplain trees along tidal rivers and creeks and are flushed daily by tides. Mangrove communities in these settings are enhanced by freshwater inputs and terrestrial nutrient inputs (Odum et al. 1985).

Scrub or dwarf forests are found in flat coastal fringes of southern Florida and the Florida Keys (Odum et al. 1985). Low nutrient levels and lack of freshwater inflows are limiting factors for growth of these forests (Mitsch and Gosselink 1993).

Overwash forests appear as islands that are washed over by tides regularly. The dominant mangrove species here are red mangroves with a prop root system that reduces wave energy (Mitsch and Gosselink 1993).

Basin forests are found in inland depressions or basins usually behind fringe mangroves and in drainage depressions where water moves slowly or is stagnant (Mitsch and Gosselink 1993). In most cases, these wetlands are dominated by white and black mangroves (Mitsch and Gosselink 1993).

Hammock forests are depressions that exist on slightly elevated ground due to peat accumulation (Odum et al. 1985).

Invasives

Plants not native to the area outgrow mangrove communities in some cases. These rapid and aggressive species are referred to as invasives. Invasives generally multiply due to changes in the environment, such as an increase or decrease in salinity caused by human inputs or channel diversions. Once established, they can become problematic for local plant and animal species. Invasives can limit the growth of mangroves by outcompeting them for light, water, and nutrients and become dominant to species that were not normally found in these areas. It is important to monitor the presence and distribution of invasives during mangrove restoration projects. If environmental conditions are suitable for invasives to establish themselves, they can disturb the success of mangrove restoration by overtaking and outgrowing mangrove habitats.

A well-known invasive species found amongst mangroves is the Brazilian pepper (*Schinus terebinthifolius*) (Renda and Rodgers 1995;

Ferriter 1997) (Figure 9). In the United States, this species is found primarily in Florida. Seeds are distributed by birds and other mobile animals. These plants grow rapidly and contain an extensive root system. Able to grow in wet or dry soil, they are also salt tolerant (Ferriter 1997).

Sampling and Monitoring Methods

During restoration, plant growth, species composition, and abundance are measured and monitored over time. Monitoring methods used to measure these community characteristics include point-sampling, quadrats, and remote sensing techniques, involving aerial or satellite photography.

Point sampling - Point sampling methods evaluate mangrove presence or absence at specific points. In this method, a point frame, about a meter long is marked at regular intervals to represent sampling points. Mangrove density, growth rate, presence/absence, and other characteristics are evaluated by performing point sampling to estimate stand basal area without direct measurement of plot or tree diameter; measuring tree diameter and density and; conducting quadrat sampling in selected areas randomly along a transect line (Cintron-Molero and Novelli 1984).

Quadrats - Quadrats can be used to obtain a representative sample of the mangrove study site. They are square or circular sampling areas of various sizes (e.g., 1 ft^2 to 100 ft^2). Quadrats are commonly used to estimate cover, density, and biomass placed randomly in an area. They can also be permanently fixed for repeated sampling. Data obtained using quadrats can determine species density, total stand density, and species dominance (Cintron-Molero and Novelli 1984; Zhenji et al. 2003).

Remote sensing - Remote sensing techniques such as color-infrared (CIR) aerial photography

Figure 9. Brazilian peppers with red berries. Photo courtesy of NOAA Restoration Center, Mike Devany and Marine Resource Council. Publication of the National Oceanic & Atmospheric Administration (NOAA), NOAA Central Library. http://www.photo-lib.noaa.gov/habrest/r0008713.htm

and Landsat TM imagery can also be used to assess mangroves before, during, and after the restoration effort (Everitt and Judd 1989; Lin et al. 1994). These methods can provide baseline information on the mangrove community, such as its distribution and abundance, as well as identify coastal activities in adjacent areas that may potentially affect restoration success. Remote sensing allows the processing and interpretation of images and other related data taken from aircrafts and satellites. Color-infrared (CIR) aerial photography and Landsat TM image-CCT digital image magnetic tape can also be used to measure the distribution of mangroves over time (Everitt and Judd 1989; Lin et al. 1994), then map and record distribution, and determine whether their communities have increased or decreased since the restoration effort. Time-series data from aerial photography is an effective way to monitor and assess mangroves response to environmental change, including hydrological variations and sea level rise (Lucas et al. 2002). Aerial photographs can be used to evaluate mangrove coverage (Figure

10) using the digital imagery or height maps that show a two-dimensional view of a three-dimensional area (Everitt et al. 1991; Lucas et al. 2002; Sulong et al. 2002). Groundtruthing[4] of aerial photos can be done using low-level helicopter flights and field observations. Although the average layperson is not expected to perform these methods, data can be obtained from scientists and agencies that perform these methods to determine whether the designated area is suitable for restoration.

Airborne color-infrared (CIR) video imagery - Infrared aerial imagery can also be used to map different species of mangroves (Everitt et al. 1991). Along the Texas coast, video imagery was used to identify populations of black mangrove and their distribution and abundance. When using video imagery, black mangroves generally show a distinct red color on the CIR video imagery that distinguishes it from other types of vegetation, soil, and water. Using this method can therefore be useful for assessing mangrove density and distribution (Everitt et al. 1991).

PHYSICAL

Turbidity/Light Availability

It is recommended that light availability be measured during restoration because of its direct affect on mangrove establishment, growth, and survival. While adult mangroves are generally considered shade intolerant, tolerance to shade varies among species. Some researchers have observed the response of black mangroves, yellow mangroves (*Cerios tagal*), and red mangroves to light availability at different life stages (Twilley et al. 1999). Results showed that adult mangroves continued to grow successfully while the seedlings under the canopy received significantly less sunlight and therefore did not grow productively. Seedling survival and growth for the three mangrove species mentioned was minimal. Light, therefore,

Figure 10. Aerial photograph of mangrove shoreline. Photo courtesy of Ben Mieremet, NOAA Office of Sustainable Development. Publication of the National Oceanic & Atmospheric Administration (NOAA), NOAA Central Library. http://www.photolib.noaa.gov/mvey/mvey0291.htm

proved in this study to be a limiting factor for seedling survival and growth and an essential factor for continuing growth of adult mangroves (Twilley et al. 1999). In another study, adult mangrove tolerance to shading was observed. Results showed that growth in black and white mangroves was much slower when exposed to lower light levels, whereas red mangroves were able to thrive in areas where light is limited compared to the other two mangrove species studied (McKee 1993b). Light is therefore an important parameter to measure because it is needed for seed germination, which is the first step of many successful restoration efforts and because minimum light may affect the growth of adult mangroves.

Sampling and Monitoring Methods

Turbidity - A turbidimeter measures turbidity in water by passing a beam of light through the water sample and measuring the quantity of light scattered by particulate matter (Clesceri 1998; Rogers et al. 2001). The turbidity measurements are then shown in Nephelometer Turbidity Units (NTU'S) on the display (Rogers et al. 2001).

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[4] The use of a ground survey to verify the results of an aerial survey.

Transparency - Depth of light penetration (water clarity) can also be measured using a secchi disc. It is a painted disc attached to a cord. To use properly, the disc should be lowered slowly from the water's surface. As light travels through the water column, some of it is absorbed by phytoplankton and dissolved material. The remaining light reflects off the secchi disc and travels back through the water column where more is absorbed. The deeper the disc is lowered in the water, the harder it is to see the disc as increasing amounts of light are absorbed. The depth in which the disc can no longer be seen is the depth at which all the light is being absorbed as it passes down and back up through the water column. Usually three measurements from the same point are recorded. The practitioner can then determine the depth in which light penetrates through the water column by multiplying 1.7 times the mean of these three measurements.

Light penetration - Photosynthetically active radiation (PAR) and ultraviolet radiation (UV) can be measured to determine light availability reaching mangroves. PAR refers to the amount of sunlight that reaches plants/algae and is used for photosynthesis (wavelengths of 380 to 710 nm) (Rogers et al. 2001). A Li-Cor quantum meter with an underwater spherical sensor can be used to measure PAR. This instrument is lowered into the water using a cable and the PAR is recorded. (Rogers et al. 2001).

A Martek transmissometer can be used to measure the amount of light that is not scattered or absorbed within a 1-meter path of water, providing measurements that are not affected by angle of the sun or time of day (Bishop 1999; Rogers et al. 2001).

Sediment

Since sediment composition supports many animals and plants in mangrove communities and affects their abundance and distribution, it is important to assess sediment characteristics before and during restoration. Prior to restoration efforts, grain size and nutrients levels in sediment can be measured to determine whether the potential restoration site is suitable for restoration to be conducted. A large variation in sediment grain size or, significantly high nutrient levels within the restoration site may also be an indication of materials deposited or runoff during coastal development near the restoration project that may influence mangrove progress towards restoration goals.

Grain size

Most mangrove soils are generally formed when sediment derived from coasts, river banks, or from upland areas accumulates after being transported down rivers and creeks. Mangrove topsoil is generally sandy (coarse-grained), or contains clay (fine-grained) whereas the soil beneath the surface is a mixture of silt and clay (known as mud) (Lugo and Snedaker 1974). Sediment grain size as well as other environmental factors (e.g., salinity, inundation, nutrient availability, or pollution level) can influence floral and faunal species presence and distribution (Lugo and Snedaker 1974). Macrobenthos for example, is commonly found in fine and medium sandy grains within mangrove habitats. Transportation of coarser or finer grains during tidal movements into these habitats may result in migration of various species of macrobenthos to more suitable areas (Gueirrero et al. 1996).

Organic content and depositional environment

Mangrove soil consisting of a mixture of silt and clay is typically saturated and has minimal aeration which decreases with depth. Organic matter, deposited over time in mangrove soils, plays a significant role in supporting plants and animals by providing nutrients to support growth. The sediment acts as a sink, storing large amounts of organic matter that decomposes at

a very slow rate. The source of organic matter found in mangrove sediments may have derived from plant (e.g., litterfall, wood litter) and animal detritus, bacteria or plankton as well as from sewage and agricultural run-off. These nutrients (i.e. organic matter) are then cycled throughout mangrove environments to be used by plants and animals (See "Nutrient Cycling"). Because the finer grained saturated soil has minute spaces between particles, no oxygen can infiltrate deeper than the top few horizons and therefore creates anoxic conditions (Lugo and Snedaker 1974). Such anoxic sediment conditions enable bacteria to survive in lower soil depths in which they produce hydrogen sulphide. The distinct scent of hydrogen sulphide reaching the soil surface is similar to that of rotten eggs.

Studies have been conducted by some researchers on mangrove development in relation to environmental factors, such as nutrient levels taking into consideration salinity. A gap dynamic model (FORMAN) was used to provide data on long-term mangrove recolonization along soil salinity gradients and nutrient resources for three Caribbean mangrove species (Chen and Twilley 1998). Results showed that (1) white mangrove dominated in fertile soils with low salinity during early stages of recovery but declined over time, (2) red mangrove dominated in low nutrient availability and low salinity areas only and, (3) black mangrove dominated at higher salinity levels and fertile soils.

Sediments also have the ability to retain pollutants that enter mangrove communities and affect mangrove growth (Wasserman et al. 2000). Chemicals such as mercury, for example, may seep into mangrove sediments from industrial waste and contribute significantly to mangrove degradation (Wasserman et al. 2000).

Sampling and Monitoring Methods

Many types of corer devices can be used to collect underwater sediment samples. They are generally operated by driving the instrument (e.g., collection tube or corer) into the bottom sediment, and extracting the sediment sample. Two examples of these sampling devices include hand cores and piston core samplers (Miller and Bingham 1987; US Army Corps of Engineers 1996; Radtke 1997). Hand cores are hollow tubes that are pushed into sediment to obtain samples (Radtke 1997). The core is driven into the sediment to the point marked on the instrument and then removed and stored. Once retrieved, the cores can be divided so that separate samples from different depths of sediment can be distinguished (Radtke 1997). Piston corers can use both gravity and hydrostatic pressure. As the instrument penetrates the sediments, an internal piston remains at the level of the sediment/water interface to prevent sediment compression (US Army Corps of Engineers 1996).

Sediment can be analyzed by measuring grain size and organic content. Grain size distribution can be determined by using a sieving analysis method (Pope and Ward 1998). Sediment samples can be analyzed by dried sieving or wet sieving the collected samples. A sediment sample is weighed and then passed through sieves with mesh sizes that decrease in diameter (Pope and Ward 1998). The sieves are then vibrated for a set time period allowing sediment grain to be separated based on its size. The weight of the sediment that remains on the sieve is measured, and the total sediment sample is determined (Pope and Ward 1998).

Organic matter in sediment includes Total Nitrogen (TN) and Total Organic Carbon (TOC). Total Nitrogen can be determined by drying and grinding the sediments into fine particles and then weighing a small sample (<1g) into a digestion tube (Bremner 1965a; Snedaker and Snedaker 1984). Organic N is then converted to ammonium-nitrogen using any of the Kjeldahl reagents (acid and a catalyst). Following ammonium-nitrogen conversion, steam distillation of the converted sample can

be done to estimate the amount of ammonium-nitrogen (Snedaker and Snedaker 1984). Auto analyzers such as the carbon, hydrogen, and nitrogen (CHN) analyzer can also be used to rapidly determine nitrogen content for large numbers of sediment samples (Prochnow et al. 2001; Tung and Tanner 2003).

Total organic carbon can be measured using wet oxidation methods (Walkley 1974; Snedaker and Snedaker 1984; Tam and Yao 1998) such as the Walkley-Black method (Walkey 1947). Some researchers have modified the Walkley-Black wet oxidation method to determine total organic carbon (TOC) in mangrove and marine sediments (Tam and Yao 1998). A study was performed using a modified Walkley-Black method by assimilating sediment samples with acid dichromate in a domestic microwave for 7 minutes. The TOC results were comparable to the results of the traditional Walkley-Black method. The modified method used in this experiment proved in this study to be simpler, easy to duplicate, accurate, and precise compared to the traditional Walkley-Black method (Tam and Yao 1998).

Organic matter content in a sediment sample can be determined by measuring weight loss in subsamples after drying then sequential heating/burning at selected temperatures (550 °C and 950 °C) in a muffle furnace (Heiri et al. 2001). If the samples are from freshwater areas, the majority of "loss-of-ignition" (LOI) will stem from organic carbon oxidizing to CO_2. The results are typically accurate to 1-2% for sediment with over 10% organic matter. In high clay sediments, water may be lost during the burn resulting in additional error. If the samples are from saline environments, additional steps must be taken to subtract weight loss due to oxidation of sulfur to SO_2. Some researchers demonstrated that LOI is an accurate and cost and labor-efficient technique for determination of organic carbon and organic matter in sediment samples (Schulte and Hopkins 1996).

Topography/Bathymetry

Topography is an important structural feature in mangrove habitats, as any change in topography/bathymetry may alter ecological communities. When less inundated mangrove zones suddenly experience frequent inundation due to diking or flooding, animal and plant composition and abundance may be altered (Chow and Booth 1994). Mangroves are commonly found in mudflats as well as sloping areas with specific elevations. In most instances, relatively level or flat mangrove depressions are not as productive due to stagnant, standing water. Therefore, restoration practitioners must measure and monitor slope changes and record sources responsible for the change (Crewz and Lewis 1991).

The three zones in mangrove communities are seaward, middle, and landward. Along the Florida coastline and the Gulf Coast, distinct mangroves zonation patterns are seen in relation to elevation. In many areas, red mangroves grow closer to the shoreline (seaward) where the area is relatively flat. Black mangroves are found in areas that are more elevated and grow closer inland (Jimenez and Lugo 1985). White mangroves grow at relatively higher land elevations (landward) compared to red and black mangroves (Elias 1980).

Regardless of geographic location, mangroves tend to grow in specific topographic/bathymetric zones. Some researchers assessed the variation in structure and composition of mangroves from the eastern and western areas of the Sunderbans Islands in India in relation to topography (Matilal and Mukherjee 1989). Black mangroves and river mangroves (*Aegiceras* sp.), for example, were abundant in low-lying areas towards western and eastern areas of Sunderbans respectively while scrub tree *(Excoecaria)* and yellow mangrove (*Ceriops decandra*) were present throughout the entire forest. This shows that mangroves

species prefer specific elevations and may not be as productive in altered elevations.

Sampling and Monitoring Methods

A Landsat TM satellite may be used to map mangroves and assess mangrove topography. Accuracy of the map can be enhanced with a Geographic Information System (GIS) using ecological information pertaining to mangroves found in tidally inundated areas. This system can be used to subdivide the mangrove areas identified by satellite data image processing on their proximity to water, ground elevation (above and below 10 m above mean sea level), and distance from water (greater than 2 m and less than 2 km). Each zone can then be verified using 1:50,000 aerial photographs allowing mangrove zones to be identified (Long and Skewes 1996).

Analyzing topographical maps and temporal, remotely sensed satellite data is an effective method to monitor and quantify mangrove cover (Samant 2002). Digital image processing of Remote Sensing Satellite in a Personal Area Network (PAN)[5] along with LandSat4 TM multispectral data can identify whether mangrove cover increased or decreased over time and what topographical changes occurred (Samant 2002). This method can provide a good representation of mangrove distribution and topography changes that may occur over time.

HYDROLOGICAL

Tides/Hydroperiods

Hydroperiod refers to the pattern of water level fluctuations in a habitat. Mangroves can be regularly or irregularly exposed to tides or irregularly inundated for long periods of time (Mitsch and Gosselink 1993). Tidal patterns, measured by the hydroperiod, influence mangrove productivity and are responsible for circulating nutrients, aerating the soil, and stabilizing soil salinity. To ensure healthy growth, mangrove

areas require consistent tidal flushing to prevent sediment and nutrient build up and prevent standing water that may eventually drown some species intolerant of constant inundation. A mangrove restoration project may not succeed if there are no channels or tidal creeks to allow consistent tidal flushing. Tidal flushing also distributes propagules along the coast allowing mangroves to become established in new areas. If a natural supply of propagules is available, this process can more cheaply and efficiently restore mangroves than transplanting seedlings by hand. In addition, monitoring tidal patterns during restoration is important because tides influence both propagule distribution (affecting mangrove establishment and development) and nutrient availability needed for mangrove growth.

Tidal influence may also influence seedling establishment and survival, surface salinity, and pH in mangroves. These parameters were monitored in three red mangrove forests at Hutchinson Island, Florida (Lahmann 1989). The study sites included:

- A managed impounded mangrove forest that was artificially flooded with seawater during the summer for mosquito-control purposes

- An unmanaged (not artificially flooded) mangrove impoundment, and

- A fringe mangrove forest exposed to daily tidal exchange

The net aboveground primary production was estimated to be 4,335 g m^{-2} yr^{-1}, 4,016 g m^{-2} yr^{-1}, and 5,384 g m^{-2} yr^{-1} respectively. This shows that daily tidal fluctuations played a significant role in distributing nutrients throughout the mangrove habitat and contributed to higher levels of primary productivity.

Sampling and Monitoring Methods

Hydroperiods can be assessed by measuring flood frequency and duration (Mitsch and

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[5] Allows devices to work together and share information and services.

Gosselink 1993). Flood frequency is the average number of times that a wetland is flooded within a specific time period. Flood duration refers to the amount of time that the wetland is actually covered with water. Water level recorders measure flood frequency and duration (Twilley and Rivera-Monroy 2003). These recorders are pressure-based[6] and can be applied for short- or long-term use, to create a hydrograph that shows changes in water levels over time.

Tide gauges are mechanical devices that are usually placed on piers or pilings and may be used for recording water level (IOC 1985; Emery 1991; Giardina et al. 2000). The tide gauge consists of a data logger that reads and stores data from different sensors and a modem that communicates with a computer (IOC 1985). The water level sensor should be even from a stable bench mark and calibrated at regular intervals to ensure accurate water level measurements.

Acoustic Doppler flow meters can also be used to evaluate tidal flow by measuring velocity and particles moving through the water. When using this instrument, the acoustic signals are transmitted, then reflected from particles, and collected by a receiver. The signals that were received are then analyzed for frequency changes. The mean value of the frequency changes can directly relate to the average velocity of the particles moving through the water (Gross and DeAngelis 1999).

Water Sources

Sources of water entering mangrove forests can influence the success or failure of a restoration project. Diversion channels may reduce the amount of nutrients entering the mangrove restoration site or may not readily distribute mangrove propagules. Also, upstream land uses may result in run-off containing agricultural or industrial chemicals that enter mangrove habitats. One of the potentially detrimental impacts of these chemicals on mangrove forests

is increased algal growth that may out-compete other plant species that live there. Industrial chemicals that runoff into the water column may contaminate fish and bird food supplies affecting their health and survival. Other water sources that enter mangroves include groundwater and surface water. By evaluating mangrove water sources and the potential impacts that can result from these inputs, restoration practitioners can design a more effective restoration plan that includes parameters that can be used to monitor and measure water quality. Discussed below are examples of two water sources and how they may affect mangrove communities.

Groundwater

The relationship between hydrology and nutrient dynamics in a mangrove-fringed creek influenced by groundwater was studied (Kitheka et al. 1999). Nutrient concentrations increased in the creek during flood tide, about 2-3 hours prior to high waters. Nitrite and nitrate ($NO_2^- + NO_3^-$) concentrations, however, declined significantly during ebb tide. Groundwater outflow added to the nutrients flux in the dry seasons help to maintain mangrove productivity.

Surface Water

Surface waters may also affect mangrove biological communities (Elster and Polania 2000). In some cases, mangrove communities experience higher than normal salinities from industrial run-off, causing a decrease in animals and plants. Introducing surface freshwater to mangrove communities may help to restore them (Elster and Polania 2000). Some mangrove forests in Colombia recovered after obstructed channels were re-opened to introduce additional freshwater into degraded mangrove areas (Elster and Polania 2000). Studies in mangrove growth changes at different sites showed regrowth of degraded mangrove forests with black mangroves, white mangroves, and red mangroves occurred once freshwater inflow was restored (Figure 11). Restoring the hydrology will not always lead to reestablishment or

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[6] Sensitive to the amount of water over them.

enhancement of mangrove productivity. This will only occur when hydrology is one of the main factors preventing successful mangrove growth (Elster and Polania 2000).

CHEMICAL

Salinity

Mangroves often grow in areas that receive large amounts of freshwater yet can still tolerate saline waters, giving them a competitive advantage over salt-intolerant species (Mitsch and Gosselink 1993). Some mangrove species such as red and black mangroves have the ability to extract salt from seawater by osmosis. Although mangroves regulate the amount of salt entering their roots, their salinity levels are still significantly higher than most other plants. White mangroves have salt glands in their leaves that allow them to secrete a significant amount of salt that enters the plant through the roots. Although mangroves are salt-tolerant plants, hypersaline conditions (greater than 35 ppt) can affect productivity (Hogarth 1999). In south Florida Everglades, red mangrove seedlings when exposed to hypersaline conditions (greater than 45 ppt), caused structural changes of

mangrove terminal buds, preventing them from developing (Koch and Snedaker 1997).

Sampling and Monitoring Methods

Commercial instruments, such as a refractometer may be used to measure salinity. It is a hand-held instrument that measures the bending of light between dissolved salts as it passes through seawater (Rogers et al. 2001). Salinity is measured on a calibrated refractometer by placing a few drops of the seawater sample under the transparent slide, and then reading the salinity measurement through the eye-piece (Rogers et al. 2001).

A hydrometer can measure salinity by comparing the weight of the seawater sample to fresh water (Rogers et al. 2001). The glass hydrometer is placed into a cylinder containing the seawater sample and measured for buoyancy. The number on the hydrometer scale at the water surface and the temperature of the water are then identified, and salinity is determined by comparing these values with those on specific tables that are associated with hydrometers (Rogers et al. 2001).

Figure 11. Mangrove seedlings planted by Forestry Department and Village Government without restoring hydrology experienced 30% mortality in the first week. After two months 10% of seedlings remain, all the same species. Photo courtesy of the Mangrove Action Project, Port Angeles, WA. http://www.earthisland.org/map/mngim_indonesia.htm

FUNCTIONAL CHARACTERISTICS OF MANGROVES

Mangrove forests provide a habitat that shelters many plant and animal species adapted to tidal influences and changes in temperature and salinity. Mangroves:

Biological
- Habitat created by plants (i.e., mangroves)

Chemical
- Supports nutrient cycling

Physical
- Modifies water quality
- Reduces shoreline erosion

By performing these functions, mangroves are able to support important local and commercial fisheries as well as maintain plant and animal diversity and abundance. If the health of the mangrove is degraded in any way, it can affect the functioning of this habitat, such as affecting its ability to provide food for animals (e.g., fish, crustaceans, etc.) or provide healthy nursery and breeding grounds for some species. Understanding how this habitat functions is important when attempting to restore it. In addition, monitoring should be performed before, during, and after restoration efforts to determine whether the habitat is suitable for restoration and to track the success of the restoration project.

This section concentrates on the biological, physical, and chemical functions performed by mangroves. Also provided are some methods that can be used to sample, measure, and monitor functional parameters affiliated with each characteristic described. For example, mangroves are used as breeding, feeding, and nursery grounds by many species of animals. These functions are measured by counting the number of animals that use the habitat for these reasons. Also recorded is the type of species that utilize the habitat. Not all functional characteristics described, however, are expected to be measured. The additional information provided simply illustrates the importance of the habitat. The examples provided are just a few of the many methods that can be used. Sources cited throughout the text and in the Appendices of this chapter can be used to guide readers to additional information.

BIOLOGICAL

Habitat Created by Plants (i.e., Mangroves)

Mangroves support high biomass production, high biodiversity, and a complex trophic structure.

Some fauna occupying this habitat include:

Oysters (*Crassostrea* spp.)
Invertebrates, such as (*Chthamalus* spp.) and tunicates (*Cnemidocarpa* spp.)
Crustaceans, such as crabs (*Aratus pisonii*)
Fishes, such as
  Mangrove snapper (*Lutjanus griseus*) (Figure 12)
  Spotted seatrout (*Cynoscion nebulosus*)
  Sheep-head minnows (*Cyprinodon variegates*) (Figure 13)
  Goldspotted killifish (*Floridichthys carpio*)
  Rainwater killifish (*Lucania parva*)
  Sailfin molly *(Poecilia latipinna*), and
  Exotic Mayan cichlid (*Cichlasoma urophthalmus*)
Reptiles including alligators (*Alligator mississippiensis*) and crocodiles (*Crocodylus acutus*), and
Birds such as blue herons (*Egretta caerulea*) (Figure 14) and pelicans (Pelecanidae) (Figure 15)

Figure 12. Mangrove snapper found amongst mangrove roots. Photo courtesy of NOAA Center for Coastal Monitoring and Assessment.

Figure 13. Species of minnows found near mangrove roots. Photo courtesy of NOAA Center for Coastal Monitoring and Assessment.

Vegetative species commonly found in and around mangroves include:

Tropical hammocks
Buttonwood
Invasive Brazilian peppers
Longleaf pine trees (*Pinus palustris*)
Sea oats (*Uniola paniculata*
Seagrass (*Thalassia testidinum*) (Figure 16)
Saltwort (*Batis maritima*)

Epiphytic algae (e.g., diatoms and blue-green algae), and
Phytoplankton

Fish species, shorebirds, wading birds, and seabirds commonly use mangrove habitats as feeding grounds, nursery grounds, or for shelter amongst mangrove roots (Butler et al. 1997; Lorenz et al. 1997).
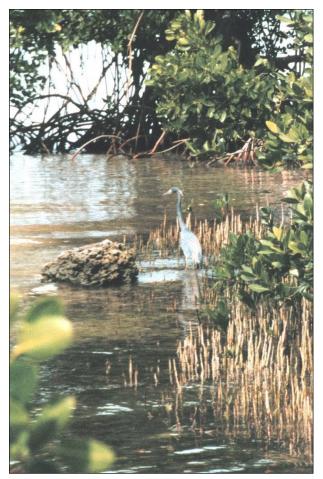
Figure 14. Blue Heron along a mangrove shoreline. Photo courtesy of Alison G. Delaplaine. Publication of the National Oceanic & Atmospheric Administration (NOAA), NOAA Central Library. http://www.photolib.noaa.gov/coastline/line1141.htm

Figure 15. Pelicans perching on red mangroves in Florida. Photo courtesy Larry Richardson, Florida Wildlife Service District. http://southeast.fws.gov/august04/Pelicans.jpg

Figure 16. Seagrass found near mangrove roots and is used by organisms such as fishes and crustaceans as breeding grounds. Photo courtesy of NOAA Center for Coastal Monitoring Assessment.

Provides breeding grounds

Mangroves provide breeding grounds for fish, reptiles, resident and migratory birds, and mammals. Species are protected by the canopy and roots where they can consume nutrients, such as decayed leaves, algae, fruits, and seeds found in the water column or along the shore. Birds such as the white-crowned pigeon[7] (*Columba leucocephala)* typically nests higher up on mangrove trees to produce young successfully (Bancroft et al. 1991; Bancroft 1996). Nesting takes place on isolated mangrove islands where there are few predators. These birds build their nest using mangrove branches from ground level to high in the canopy (Wiley and Wiley 1979).

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[7] Typically found in the Florida Keys, the Bahamas, and in the Antilles, the Cayman Islands, and islands of the western Caribbean Sea.

The eggs are then laid in the nest and protected by branches and incubated with brooding duties by both the male and female parents. Of course, there are many other species of birds that breed in mangrove communities as well.

Some researchers have also studied breeding patterns of crustaceans to determine how frequently they breed in mangrove forests. In mangrove areas in South Africa, continuous breeding of burrowing crabs (*Macrophthalmus grandidieri*) occurred in the low shore while seasonal breeding took place on the middle to high shore (mangrove crabs, fiddler crabs, *Uca* and marsh crab, *Sesarma* spp. - Emmerson 1994). Higher up the intertidal zone, breeding season was more defined (*Sesarma meinerti*). Crab species, such as marsh crab (*Sesarma catenata*), began breeding in August, while the high intertidal species of brackish water crab (*Uca lactea annulipes)* was in March. Overall the breeding activity varies over time and within mangrove zones. During and following restoration activities, practitioners should conduct seasonal surveys on crab and bird breeding patterns to show whether breeding activities have changed over the years. Such changes can be an indication of whether the habitat is functioning successfully.

Provides feeding grounds

Many species use mangroves as feeding grounds. Mangrove snapper and spotted seatrout feed on decayed leaves, fruits, and seeds floating in the water column and on bottom sediments, as well as benthic organisms. Red drum (*Sciaenops ocellatus*) and spotted seatrout feeding behavior was observed in a restored, mangrove-rimmed impoundment in Tampa Bay, Florida, and a nearby, natural mangrove site (Llanso et al. 1998). Smaller red drum species fed mainly on amphipods, mysids, Nereid, and thick fleshy polychaetes, while large (200-590 mm) red drum preyed on polychaetes xanthid crabs shrimp, and small fishes. Spotted seatrout, however, fed primarily on mysids, shrimp, and small fishes

(Llanso et al. 1998). In general, both species fed primarily on the abundance of amphipods and detritus.

In most mangrove communities, insects such as beetles, and some crab species feed on mangrove propagules. Birds as well as other organisms feed on insects that occupy mangrove communities (Hogarth 1999). Some invertebrates such as prawns, polychaetes, amphipods, gastropods, and crabs that occupy mangroves are also food sources for commercial fishes (Oluoch 1993). Snails and crabs play a significant role in breaking down organic material, such as leaf litter so that materials can be utilized by other organisms (Smith 1987). Macrophytes and algae in or near the water are also a good food source for fish, isopods, and amphipods.

During low tide, mudflats provide good feeding grounds for wintering, foraging, and wading birds (Nitsure and Pejaver 2002). Bird species that feed in mangrove habitats include:

> Herons *(Ardeidae)*
> Roseate spoonbill *(Ajaja ajaja)*
> Sandpipers *(Scolopacidae)*
> Plovers *(Charadriidae)*
> Brown pelican (*Pelecanus occidentalis*)

They feed by diving down, snatching fish from the water, and then flying to nearby land to consume the fish (Nitsure and Pejaver 2002). They also feed on decayed fruits and their seeds as well as on benthic organisms, such as insects, shrimps, and polychaetes.

Provides nursery grounds and refuge from predation

Mangroves also provide nursery grounds for commercial and recreational fish species, birds, crustaceans, and other wildlife (Tobias 2001). The examples provided here are by no means a complete listing of the all of the types of organisms that use mangroves as nursery grounds. Fish and crustaceans for example spawn in different areas along the roots of the trees (Thayer and

Sheridan 1999) where nutrients are readily available. Because the roots and aboveground features have such strong structures, they protect juveniles from predation. Birds also use the canopy of the mangrove trees to shelter their juveniles. The advantage to using canopy areas as nursery grounds is that it makes it difficult for some predators to reach juveniles.

Sampling and Monitoring Methods

Birds

Birds can be monitored using aerial surveys and direct counts along coastal and estuarine habitats. Aerial surveys can inventory migrant shorebirds (Erwin et al. 1991) and monitor wintering populations (Morrison and Ross 1989). Surveys are also used to estimate relative abundance of migratory and wintering populations and for assessing population trends of migratory shorebirds. Direct counts can also be used to estimate the number of shorebirds or bird density. Data collected can be recorded using tape recorders and then transferred onto data sheets. In some cases, video cameras and aerial photography are used along with aerial surveys (Dolbeer et al. 1997). In addition to providing precise estimates of birds, aerial photography creates visual records of the structure of mangrove habitats.

Counting birds within fixed-width transects is a method used for determining bird types and densities (Noske 1995). This can be done by first selecting a study site and placing transects within that specified area. The practitioner then records the species type and the number of each individual species along each transect. This helps the practitioner to determine species of birds, their diversity, and abundance within a habitat.

Fish

Beach seines - Beach seines are nets that can be used to temporarily capture fish for the purpose of identification and counting. The nets contain a bunt (bag or lose netting) and long wings that are extended. Ropes are used for towing the seine along the shore to sample fish. The seine prevents fish from escaping from the area enclosed by the net. Seines as well as traps can be used for quantitative sampling of species composition and abundance (Tobias 2001). Methods used to estimate fish species abundance include random stratified sampling and fixed station sampling (Trippel 2001). Stratified sampling involves selecting a representative sample of the habitat within a larger area. Fixed station involves continuous sampling at permanent points. Using these standardized procedures helps maintain sampling precision.

Gill nets - Gill nets can be used to sample fish in mangrove habitats for small-scale projects. They consist of smaller panels of netting connected together with bridles so that the net can be extended to any size (Adkins and Bourgeois 1982). The nets contain a floatline consisting of air filled structures that keeps one end of the net afloat and a leadline containing weights that keeps the bottom of the net below the water surface. Once the net is deployed, fish swim into the invisible mesh nets where they are trapped. Samplers then remove fish from the net for identification, count the number of each species, record length and width of each individual, and note the condition of each (Adkins and Bourgeois 1982). Other measurements or samples may be taken at that time as well.

Fish species can also be monitored using point counts and transect surveys (Hodgson et al. 2004). Point-count surveys are performed by a SCUBA diver observing and recording fish species within a targeted area, for a set time interval. Transect surveys are performed by a diver who swims a certain distance and monitors fish by counting them on either side of the transect. Divers and researchers then estimate abundance by calculating the number of fish per sample area.

Crustaceans

The diversity, abundance, and biomass of macrofauna, such as molluscs and crustaceans within a mangrove forest can be sampled using quadrats at each study site. A quadrat is a square or rectangular object that is used as a sample unit and can vary in size. The size used will depend on the size of the sample area. Species abundance is estimated by calculating the mean of two to three samples collected from each study area. To keep track of organisms counted in quadrats, some organisms, if not too small, can be marked as they are counted and then recorded on a data sheet. Quadrats can be fixed so that a sample area can be measured repeatedly. Crustaceans can also be sampled using a 3 x 15 minute timed hand catch per site. This method allows practitioners to effectively assess macrofauna species in selected areas throughout mangrove habitats at certain time periods (MacIntosh et al. 2002; Ashton et al. 2003). Transects are also used to collect observational data by recording or collecting species samples along a line within a habitat (Dittman 2000). Quadrats and transects can be used along with photography to record species type and density in each study site.

Crustaceans such as fiddler crabs (*Uca annulipes)* can be evaluated for abundance by visual counts using binoculars and by counting burrows to estimate population density (Macia 2001). Binocular and direct burrow count methods can be used along with quadrats to quantify crustacean densities. In some cases burrow counts may give better density estimates than binocular counts (Macia 2001). Selection of methods, however, will vary between projects. Both methods can help determine whether the habitat is functioning effectively by supporting a large number of crustaceans.

Counting the number of individual crabs escaping from burrows is also used to assess crab densities in mangroves (Nobbs and McGuinness 1999). Counts made can be assessed using quadrats, recording distance of observer, and

selecting a suitable quadrat size and recovery time. For species such as fiddler crabs, activity can be recorded during the first 10 min of the 30 min period. Long-term sampling, however, is suggested for efficiently determining crab abundance (Nobbs and McGuinness 1999).

PHYSICAL

Modifies Water Quality

Mangrove roots and branches can deflect wave energy and improve water quality by filtering sediments and nutrients and assimilating pollutants present in the water column. This provides a healthier environment for plants and animals. By performing this filtering process, mangroves also protect other coastal habitats, such as seagrasses, oyster beds, and coral reefs, from high sedimentation and pollutants. When monitoring water quality in mangroves, there are basic performance measures that can be evaluated:

- Total and/or dissolved inorganic forms of nitrogen and phosphorus can be used as measures of the mangrove's ability to remove or process nutrients

- Light penetration through the water column can be used to evaluate mangrove's ability to reduce sediment load, and

- Dissolved oxygen can be used to indicate the water body's recovery after being affected by pollutants (Twilley and Rivera-Monroy 2002)

Reduces Shoreline Erosion

Mangrove trees act as a protective barrier for coastlines against erosion, storm damage, and wave action by absorbing the energy of the waves in and amongst the variety of their root structures. The extensive root systems of mangrove trees reduce current velocities and increase sedimentation rates and retention, thus reducing coastal erosion (Augustinus 1995).

Mangrove root systems and leaves also help stabilize land elevation by sediment accretion (Carlton 1974). Erosion along the coastline may be more frequent because mangrove vegetation is eliminated for development or deteriorated due to long-term human impacts such as industrial run-off (Mazda et al. 2002). If reduction of mangrove forests along coastlines increases, so does erosion along the shoreline.

CHEMICAL

Nutrient Cycling

Mangroves are one of the most productive intertidal ecosystems with gross primary production[8] estimated at 3-24 g C/m^{-2} day^{-1}, and net production[9] estimated at 1-12 g C/m^{-2} day^{-1} (Lugo and Snedaker 1974; Lugo et al. 1976). These plants provide nutrients for many species and accumulate nutrients such as nitrogen and phosphorus, but also heavy metals and trace elements that are deposited into estuarine waters from land. Mangrove roots, invertebrates, epiphytic algae, and other microorganisms, take up and sequester nutrients over time. The nutrient cycling process within mangrove communities begins when plants use carbon present from carbon dioxide in the atmosphere for photosynthesis. Organisms such as fish, birds, invertebrates, and other consumers then feed on living biomass and decomposed materials such as leaves (litterfall), stems, twigs, prop roots, flower parts, and decayed fruits (Odum 1971; Feller et al. 1999). Plant material is then converted to organic material by organisms such as macro-invertebrates (e.g., insects and snails) and further reduced microbially to dissolved organic carbon. When benthic organisms in mangrove communities (such as polychaetes and shrimp) die, their remains seep into the soil contributing to the organic content and are utilized as nutrients (primarily nitrate) by understory vegetation and

mangroves (Mitsch and Gosselink 1995; Feller et al. 1999) (carbon and nitrogen assessments in soil is discussed under "Sediment: Sampling and Monitoring Methods"). Tidal movements also assist in distributing decomposed material to areas within mangrove communities where other organisms can consume it.

Sampling and Monitoring Methods

Litterfall, containing both vegetative and reproductive features, represent a portion of the net primary production that can be accumulated on the floor, remineralized through decomposition or exported (Lugo and Snedaker 1974). One common method used to determine litter production is litter traps (Lugo and Snedaker 1974). Litter traps may be square, circular or triangular and consists of a wooden frame with a plastic screen bottom. The bottom of the trap is covered with flexible, plastic coated, fibre-glass window screening with a mesh size of approximately 1x1 mm. Attached at each corner of the trap are wooded stakes which secures the trap in the ground. Litter collected in each trap is placed in bags, labeled according to location, dried (dried at about 70 °C for 3 days), sorted into compartments and then weighed. The total amount of litter in each trap as well as in each compartment is used to determine the total amount of litter produced and phenological[10] patterns (Lugo and Snedaker 1974).

In addition to litterfall, net primary production can also be determined by biomass change of the plants and photosynthetic production. Above ground-biomass estimates (which include stem growth) can be made using allometric techniques[11] (Gwado 1993; Ross et al. 2001). A light attenuation approach can also be used to determine net canopy photosynthetic production (Bunt et al. 1979; Cox and Allen 1999). See references for a detailed description on each method mentioned.

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[8] Refers to the total energy accumulated.
[9] The difference between material accumulated and material available for the food web.
[10] Change in plant growth and development over time during growth stages.
[11] Method used to assess the relative growth of various parts of plants or organisms.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The matrices provided below present the structural and functional parameters for restoration monitoring. Parameters selected for monitoring were based on information obtained from mangrove restoration, ecological monitoring-related literature, and from consulting with experts in the field of mangrove restoration. Parameters with closed circle (●) denote a parameter that, at a minimum, should be considered in monitoring restoration performance. Variables with an open circle (○) may also be measured depending on specific restoration goals. This matrix is not exhaustive but represents those elements commonly used in restoration monitoring of mangrove communities.

Parameters to Monitor the Structural Characteristics of Mangroves

Parameters to Monitor	Biological	Habitat created by plants	Physical	Sediment grain size	Topography / Bathymetry	Hydrological	Current velocity	Tides / Hydroperiod	Water sources	Wave energy	Chemical	Nutrient concentrations	pH, salinity, toxics, redox, DO[12]
Geographical													
Acreage of habitat types		●											
Biological													
Plants													
Species, composition, and % cover of:													
Algae		○											
Herbaceous vascular		○											
Woody		●											
Epiphytes		○											
Canopy aerial extent and structure		○											
Plant height		○											
Seedling survival		○											
Stem density		○											
Hydrological													
Physical													
Temperature							○	○					
Upstream land use								●					
Water level fluctuation over time							●	●					
Chemical													
Nitrogen and phosphorus												○	
Salinity (in tidal areas)							●	●					●
Toxics													○
Soil/Sediment													
Physical													
Geomorphology (slope, basin cross section)					●		●						
Organic content				○			○						
Percent sand, silt, and clay				○									
Sedimentation rate and quality				○	○		○	○					

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[12] Dissolved oxygen.

Parameters to Monitor the Functional Characteristics of Mangroves

Parameters to Monitor	Functional Characteristics — Biological										Physical						Chemical
	Contributes primary production	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Supports nutrient cycling
Geographical																	
Acreage of habitat types	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Biological																	
Plants																	
Species, composition, and % cover of:																	
Algae	○		○	○	○	○	○	○	○	○	○	○			○	○	○
Herbaceous vascular	○		○	○	○	○	○	○	○	○	○	○	○		○	○	○
Woody	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Epiphytes	○		○	○				○	○	○	○						○
Invasives			○	○	○			○		○							
Interspersion of habitat types				○	○	○		○	○	○	○	○	○	○			○
Litter fall	○					○		○	○		○	○					○
Plant health (herbivory damage, disease[13])				○													
Rate of canopy closure	○	○							○				○				
Seedling survival[9]	○	○	○	○	○	○	○	○		○					○		
Woody debris (root masses, stumps, logs)		○													○	○	
Biological																	
Animals																	
Species, composition, and abundance of:																	
Amphibians			○	○	○	○		○	○	○							
Birds			●	●	●	●		●	●	●							
Fish			○	○	○	○		○	○	○							

Parameters to Monitor the Functional Characteristics of Mangroves (cont.)

Parameters to Monitor	Functional Characteristics — Biological										Functional Characteristics — Physical						Chemical
	Contributes primary production	Produces wood	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Affects transport of suspended/dissolved material	Alters turbidity	Modifies water temperature	Provides temporary floodwater storage	Reduces erosion potential	Reduces wave energy	Supports nutrient cycling
Biological (cont.)																	
Animals																	
Species, composition, and abundance of:																	
Invertebrates			○	○	○	○		○	○	○							
Mammals			○	○	○	○		○	○	○							
Reptiles			○	○	○	○		○	○	○							
Hydrological																	
Physical																	
Fetch	○										○	○			○	○	
PAR	○								○		○	○					
Secchi disc depth									○		○	○					
Trash				○							○	○					
Water column current velocity											○	○			○		
Water level fluctuation over time			●	●	●	●					●	●		●	●		●
Chemical																	
Nitrogen and phosphorus	○		○	○					○	○		○					○
Toxics			○	○	○												
Soil/Sediment																	
Physical																	
Geomorphology (slope, basin cross section)			●	●	●	○	○			○	○	○	○	○	○		
Sediment grain size (OM[14]/sand/silt/clay/gravel/cobble)						○	○		○		○	○			○	○	○

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[14] Organic matter.

Acknowledgments

The authors would like to thank Roy R. Lewis III., Robert Twilley, Victor Rivera-Monroy, Alfredo Quarto, and graduate students of the Center for Ecology and Environmental Technology, University of Louisiana at Lafayette for reviewing and commenting on various versions of this chapter.

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Twilley, R. R., and V. H. Rivera-Monroy. 2003. Developing Performance Criteria Using Simulation Models of Mangrove Ecosystem Restoration: A Case Study of the Florida Coastal Everglades. Center for Ecology and Environmental Technology, University of Louisiana at Lafayette, Lafayette, LA. rtwilley@louisiana.edu.

Twilley, R. R. 1998. Mangrove wetlands, pp. 445-473. In Messina, M.G. and W.H. Conner (eds.), Southern Forested Wetlands Ecology and Management. Lewis Publishers, Boca Raton, FL.

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coastal environment. *Environmental Technology* 21:297-305.

Yañez-Arancibia, A., A. L. Lara-Dominguez and J. W. Day, Jr. 1993. Interactions between mangrove and seagrass habitats mediated by estuarine nekton assemblages: Coupling of primary and secondary production. *Hydrobiologia* 264:1-12.

Zhenji, L., Z. Wenjiao, Y. Zhiwei, L. Yiming and L. Peng. 2003. Vegetation of mangroves: spatial and temporal pattern of its dominant populations in Futian National Nature Reserve. *Marine Science Bulletin* 5:40-53.

APPENDIX I: MANGROVES - ANNOTATED BIBLIOGRAPHY

This annotated bibliography contains summaries of restoration case studies and basic ecological literature. It is designed to provide restoration practitioners with examples of previous restoration projects as well as overviews of papers from the ecological literature that offer more detail than that covered in the associated chapter. Entries are presented from both peer reviewed and grey literature. They were selected through extensive literature and Internet searches as well as input from reviewers. They are not, however, a complete listing of all of the available literature. Entries are arranged alphabetically by author. Wherever possible, web addresses or other contact information has been included in the reference to assist readers in more easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract*' or '*Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapter.

Akil, J. M. and N. S. Jiddawi. 2001. A preliminary observation of the flora and fauna of Jozani-Pete mangrove creek, Zanzibar, Tanzania. *Marine Science Development in Tanzania and Eastern Africa* 1:343-357.

Author Abstract. In this study researchers observed and documented the living organisms present in the Jozani-Pete mangrove creek, by first surveying the area from December 1997 and March 1998 (northeast monsoon). One section of the creek has become a popular tourist-visiting site with some constructed features such as the presence of a boardwalk initiated in 1997. No prior studies on this site had been conducted and therefore the present survey aimed at establishing baseline information on the biodiversity of the flora and fauna present in the area, which could be, used for comparison in future studies. See publication for more information on techniques used for monitoring. There were twenty 10 m^2 randomly selected quadrats observed both at low and high tides. The benthic organisms observed in transects were collected and classified up to species level. Based on the results, there were five mangrove species and nine other major groups of plants comprising 65 species present. There were also nineteen families of animals comprising 76 species identified, which included mainly fishes, crustaceans and molluscs. Exploitation of the mangrove plants, which cover 75% of the total area, was also recorded from various parts especially along the lower rim of the creek. Researchers suggested that an in-depth study and monitoring of the flora and fauna of the area is important as well as educating the community on ways to utilize resources to ensure the sustainability of the mangroves with the associated organisms.

Bosire, J. O. 1999. Floral and faunal secondary succession in a restored mangrove system in Kenya, 89 pp. In Bosire, J. O. (ed.), Floral and faunal secondary succession in a restored mangrove system in Kenya. Ecological Marine Management thesis, Vrije Universiteit Brussel, Brussels, Belgium.

Author Abstract. The environmental variables, vegetation structure and floral and faunal recruitment of *Rhizophora mucronata, Sonneratia alba,* and *Avicennia marina* reforested plots (5-yrs, 7-yrs, and 5-yrs old respectively) in Kenya were investigated. Emphasis was made on the recruitment of 'new' mangrove species into the monospecific reforested stands, invasion of the stands by macrobenthos (crabs and soil-infauna) and the shift in environmental gradients following reforestation. The pre-restoration conditions of the reforested area were assessed by a naked

system (denuded or open) while a natural system (relatively undisturbed) was used to evaluate the expected post-recovery conditions of the reforested area. See publication for additional information on techniques used. The results for this study were as follows: 1) salinity and temperature were lower (p<0.05), while organic matter content was higher (p<0.05) in the areas with mangrove cover; 2) the naked systems were more sandy, and areas with mangrove cover had higher proportions of clay and silt; 3) there was no floral recruitment into the naked areas, but the reforested stands of *S. alba, A. marina,* and *R. mucronata* had 5,400 recruits ha-1, 4,000 recruits ha-1 and 700 recruits ha-1 respectively; 4) macrobenthic density and soil-infauna taxa richness were higher in the reforested systems (p<0.05) compared to the naked systems.

Chen, R. and R. R. Twilley. 1998. A gap dynamic model of mangrove forest development along gradients of soil salinity and nutrient resources. *Journal of Ecology* 86:37-51.

Author Abstract. A gap dynamic model (FORMAN) was developed as a first synthesis of available data for three Caribbean mangrove species into an individual-based model that simulates the long-term dynamics of mangrove forest development. Field observations at three sites along the Shark River estuary were compared with simulation results, assuming development following Hurricane Donna in 1960. Total basal area simulated for each site was within plus or minus 10% of that observed, although species-specific basal area predictions were less accurate. A decrease in nutrient availability from marine to mesohaline sites modelled the reduced basal area of *Avicennia germinans* and *Laguncularia racemosa*. However, at the lower nutrient site a 83% reduction in maximum sapling recruitment of both *A. germinans* and *L. racemosa* was required to fit field results. Increased basal area of *A. germinans* and *L. racemosa* limited the development of *Rhizophora mangle* at higher nutrient downstream sites, apparently due to competition for light resources. Both observed and simulated results indicated that *R. mangle* had higher frequencies in the smaller size classes at all three sites, compared to a bell-shaped size-class distribution of *L. racemosa*, particularly at the higher nutrient sites. Succession was projected for the next 500 years at a site in the lower estuary. Long-term forest dynamics were sensitive to species-specific maximum sapling recruitment rates. In the absence of large-scale disturbance, initial dominance by *L. racemosa* was predicted to be replaced eventually by *A. germinans*, even when maximum sapling recruitment rate of *A. germinans* was set at half of *L. racemosa* and *R. mangle*. Response curves for each species along gradients of soil nutrient resource and salinity illustrated their relative competitive balance over time (up to 300 years). *Laguncularia racemosa* dominated in fertile soils with low salinity at early stages of recovery, but its abundance decreased over time while *A. germinans* increased. The dominance of *R. mangle* was limited to regions with low nutrient availability and low salinity. *Avicennia germinans* dominated at higher salinities, where the effect of nutrient availability was overwhelmed by the tolerance of individual species to salt stress.

Davis, S. E. III, D. L. Childers, J. W. Day, Jr., D. T. Rudnick and F. H. Sklar. 2001. Wetland-water column exchanges of carbon, nitrogen, and phosphorous in a southern Everglades dwarf mangrove. *Estuaries* 24:610-622.

Author Abstract. We used enclosures to quantify wetland-water column nutrient exchanges in a dwarf red mangrove (*Rhizophora mangle* L.) system near Taylor River, an important hydraulic linkage between the southern Everglades and eastern Florida Bay, Florida, USA. Circular enclosures were constructed around small (2.5-4 m diam) mangrove islands (n = 3) and sampled quarterly from August 1996 to May

1998 to quantify net exchanges of carbon, nitrogen, and phosphorus. The dwarf mangrove wetland was a net nitrifying environment, with consistent uptake of ammonium (6.6-31.4 mu mol m^{-2} h^{-1}) and release of nitrite + nitrate (7.1-139.5 mu mol m^{-2} h^{-1}) to the water column. Significant flux of soluble reactive phosphorus was rarely detected in this nutrient-poor, P-limited environment. We did observe recurrent uptake of total phosphorus and nitrogen (2.1-8.3 and 98-502 mu mol m^{-2} h^{-1}, respectively), as well as dissolved organic carbon (1.8-6.9 mu mol m^{-2} h^{-1}) from the water column. Total organic carbon flux shifted unexplainably from uptake, during Year 1, to export, during Year 2. The use of unvegetated (control) enclosures during the second year allowed us to distinguish the influence of mangrove vegetation from soil-water column processes on these fluxes. Nutrient fluxes in control chambers typically paralleled the direction (uptake or release) of mangrove enclosure fluxes, but not the magnitude. In several instances, nutrient fluxes were more than twofold greater in the absence of mangroves, suggesting an influence of the vegetation on wetland-water column processes. Our findings characterize wetland nutrient exchanges in a mangrove forest type that has received such little attention in the past, and serve as baseline data for a system undergoing hydrologic restoration.

Day, S., W. J. Streever and J. J. Watts. 1999. An experimental assessment of slag as a substrate for mangrove rehabilitation. *Restoration Ecology* 7:139-144.

Author Abstract. Rehabilitation of mangrove habitat has become common practice, but few studies have investigated the growth and survival of mangrove on artificial substrates. Managers attempting to plant mangrove in sites containing artificial substrates must remove substrates or risk poor performance of rehabilitation efforts. This study compared propagule retention, early survival, growth, flowering success, and nutrient concentrations of *Avicennia marina* (grey mangrove) grown on sand, naturally occurring substrate, and rock blast furnace slag over two growing seasons at an experimental site near Newcastle, Australia. Nutrient concentrations of experimental plants were also compared to those of naturally occurring plants. Experimental results showed significant differences (p < 0.05) in short-term survival, growth over the two growing seasons, and carbon and nitrogen concentrations between plants grown on different substrates. Comparison of plants grown in slag and plants from reference sites suggests, however, that slag does not lead to anomalies in nutrient concentrations of young mangroves. Although the results identified some differences between plants grown on river sand, naturally occurring substrate, and slag substrate, the absence of consistent differences suggests that mangroves planted in slag are under no greater risk of future failure than mangroves planted in naturally occurring substrate.

Elster, C. 2000. Reasons for reforestation success and failure with three mangrove species in Colombia. *Forest Ecology and Management* 131:201-214.

Author Abstract. As a result of human-induced changes in the hydrology of the lagoon system of the Cienaga Grande de Santa Marta, Caribbean coast of Colombia, 60% of the originally 51 000 ha of mangrove forest have died. The main reasons for this mass mortality were hypersalinization, increased sedimentation rates, and lowering of the water level. During the 1989-1998 period, efforts were made to reestablish the destroyed areas. The rehabilitation measures started with monitoring and the reopening of obstructed channels to introduce more freshwater into the area. Between 1994 and 1997, the first reforestation experiments with propagules, seedlings, and saplings were carried out at two sites with reestablished hydrology. The

experiments with *Avicennia germinans, Laguncularia racemosa*, and *Rhizophora mangle* showed that the reforestation success depends mainly on site selection and preparation. Generally, all species developed best at sites with low salinities and a water level near the soil surface. Highest mortalities were found in set propagules and seedlings of *L. racemosa* and *A. germinans,* whereas the best survival rates occurred in R. mangle propagules as well as in *L. racemosa* saplings. Growth rates, especially of *L. racemosa*, were extremely high when the ecological factors were favorable, and flowering set in early.

Erftemeijer, P. L. A. and R. Nukul. 1999. Involving local communities in coastal wetland restoration: A case study of mangrove rehabilitation efforts in southern Thailand, 28 pp. In Limpsaichol, P., A. Edwards, and B. E. Brown (eds.), Proceedings of an International Workshop on the Rehabilitation of Degraded Coastal Systems, 19-24 January 1998. Phuket Marine Biological Center.

Author Abstract. Intensive logging and conversion for shrimp aquaculture have caused a rapid loss of large areas of productive mangrove forests and other coastal wetlands in Thailand over the past three decades. Although detailed information on the techniques for mangrove reforestation is available, and the government as well as private sector appear to be willing to invest huge amounts of money into mangrove rehabilitation, the success of these efforts are often limited, in terms of time and area. Besides technical and financial constraints, the success of coastal restoration efforts may be hampered by issues relating to land ownership, land-use conflicts, and the lack of follow-up and attention after initial planting. An increasing number of projects and initiatives have emerged throughout Thailand that are involving local communities in the planning and implementation of mangrove reforestation efforts. Recognition of the user-rights of these communities in sharing the benefits of the rehabilitation (e.g., extraction of non-timber products) through the granting of community forest status, can provide an important incentive for their active involvement in replanting and follow-up, to ensure high rates of survival and success. This paper examines three case studies of community participation in mangrove rehabilitation in Trang, Songkhla and Pattani provinces, Southern Thailand. The three examples differ in approach and in stage of progress (timescale), ranging from a low-key long-term grassroots initiatives with NGO support emphasising community, capacity building for self-reliance, to ICZM style projects with major technical, academic and financial inputs from outside. All three examples clearly demonstrate the benefits of community participation in mangrove rehabilitation. The building of confidence and understanding within the community may be time-consuming and hamper immediately measurable progress in replanting. This investment, however, will pay off in the long term because it builds a strong sense of ownership and commitment within the community and therefore ensures the long-term sustainability of the rehabilitation. By combining the rehabilitation with environmental awareness building and socio-economic development activities, this approach will not only ensure successful reforestation of mangroves but also contribute to the prevention of further degradation.

Erftemeijer, P. L. A. 2002. A new technique for rapid assessment of mangrove degradation: A case study of shrimp farm encroachment in Thailand. *Trees* 16:204-208 University of Dar es Salaam, Department of Botany, Dar es Salaam, Tanzania. Contact information: Paul Erftemijer, epaul@science.udsm.ac.tz.

Author Abstract. A new technique (Aerial Video Manta Analysis) was developed for the rapid

assessment of mangrove degradation due to logging and conversion for shrimp aquaculture. Video recordings were made of mangroves along the Andaman Sea coastline, Thailand, during a 2-day aerial survey (16–17 September 1997) in a small Cessna 206 aircraft at an altitude of 800–1,000 feet and flying speed of 100 knots/h. The video recordings were analyzed following a modified Manta-Tow technique, originally developed for coral reef surveys. The percentage cover of good mangrove stands, mangrove areas degraded by logging, and mangrove areas converted into shrimp farms, was estimated for each consecutive 1-min interval of video playing time. The analysis revealed that 9.9–2.2% of the mangroves along the Andaman coastline were severely degraded by logging and 23.3–1.9% had been converted for shrimp farming (a total of 3,255–370 shrimp ponds were counted). The encroachment for shrimp farming was most severe (34%) in Krabi Province, while Phang-nga Province had the most (75%) good mangroves. These results demonstrate that illegal development of new shrimp farms along the Andaman Sea coast has been substantial in recent years. The results obtained by four independent observers using this new method were remarkably close (SD ± 25% of mean). The new method allowed cheap, rapid and accurate evaluation of the status of the mangrove resources over a long stretch of coastline within a time-span of a few days. Aerial Video Manta Analysis is a valuable tool to support coastal conservation and management efforts.

Field, C. D. 1998. Rehabilitation of mangrove ecosystems: An overview. *Marine Pollution Bulletin* 37:383-392.

This paper discusses considerations to be made when monitoring and rehabilitating mangrove ecosystems. These include site selection for mangrove planting and planting approaches. For example mangroves develop best on low energy muddy shorelines with suitable intertidal zone, and an abundant supply of fine grain sediment. The soil should be stable and non-eroding and of sufficient depth to support planting. Topography of the site should slope gently to permit proper drainage. The condition of adjacent sites should also be considered. If areas adjacent to site are degraded it may influence mangrove restoration success.

Planting methods include natural regeneration and artificial regeneration. Natural regeneration involves the use of natural occurring propagules or seeds. The advantages of natural regeneration is that it is cheap to establish, less labor required, less soil disturbance and seedlings establish vigorously and the mangrove forest is likely to resemble the original mangrove vegetation. When using this technique there should be adequate supply of seeds or propagules. Artificial regeneration includes the planting of seeds, propagules or seedlings in areas where there is not sufficient natural regeneration. This includes transplanting seedlings to a new location or to collect ripe seeds or propagules and planting them directly into the site. Seedlings may also be raised, or small trees, under nursery conditions and then to transplant them to the field.

Finn, M., P. Kangas and W. Adey. 1999. Mangrove ecosystem development in Biosphere 2. *Ecological Engineering* 13:173-178.

Ecological Engineering Abstract. Southwest Florida mangrove forest vegetation has been divided into a mesocosm within Biosphere 2. There were similar characteristics for dense stands of mangroves with Florida mangrove forests developed from the small seedlings and saplings initially installed in the mesocosm. The mangrove overstory was evaluated by leaf area index which ranged from 2.16 to 4.02 m^2/m^2. The mangrove understory decrease was monitored as the mangrove overstory developed. The Biosphere 2 mesocosm was compared with a similarly planted mesocosm at the Smithsonian

Institution in Washington, DC. Based on these studies mesocosms performance was used to evaluate existing theories on natural mangrove forest species composition. See publication for additional information on techniques used.

Haller, R. 1993. Experimental results of planting of mangrove trees in the Bamburi cement quarries and fisheries experiments. 33 pp. National workshop for improved management and conservation of the Kenyan mangroves.

Author Abstract. The paper describes the rehabilitation of the strip-mined quarries for cement manufacture by the Bamburi Portland Cement Company (BPCC) in Mombasa, Kenya. The management of BPCC felt that it was their moral obligations to rehabilitate quarries. They embarked on a rehabilitation project in 1971. The rehabilitation project has proved very successful and part of the initial trials is now enclosed in the Bamburi Quarry Nature Trial. The species which grew best were *Casuarina equisetifolia* and *Conocarpus lancifolius*. The leaf fall from these trees was broken down to form a layer of organic matter on top of the limestone. This nutrient rich layer allowed plants which could not survive the same harsh conditions as the first tree species to grow. Birds, animals, insects, and fish were introduced and this in turn attracted more wildlife; a new ecosystem was created. At the very beginning of the quarry rehabilitation project, the need to test alternatives to casuarinas, which may survive and thrive under conditions of rising ground water salinities was considered important. About fifteen years into the quarry reafforestation, it became obvious that the Casuarinas planted in swampy areas, where excavation had gone a bit too low, were much more prone to windfall. Casuarinas planted in areas where excavation had stopped at the usual level of 50 cm above ground water, were not as easily uprooted by strong winds and also produced more massive stems. For better economic use of the lower-flying, swampy sites, an alternative to Casuarinas had to be found and new trials with mangroves started. *Rhizophora mucronata, Heritiera littoralis, Xylocarpus granatum* and *Avicennia marina* were planted at different sites in the rehabilitation scheme. Later, *Bruquiera qymnorrhiza* and *Ceriops tagal* were also included. All these species were propagated from seeds. *Heritiera* and *Xylocarpus* seeds had been collected as drift seeds, *Rhizophora, Bruquiera, Ceriops* and *Avicennia* seeds were collected directly from seeding mother trees. The conclusions that can be drawn are: at least *Rhizophora mucronata, Heritiera littoralis, Xylocarpus granatum*, and *Avicennia marina* can grow and thrive in water of minimum salinities (1–3 ppt), with minimum tidal fluctuations (plus or minus 30 cm during spring tides, almost nil during neap tides). *Heritiera littoralis, Xylocarpus granatum*, and *Avicennia marina* grow well in shade, while *Rhizophora mucronata* seems to perform better with more light available. The four mangrove species tested all rooted and thrived on rocky underground. *Rhizophora mucronata* seems to respond favorably to high nutrient availability.

Imbert, D., A. Rousteau and S. Pierre. 2000. Ecology of mangrove growth and recovery in the Lesser Antilles: State of knowledge and basis for restoration projects. *Restoration Ecology* 8:230-236.

Author Abstract. Whereas the increasing knowledge on tropical coastal wetlands highlights the ecological and economical importance of such ecosystems, anthropogenic activities within the coastal zone have caused substantial, irreversible losses of mangrove areas in the Lesser Antilles during the last decades. Such a paradox gives strength to compensatory policy efforts toward mangrove restoration. We review the available knowledge on the ecology of mangrove growth and recovery in the Lesser Antilles as a contribution to possible restoration

projects in such islands. Distribution of species follows a general pattern of seaward/landward zonation according to their respective tolerance to flooding and to pore-water salinity. An experimental study of seedling growth following simulated oil spill has documented the tolerance of *Rhizophora mangle* and *Avicennia germinans* seedlings to oil concentration in soils and the effects of natural biotic and abiotic factors on seedlings growth and survival. Monitoring mangrove recovery following hurricane Hugo has given information on growth patterns, from seedling to sapling stages, according to species and site conditions. Forest recovery was mostly due to pre-established seedlings. For the large *Rhizophora* propagules, buoyancy appears to be a quite inefficient way of dispersal far inland from the seashore or riversides. Causes of recovery failure are discussed. From these results we attempt to answer the questions when, where, how to plant mangroves, and what species to use.

Kairo, J. G. 1993. Mangrove re-afforestation: A Kenyan experience. National Workshop For Improved Management and Conservation of the Kenyan Mangroves. Kenya Marine and Fisheries Research Institute, Mombasa, Kenya. 25 pp. Contact information: jkairo@recoscix.org.

Author Abstract. The mangrove areas in Kenya are estimated to cover about 50,000 to 60,000 ha. However, non-sustainable utilization, over-exploitation of resources and conversion to other land uses principally for fish ponds, salt pans, human settlement and infrastructure development are drastically removing this resource base at an alarming rate. This has unfavorable effect on fisheries, fuel, coastal erosion, etc. Conservation alone is not enough. Mangrove afforestation will be essential for the areas where forests have decreased or been destroyed. In addition, the paper discusses part of a pilot study for practical afforestation. A reafforestation project to rehabilitate degraded areas, restock denuded mudflats, and transform disturbed forests into uniform stands of higher productivity was launched in October 1991 at Gazi Bay. Basically three artificial regeneration techniques were employed: use of seeds, use of saplings (less than 1.0 m height), use of 'small trees' (up to 2.0 m height). More than 7000 saplings and 'small trees' of *Sonneratia alba* (Milana), *Avicennia marina* (Mchu), *Xylocarpus granatum* (Mkomaafi), *Heritiera littolalis* (Msikundazi), *Rhizophora mucronata* (Mkoko), *Ceriops tagal* (Mkandaa) and *Bruguiera gymnorrhiza* (Muia) were transplanted or planted at different heights along inter-tidal complex, growth was monitored at 14 days, 1 month, or 2 month intervals depending on the experiment. The rate of the planted propagule and saplings after 12 months varied between 10% in areas heavily exposed to wave action and more than 85% in well protected areas. *Sonnertia alba* growing at the most seaward plots, showed the highest growth rate among all the transplanted saplings with a maximum diameter increment of 1.9 cm and height increment of 1.18 m. Besides field and nursery experiments, air-layering of Milana, Mkomafi and *Lumnitzera racemosa* (kikandaa) is also mentioned as promising technique of providing stock plants for transplanting without removing mangroves from source area. Rooting success was highest in Milana followed by Kikanda and Mkomafi. The paper presents a strong argument that research should increasingly be developed to study disturbed and manipulated mangrove areas, if positive contributions to management practices are to be achieved.

Kairo, J. G. 1995. Mangrove Restoration and Management: Monitoring of the Artificial Regeneration Plots in Gazi Bay, Kenya. 116 pp. Master thesis Botany, University of Nairobi, Nairobi, Kenya. http://www.specola.unifi.it/mangroves/human/restoration1.htm

A development project entitled "*Community Participatory Forestry for the Rehabilitation of Degraded Mangrove Forests at Gazi bay, Kenya*" was implemented in 1993/95 to monitor mangrove rehabilitation success. Assessment were made of the Gazi plantation site, to see whether it was suitable for re-afforestation with *Rhizophora mucronata, Ceriops tagal, Bruguiera gymnorrhiza, Avicennia marina, Xylocarpus granatum, Heritiera littoralis* and *Sonneratia alba.* Seeds and propagules were collected between March and June, corresponding with lengthy rain period. Mature propagules were collected from the parent tree or litter under trees. Local people were trained to identify and select mature and healthy propagules. After field collection, propagules were packed in plastic bags and transported to the planting site. Quality control was performed to remove damaged, infected or malformed propagules. Propagules were planted similarly to the natural distribution or zonation pattern. The propagules were then stored for two to three days under natural shed, and kept wet by sprinkling water throughout the period. Species of *Rhizophora* and *Sonneratia* that can withstand high inundation and deep mud were planted near to the water. Others including *Ceriops* and *Avicennia* were planted further off from the creeks.

Data was collected on growth performance and survival/mortality fortnightly, monthly, two, four, six, eight, nine and twelve months after planting/transplanting. Results show that the survival of the transplanted saplings or propagules was significantly better (80 - 100% of 70,000 after twenty-four months) than for sapling ($< 5\%$ after twelve months); planting of nursery saplings gave a higher survival rate (80-100% after twenty-four months) compared to transplanting of wildings; for most observed parameters, *C. tagal* showed the lowest growth rates of less than 0.5 m/year; and the maximum growth rate of 1.18 m/year was achieved by *Sonneratia alba* that were planted on the seaward denuded areas.

Kaly, U. L., G. Eugelink and A. I. Robertson. 1997. Soil conditions in damaged North Queensland mangroves. *Estuaries* 20:291-300.

Author Abstract. Selected physical, chemical, and biological characteristics of soils in mechanically damaged North Queensland mangrove forests were examined and compared with undisturbed controls. The soils in nine of the selected forests were tested in a factorial sampling program that was designed to examine effects of severity of mechanical damage to forests (severely damaged: trees removed and soils disrupted by bulldozing; versus damaged: trees felled no bulldozing; versus controls: trees and soils undisturbed); soil depth; forests (10s-100s km apart); and sites within forests (10s-100s m apart). The characteristics examined were soil compaction, grain size, pH, percent by weight of total carbon, nitrogen, phosphorus, potassium, sulfur, and iron and the density of crab burrows. Three of the ten variables examined included: total N, total P, and density of crab holes, decreased with mechanical damage to forests. Researchers stated that the loss of potentially-limiting nutrients and of an important bioturbator at severely damaged sites suggests the need for further experimental investigation of soil characteristics in relation to natural regeneration and efforts of mangrove restoration. See publication for additional information.

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

Author Abstract. This paper discusses mangrove restoration as a potential tool for the management and conservation of coastal ecosystems. Researchers examined the connections between mangroves and fisheries, and outlined an ecosystem approach to evaluate

mangrove restoration initiatives. The goal of mangrove restoration projects is said to actively promote a return to the natural assemblage structure and function (within the bounds of natural variation) that is self-sustaining. This goal requires: (i) identifying the natural state, including key organisms in maintaining the physical substratum, community structure and food webs maintaining fish stocks; (ii) developing biotechnology for restoring key organisms; and (iii) assessing the long-term success of the project. See publication for more information on techniques used for successful mangrove restoration efforts.

Kent, C. P. S. and J. Lin. 1999. A comparison of Riley encased methodology and traditional techniques for planting red mangroves (*Rhizophora mangle*). *Mangroves and Salt Marshes* 3:215-225.

Author Abstract. The effectiveness of encasement and traditional techniques for planting red mangroves (*Rhizophora mangle*) in moderate to high wave energy environments was evaluated. The three encasement types were half-length PVC pipes, full-length PVC pipes, and bamboo pipes. In August, 1997, plantings were conducted at two locations in the Indian River Lagoon, Florida: Sebastian and Rocky Point. Furthermore, plantings were also conducted in November 1997 using full-length encasements and conventional planting. See publication for additional information on techniques used. Results showed that seedlings planted within full-length PVC encasements had the highest survivorship and growth because of their protection from waves and currents. Failure of seedlings within bamboo encasements appeared to be caused by low light exposure. Based on observations made for the two locations, there was a significantly greater growth at the Sebastian location than at the Rocky Point location for the planting conducted in November, but not for those planted in August. However, there was no significant difference observed in seedling survival between those planted in August and November. There was however a significantly greater growth in mangroves planted in August.

Kitheka, J. U., E. N. Okemwa and J. M. Kazungu (eds.). 1999. Monitoring of nutrient levels, turbidity and sediment transport at Port-Reitz Creek (Kilindini Creek) in Kenya. Kenya Marine and Fisheries Research Institute, Mombasa, Kenya, Contact information: jkitheka@recoscix.com.

Author Abstract. A significant gradient in the spatial distribution of suspended particulate matter (SPM) concentrations, salinity and temperature exists at Port-Reitz. Stations located in the upper backwater zones fringing the mangroves experience high SPM concentrations as well as lowest and highest salinities in wet and dry respectively. SPM concentration varied from 0.019 g/l to 0.900 g/l with a mean of 0.162 g/l in the upper zones and ranged from 0.010 g/l to 0.08 g/l with a mean of 0.033 g/l in central zone. In the lower region, the concentration varied from 0.011 g/l to 0.073 g/l with a mean SPM concentration of 0.022 g/l. There is no significant re-suspension of the bottom sediments when currents are < 0.4 m/s, but for currents > 0.5 m/s tidal driven re-suspension occurs and SPM concentrations rises from almost 0.0 g/l to 0.17 g/l. At higher current speeds > 0.5 m/s, the SPM concentration increases dramatically from 0.2 g/l to 1.0 g/l. Greater re-suspension occur during flood tide despite the ebb tide dominance. A comprehensive turbidity-monitoring program is recommended. As for nutrients distribution, the highest nutrients levels were recorded during the wet season signifying the relative importance of riverine contribution into Kilindini Creek. Nitrate-nitrogen concentrations during wet season were as high as $22 \pm$ M at the upper backwater zone and decreased gradually to 4 mu M at the open water end. During dry period

nitrate concentrations oscillated around $2 \pm$ M throughout the creek system. As for phosphates concentration varied between $2.5 \pm$ M and $0.8 \pm$ M at the two extreme stations during the wet seasons. Dry season concentrations were mostly $< 0.6 \pm$ M. The highest ammonium concentration (ca. $14 \pm$ M) was observed at station 1 immediately after the heavy rains of May/June. However, during this period, all the other two stations recorded almost nil concentrations.

seagrass beds adjacent to fringe mangroves have higher nutrient availability. Based on the results for sediment, water column nutrient patterns and tissue stoichiometry, seagrasses in close proximity to the mangrove fringe had the greatest nutrient availability among sites. The fringe mangrove zone supported high algal production rates, contributing to total ecosystem primary production. Based on the results, mangroves are valuable resources for other species within this ecosystem.

Koch, M. S. and C. J. Madden. 2001. Patterns of primary production and nutrient availability in a Bahamas lagoon with fringing mangroves. *Marine Ecology Progress Series* 219:109-119.

Author Abstract. This study investigated the role of submerged autotrophs in the productivity of tropical lagoons and the potential influence of fringing mangroves by characterizing primary productivity and nutrient patterns in a Bahamas lagoon. At 5 sites along a transect from a fringe mangrove to tidal channel site, sediment, water, and seagrass tissue nutrient content was determined. The mangrove prop-root algal community was measured along the transect using benthic chambers, while phytoplankton and epiphyte production was quantified via light-dark bottle experiments. See publication for more details of techniques used in this study. Results showed that sediment phosphorus and nitrogen decreased from 0.24 ± 0.04 to 0.09 ± 0.01 and 3.23 ± 1.01 to 1.44 ± 0.69 mg/g dry wt from the mangrove to seagrass channel site. The nutrient levels in the water column and plant tissues followed a similar spatial trend. Leaf, root, and rhizome C:P molar ratios at the mangrove site (641 ± 30, 1208 ± 385, and 595 ± 71) were low compared to those of the lagoon (761 ± 70, 2220 ± 463, and 1137 ± 289) and channel (953 ± 42, 2177 ± 349, and 2003 ± 293) sites. These results indicated that

Lewis, R. R. III. 2003. Ecological engineering for successful management and restoration of mangrove forests. Lewis Environmental Services, Inc., Salt Springs, FL. Contact information: LESrrl3@aol.com.

Author Abstract. Great potential exists to reverse the loss of mangrove forests worldwide through the application of basic principles of ecological restoration using ecological engineering approaches, including careful cost evaluations prior to design and construction. Previous documented attempts to restore mangroves, where successful, have largely concentrated on creation of plantations of mangroves consisting of just a few species, and targeted for harvesting as wood products, or temporarily used to collect eroded soil and raise intertidal areas to usable terrestrial agricultural uses. Documented are the importance of assessing the existing hydrology of the natural extent of mangrove systems, and applying this knowledge to achieve successful and cost-effective mangrove forest ecological restoration. Previous research has documented the general principle that mangrove forests worldwide exist largely in raised and sloped platform above mean sea level, and inundated at approximately 30% or less of the time by tidal waters. More frequent flooding causes stress and death of these tree species. Prevention of such damage requires application of the same understanding of mangrove hydrology.

Lin, R., M. Lin, J. Teng, and W. Zhangi. 1994. Remote sensing survey and mapping of mangroves in western Xiamen Harbour. *Journal of Oceanography in Taiwan Strait/ Taiwan Haixia* 13:297-302.

Author Abstract. Satellite remote sensing technology was used for monitoring mangrove distribution in the western Xiamen Harbor because it provides a macroscopic, rapid and precise method for mangrove resources monitoring and plotting, and it is cheaper and less time-consuming than traditional artificial investigation methods. The Landsat TM image-CCT digital image magnetic tape has been used as an information source. With a computer the image pre- processing is carried out, such as image geometric rectification, pseudo- color composition, linear scale image enhancement and histogram linearization. Then, supervised classification was used to class the mangroves according to training samples, and the mangrove area was calculated by integrating the pixels. Finally, researchers made a 1:50,000 pseudo-color composed imagery map of mangrove distribution. The mangrove area calculated by computer was 73.89 hectares, compared to the 75.40 hectares by grid statistic method, the accuracy being 98%. This research provides a convenient method and model for mangrove resources dynamic monitoring and remote sensing survey and mapping.

McKee, K. L. and P. L. Faulkner. 2000. Restoration of biogeochemical function in mangrove forests. *Restoration Ecology* 8:247-259.

Author Abstract. Forest structure of mangrove restoration sites (6 and 14 years old) at two locations (Henderson Creek [HC] and Windstar [WS]) in southwest Florida differed from that of mixed-basin forests (>50 years old) with which they were once contiguous. However, the younger site (HC) was typical of natural, developing forests, whereas the older site (WS) was less well developed with low structural complexity. More stressful physicochemical conditions resulting from incomplete tidal flushing (elevated salinity) and variable topography (waterlogging) apparently affected plant survival and growth at the WS restoration site. Lower leaf fall and root production rates at the WS restoration site, compared with that at HC were partly attributable to differences in hydroedaphic conditions and structural development. However, leaf and root inputs at each restoration site were not significantly different from that in reference forests within the same physiographic setting. Macrofaunal consumption of tethered leaves also did not differ with site history, but was dramatically higher at HC compared with WS, reflecting local variation in leaf litter processing rates, primarily by snails (*Melampus coffeus*). Degradation of leaves and roots in mesh bags was slow overall at restoration sites, however, particularly at WS where aerobic decomposition may have been more limited. These findings indicate that local or regional factors such as salinity regime act together with site history to control primary production and turnover rates of organic matter in restoration sites. Species differences in senescent leaf nitrogen content and degradation rates further suggest that restoration sites dominated by *Laguncularia racemosa* and *Rhizophora mangle* should exhibit slower recycling of nutrients compared with natural basin forests where *Avicennia germinans* is more abundant. Structural development and biogeochemical functioning of restored mangrove forests thus depend on a number of factors, but site-specific as well as regional or local differences in hydrology and concomitant factors such as salinity and soil waterlogging will have a strong influence over the outcome of restoration projects.

Nagelkerken, I., S. Kleijnen, T. Klop, R. A. C. J. Van den Brand, E. C. De la Moriniere and G. Van der Velde. 2001. Dependence of Caribbean reef fishes on mangroves and seagrass beds as nursery habitats: A comparison of fish faunas between bays with and without mangroves/seagrass beds. *Marine Ecology Progress Series* 214:225-235.

Author Abstract. Mangroves and seagrass beds are considered important nursery habitats for coral reef fish species in the Caribbean, but it is not known to what degree the fish depend on these habitats. The fish fauna of eleven different inland bays of the Caribbean island of Curacao were compared; the bays contain 4 different habitat types: seagrass beds in bays containing mangroves, seagrass beds in bays lacking mangroves, mud flats in bays containing mangroves and seagrass beds, and mud flats in bays completely lacking mangroves and seagrass beds. Principal component analysis showed a high similarity of fish fauna among bays belonging to each of the four habitat types, despite some differences in habitat variables and human influence between bays. Juveniles of nursery species-fish species using mangroves and seagrass beds as juvenile nurseries before taking up residence on reefs-showed highest abundance and species richness on the seagrass beds, and on the mud flats near mangroves and seagrass beds, but were almost absent from bays containing only mud flats. The high abundance and species richness on the mud flats near nursery habitats can be explained by fishes migrating from the adjacent mangroves/seagrass beds to the mud flats. Seagrass beds near to mangroves showed a higher richness of nursery species than did seagrass beds alone, suggesting an interaction with the mangroves resulting in an enhancement of species richness. Comparison of fish densities from the four different habitat types indicates that for the nursery species the degree of dependence on a combination of mangroves and seagrass beds as nurseries for juvenile fish is high for *Ocyurus chrysurus* and *Scarus iserti*, the dependence on seagrass beds is high for *Haemulon parrai, H. sciurus, Lutjanus apodus, L. griseus, Sparisoma chrysopterum* and *Sphyraena* barracuda, and the dependence on mud flats near mangroves/seagrass beds is high for *L. analis*. The dependence on mangroves and/or seagrass beds is low for *Chaetodon capistratus, Gerres cinereus, H. flavolineatum* and *L. mahogoni*, which can also use alternative nursery habitats.

Nayak, S. and A. Bahuguna. 2001. Application of remote sensing data to monitor mangroves and other coastal vegetation of India. *Indian Journal of Marine Sciences* 30:195-213.

Author Abstract. Researchers in this study used remote sensing data, because of its repetitive, synoptic and multi-spectral nature, in monitoring of coastal vegetation. Indian Remote Sensing Satellite (IRS) data have been used to map mangroves and other coastal vegetation across the country's coastline. Large database on spatial extent of mangroves and their condition were created on 1:250,000, 1:50,000 and 1:25,000 scale using IRS data (the database provides information for the first time on the mangrove areas of the entire Indian coast). Researchers conducted studies on the Marine National Park, in the Gulf of Kachchh, where mangrove areas were monitored for 25 years. The degradation of mangroves continued up to 1985 and the condition significantly improved due to the adoption of conservation measures. IRS data were used in identifying dominant plant communities in many mangrove areas such as Bhitarkanika, Coringa, Mandovi estuary in Goa and the Gulf of Kachchh, etc. This approach provides spatial information at plant community level and can be seen as a first step towards bio-diversity assessment. See publication for more details on techniques used. This technique allows reasonable accuracy for mapping mangroves. Results suggest that

remote sensing-based information contributes to preparation efficiency of management action plans.

Osunkoya, O. O. and R. G. Creese. 1997. Population structure, spatial pattern and seedling establishment of the grey mangrove, *Avicennia marina* var. *australasica*, in New Zealand. *Australian Journal of Botany* 45:707-725.

Author Abstract. In the North Island of New Zealand *Avicennia marina* (Forsk.) Vierh. var. *australasica* (Walp.) Moldenke occurs as monospecific stands. Researchers used 5 m wide strip transects, to map out *A. marina* adult plants and seedlings in eight distinctive mangrove forests. In most instances, seedling density increased with increasing distance from the seaward edge of the mangrove forests. See publication for additional information of techniques used. There was no consistent pattern for mean plant size and density with respect to tidal position. Plant size showed some correlation with latitudinal gradient, with taller trees in relatively warmer regions and shorter, stunted, dwarf-like types in colder areas. The survival and growth of naturally occurring seedlings in and out of tree-fall gaps and at various distances from the seaward edge of the forest; and transplanted seedlings of different sizes (small, medium and large propagules: less than or equal to 10 cm, 10-20 cm and 21-40 cm tall, respectively) and densities (2, 5, and 9 seedlings m^{-2}) in three delineated (low, mid and high) intertidal positions were monitored for more than 18-month periods. Both natural and transplanted seedlings grown varied significantly between locations, under canopy light conditions, intertidal levels and seedling sizes. Overall seedling survival and growth were better in gaps than under closed canopy, irrespective of tidal position. Intertidal level significantly affected survival of transplanted seedlings, but did so only marginally for the natural ones, with survival being greatest in the high intertidal zone. Conversely, increases in plant height and leaf production were best promoted in the low intertidal position of the forest floor. Survival of the transplanted seedlings ranged from large greater than small greater than or equal to medium-sized. However, the small seedlings grew best in height and accumulation of new leaves. Overall patterns of survival and growth were consistent across intertidal position and seedling density.

Ramirez-Garcia, P., J. Lopez-Blanco and D. Ocana. 1998. Mangrove vegetation assessment in the Santiago River mouth Mexico, by means of supervised classification using Landsat™ imagery. *Forest Ecology and Management* 105:217-229.

Author Abstract. This paper presents a mangrove vegetation assessment from 1970 to 1993 of the Santiago River mouth, Nayarit, West of Mexico. Their goals were to describe the plant composition and structure of mangrove in the study area, and to evaluate the deforestation level and its amplitude by means of a retrospective analysis of the cover and distribution area of mangrove species using a Landsat™ image, aerial photographs and oblique video. See publication for more details on techniques used for this study. The mangroves in the study area were dominated by *Laguncularia racemosa* with the average importance value of 158.18 and 400 ha of plant cover, followed by *Avicennia germinans*, with an average importance value of 138.52 and 324 ha of plant cover. *L. racemosa* was the dominant species in six of the eight compass lines. The highest absolute frequencies for both dominant species were found in the second height class frequency, and the first diametric class frequency. Cover area and distribution of mangrove in the study area were mapped using a Landsat™5 image (April 1993). Researchers applied a supervised classification using the maximum likelihood

algorithm. The classification was evaluated by obtaining a classification error matrix and by assessing its accuracy. The results of the mangrove vegetation area reported before were overestimated in 56% regarding the value obtained in our photointerpretation (1065 ha). However within the latter mangrove area, the current cover was 724 ha, indicating a decrease of 32% in a 23-yr period.

Ramachandran, S., S. Sundaramoorthy, R. Krishnamoorthy, J. Devasenapathy and M. Thanikachalam. 1998. Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of islands with special reference to mangroves. *Current Science* 75:236-244.

Author Abstract. Sustainable use is a current theme of prime importance for better utilization of natural resources, through rational and responsible multiple-use management. Synoptic and repetitive coverage provided by orbiting satellites have opened up immense possibilities in terms of resource mapping, monitoring and management. The present study deals with the application of Remote Sensing and Geographic Information System (GIS) technologies in the study of coastal ecology with special reference to mangroves. The coastal wetland ecology of Muthupet and Pichavaram has been studied by considering the changes in wetlands. Wetland maps were prepared on 1:25,000 scale using high resolution SPOT (for the year 1989) and IRS LISS II data (for the years 1990 and 1996). Changes in coastal wetland ecology were studied by integrating remote sensing data with GIS. In Muthupet, about 86.77 m^2 of the mangrove forest have been reduced over a period of seven years (1989 to 1996). Digital analysis of 1986 Landsat TM and 1993 IRS LISS II data showed that 0.36 km^2 area of mangrove in Pichavaram was lost over a period of seven years. Ground-based spectral measurements of different mangrove species using field spectroradimeter showed highest spectral radiance between 0.7 and 1.1 μm using radiometer of MSS bands and highest spectral reflectance in 0.69-0.86 μm regions of IRS and TM band which could be used in identifying mangrove forest from other vegetation. In Andaman and Nicobar islands the total mangrove area is about 762 km^2 and degradation occurred only in very small pockets (up to 2.379 km^2).

Steyer, G. D., C. E. Sasser, J. M. Visser, E. M. Swenson, J. A. Nyman and R. C. Raynie. 2003. A proposed coast-wide reference monitoring system for evaluating wetland restoration trajectories. *Journal of Environmental Monitoring and Assessment* 81:107-117.

Author Abstract. Wetland restoration efforts conducted in Louisiana under the Coastal Wetlands Planning, Protection and Restoration Act require monitoring the effectiveness of individual projects as well as monitoring the cumulative effects of all projects in restoring, creating, enhancing, and protecting the coastal landscape. The effectiveness of the traditional paired-reference monitoring approach in Louisiana has been limited because of difficulty in finding comparable reference sites. A multiple reference approach is proposed that uses aspects of hydrogeomorphic functional assessments and probabilistic sampling. This approach includes a suite of sites that encompass the range of ecological condition for each stratum, with projects placed on a continuum of conditions found for that stratum. Trajectories in reference sites through time are then compared with project trajectories through time. Plant community zonation complicated selection of indicators, strata, and sample size. The approach proposed could serve as a model for evaluating wetland ecosystems.

Toledo, G., A. Rojas and Y. Bashan. 2001. Monitoring of black mangrove restoration with nursery-reared seedlings on an arid coastal lagoon. *Hydrobiologia* 444:101-109.

Author Abstract. This study monitored black mangroves restoration efforts with the use of nursery reared seedlings on arid lagoons. Black mangrove (*Avicennia germinans*) seedlings (n=555) were grown from field-collected propagules for three months in a terrestrial nursery. They were grown in clusters of five plants, and transplanted to a clear-cut zone in a lagoon fringed by a mangrove forest at Laguna de Balandra, Baja California Sur, Mexico. Plant survival and development of the transplants were monitored every six-months for two years. See publication for additional information on techniques used. Within one month, the survival of seedlings was 96%. Based on observations and evaluations made within twenty-four months, 74% of the plants were still living. The best cluster, showing maximum growth under mangrove swamp conditions in this arid zone, was a two-plant cluster. The lagoon has a low natural regeneration rate of 48 plants per 350 m^2 per 6 years of monitoring. Overall results indicated that restoring destroyed arid coast lagoons with black mangroves can be easily done.

Twilley, R. R., V. H. Rivera-Monroy, R. Chen and L. Botero. 1998. Adapting an ecological mangrove model to simulate trajectories in restoration ecology. *Marine Pollution Bulletin* 37:404-419.

Author Abstract. We used an ecological model to simulate the trajectories of mangrove attributes according to different restoration criteria at geographically specific conditions and at decadal time scales. This model may contribute to the design and implementation of restoration projects, and can be used to verify key mechanisms controlling ecosystem attributes during the recovery period. Presently a gap model of mangrove wetlands, FORMAN, was used to simulate restoration trajectories in one of the largest estuary rehabilitation projects (128,000 ha) in South America, Cienaga Grande de Santa Marta, Colombia (CGSM). Based on simulations of basal area following reductions of salinity to 40 g/kg within two-year or ten-year time periods, recovery of a disturbed mangrove forest in both cases suggests dominance would reach about 75% of that in the reference site (80 m^2/ha) in 40 years. Both forests are > 80% dominated by *Avicennia*, and *Laguncularia* has greater basal area than *Rhizophora* in the remaining structure. Simulations of forest recovery with a 25-year target for salinity reduction showed approximately 50% of the basal area in the reference site was recovered after 40 years. After 40 years of recovery, both the two and ten-year salinity targets displayed higher basal area and different patterns of community composition (*Laguncularia* becomes the dominant species) under enhanced recruitment (planting program) than seen under more natural recruitment. Researchers mention that ecological models can be useful improving engineering designs, project operation, and more clearly define monitoring programs and natural resource valuation. Also modeling techniques can be useful for identifying the spatial and temporal scale problems affiliated with mangrove restoration projects.

Twilley, R. R., R. Chen and V. Rivera-Monroy. 1999. Formulating a model of mangrove succession in the Caribbean and Gulf of Mexico with emphasis on factors associated with global climate change. *Wetland Biogeochemistry* 3:118-141.

Author Abstract. The structure of mangrove forests is influenced by a combination of geomorphological, climate, and ecological factors, each with specific time and spatial scales,

that determine complex patterns of zonation. And these geomorphological, geophysical, and ecological forcings respond differently to projections of global climate change such as sea level rise, fresh water discharge, frequency of frost, or tropical cyclones. We describe an individual-based gap model (FORMAN) to simulate the effects of ecological forcings on mangrove forest dynamics in response to global climate change. Physiological processes that can control the species specific responses of mangrove growth to global climate change include salinity, sulfide concentrations, nutrient resources, and flooding. The relative ability of mangrove species to adapt to these edaphic conditions influence the growth of distribution of mangroves with rise in sea level, changes in upland fresh water input, and frequency of disturbance. In addition, cold temperatures and frequency of frost can influence the relative competition of mangrove species within the intertidal zone at the global limits of mangrove

distribution. We also discuss how the time step of the gap dynamic models are not effective in simulation physiological responses that operate at much shorter time scales. Thus, the influence of diurnal temperature changes, humidity, and carbon dioxide concentrations on productivity and water use efficiency in mangroves are not presently included in the FORMAN model. In addition, the allocation of carbon in mangrove trees is important to in situ soil formation, which is significant to evaluating the response of mangroves to rise in sea level. The scale of these changes in specific forests stands in response to ecological forcings must be linked to the regional scale changes in geomorphology and geophysical energies in response to climate change. Gap models such as FORMAN, when linked to more spatially explicit models of soil characteristics of the intertidal zone in response to climate and change, can provide a clearer evaluation of climate change impacts on coastal wetlands of the tropics.

This Review of Technical Methods Manuals includes a variety of sampling manuals, Quality Assurance/Quality Control (QA/QC) documents, standardized protocols, or other technical resources that may provide practitioners with the level of detail needed when developing a monitoring plan for a coastal restoration project. Examples from both peer reviewed and grey literature are presented. Entries were selected through extensive literature and Internet searches as well as input from reviewers. As with the Annotated Bibliography, these entries are not, however, a complete list. Entries are arranged alphabetically by author. Wherever possible, web addresses or other contact information are included in the reference to assist readers in more easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract*' or *'Publisher Introduction'* or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapters.

Cintron-Molero, G. and Y. S. Novelli. 1984. Methods for studying mangrove structure, pp. 90-113. In Snedaker, S. and J. G. Snedaker (eds.), The Mangrove Ecosystem: Research Methods. United Nations Educational Scientific and Cultural Organizations. The Chaucer Press Ltd., UK.

This manual provides research methods that are used to study mangrove ecosystems. Chapter six presents methods for studying mangrove structure and growth. Described are parameters that are measured in relation to their response to change in environmental conditions over time. The structural parameters that are described and measured in mangroves are tree diameter, basal area, density, tree height and leaf area index. Some of the methods that are described in this manual to evaluate mangrove structure include: (1) point sampling to estimate stand basal area without direct measurement of plot or tree diameter; (2) point sampling by measuring its diameter (density); (3) angle gauge which is used for horizontal sampling; (4) point-centered quadrat method in which points to be sampled are located randomly along a transect line; (5) allometric techniques in which sets of trees of a given species be clear-cut and separated into compartments and weighed; and (6) multiplying the biomass of the stem of mean basal area by stand density to determine stand biomass estimates. Additional information on research methods for mangrove ecosystems is described in this manual.

Davis, G. E., K. R. Faulkner and W. L. Halvorson. 1994. Ecological Monitoring in Channel Islands National Park, California, pp. 465-482. In Halvorson, W. L. and G. J. Maender (eds.), The 4th California Islands Symposium: Update on the Status of Resources.

Author Abstract. Natural resource managers need to understand the natural functioning of and threats to ecosystems under their management. They need a long-term monitoring program to gather information on ecosystem health, establish empirical limits of variation, diagnose abnormal conditions, and identify potential agents of change. The approach used to design such a program at Channel Islands National Park, California, may be applied to other ecosystems worldwide. The design of the monitoring program began with a conceptual model of the park ecosystem. Indicator species from each ecosystem component were selected using a Delphi approach. Scientists identified parameters of population dynamics to measure, such as abundance, distribution, age structure,

reproductive effort, and growth rate. Short-term design studies were conducted to develop monitoring protocols for pinnipeds, seabirds, rocky intertidal communities, kelp forest communities, terrestrial vertebrates, land birds, terrestrial vegetation, fishery harvest, visitors, weather, sand beach and coastal lagoon, and terrestrial invertebrates (indicated in priority order set by park staff). Monitoring information provides park and natural resource managers with useful products for planning, program evaluation, and critical issue identification. It also provides the scientific community with an ecosystem-wide framework of population information.

Everitt, J. H. and F. W. Judd. 1989. Using remote sensing techniques to distinguish and monitor black mangrove (*Avicennia germinans*). *Journal of Coastal Research* 5:737-745.

Author Abstract. In this study color-infrared (CIR) aerial photography was used to determine the current distribution of black mangrove *(Avicennia germinans)* that underwent freezing in December 1983. Ground reflectance measurements were made on black mangrove and associated plant species and soil to assist in interpreting CIR photographs. Ground surveys were conducted to verify aerial photos. Black mangrove had a distinct red to dark red CIR image response that made it easily distinguishable from other vegetation and soil. The ground reflectance measurements showed that black mangrove had lower visible red (0.63-0.69 μm) reflectance than associated plant species and soil, which contributed greatly to its image response. See publication for additional information on techniques used. The results showed that the dark green leaves of the black mangroves displayed low visible reflectance. Mangroves near Port Isabel-South Bay and Port Aransas on the lower and mid Texas coast respectively, had largely recovered from the freeze and were actively growing, producing flowers and seed. Major populations near Port O'Connor on the upper Texas coast were killed by the 1983 freeze, but a number of young plants grown from seeds or that survived the freeze due to the protection provided by taller plants produced flowers and seed. Computer-based image analyses of CIR film positive transparencies showed that black mangrove populations could be quantified accurately. The advantage of this technique is that it can permit 'percent area' which can be useful for monitoring changes in vegetation distribution over time. Based on results the researchers stated that remote sensing techniques can be a useful tool for distinguishing black mangrove and determine its extent along the Texas Gulf coast.

Gordon, D. M., A. R. Bougher, M .I. LeProvost and J. S. Bradley. 1995. Use of models for detecting and monitoring change in a mangrove ecosystem in northwestern Australia. *Water Modelling* 21:605-618.

Author Abstract. This publication describes a monitoring program used to detect effects of solar salt ponds on mangroves in Northwestern Australia. Researchers established sites in different mangrove communities at five locations, two that were modified by salt ponds and the other three used as references. A conceptual model was developed to identify potential changes to the mangrove ecosystem next to ponds, to identify responses to change and to formulate a null hypothesis to test that ponds have no effect on vegetation structure. A simulation model was developed to evaluate power of tests of the null hypothesis for nominated levels of change in mangrove stem density and leaf area index (LAI). See publication for more details on techniques used in this study. Changes in groundwater salinity and LAI monitored at the five locations between 1992 and 1995 are shown to demonstrate

the similarity in behavior of these attributes at modified and unmodified locations. The results in this study for monitoring a localized disturbance to the mangrove system next to one pond demonstrates how the disturbance was successfully tracked through monitoring and how the mangrove responses to that disturbance coincided with those predicted in the conceptual model.

Halse, S. A., D. J. Cale, E. J. Jasinska and R. J. Shiel. 2002. Monitoring change in aquatic invertebrate biodiversity: Sample size, faunal elements and analytical methods. *Aquatic Ecology* 36:395-410.

Author Abstract. Replication is usually regarded as an integral part of biological sampling, yet the cost of extensive within-wetland replication prohibits its use in broad-scale monitoring of trends in aquatic invertebrate biodiversity. In this paper, we report results of testing an alternative protocol, whereby only two samples are collected from a wetland per monitoring event and then analyzed using ordination to detect any changes in invertebrate biodiversity over time. Simulated data suggested ordination of combined data from the two samples would detect 20% species turnover and be a cost-effective method of monitoring changes in biodiversity, whereas power analyses showed about 10 samples were required to detect 20% change in species richness using ANOVA. Errors will be higher if years with extreme climatic events (e.g., drought), which often have dramatic short-term effects on invertebrate communities, are included in analyses. We also suggest that protocols for monitoring aquatic invertebrate biodiversity should include microinvertebrates. Almost half the species collected from the wetlands in this study were microinvertebrates and their biodiversity was poorly predicted by macroinvertebrate data.

Lewis, R. R. and B. Streever. 2000. Restoration of Mangrove Habitat. WRP Technical Notes Collection (ERDC TN-WRP-VN-RS-3.2), U. S. Army Engineer Research and Development Center. Vicksburg, MS. http://www.wes.army.mil/el/wrp

This document provides general guidelines for restoring mangrove habitats. Highlighted in the document are costs for performing mangrove restoration efforts which may vary depending on the condition of each potential restoration site; and restoration techniques such as natural recruitment or planting seedlings. The authors described the steps to follow in order to achieve mangrove restoration success. The steps includes: understanding mangrove species ecology at the site (e.g., patterns of reproduction and propagule distribution); understanding hydrologic patterns that control distribution and successful establishment and growth of targeted mangrove species; assessing changes of the original mangrove environment that presently prevents secondary succession; designing the restoration program; and procedures for planting propagules, collecting seedlings, or cultivate seedlings whenever it has been verified that natural recruitment will not successfully establish seedlings, rate of stabilization, or rate of sapling growth and establishment. For additional information pertaining to guidelines for mangrove restoration please see document referenced above.

Miller, T., C. Bertolotto, J. Martin and L. Storm. 1996. Monitoring Wetlands: A Manual for Training Volunteers. 106 pp. Adopt-a-Beach, Seattle, WA. Contact information: Phone # (206) 624-6013 and Fax # (206) 682-0722.

This manual provides quantitative and qualitative methods for monitoring structural and functional characteristics in natural and

created wetlands. Volunteers identify major vegetation communities, locate photo points, identify surrounding land uses, and establish locations of transects. Data collected serves as a baseline for future monitoring. The manual presents protocols for monitoring hydrology; wetland buffer condition; soil types; vegetation; topography (determining elevations); and wildlife.

Methods described in this manual include plant survival counts, vegetation assessment, and percent cover surveys. Plants surveys are designed for use in wetlands or wetland mitigation sites. Data collected can be used to evaluate planting success, mark areas for replanting, and identify species that should not be replanted in an area, given their low survival rates. Vegetation assessment surveys provide qualitative information on the wetland vegetation characteristics. Plots used are circular, with the radius depending on the predominant type of vegetation in the plot (10 meters for forested, 5 meters for scrub-shrub, and 1 meter for herbaceous). For each plot, volunteers record three to five of the most dominant species in each vegetation layer (tree, shrub, and herb). Data collected can be associated with other data (for example, hydrology or soil types) in order to understand wetland functions and how it should be managed and protected. Percent cover vegetation surveys uses similar plot sizes in vegetation assessment survey but the plots are placed every 50 feet along five transects over the wetland. In each plot, volunteers identify all species and estimate the area in which they covered.

Olin, T. J., J. C. Fischenich, M. R. Palermo and D. F. Hayes. 2000. Wetlands Engineering Handbook: Monitoring. U. S. Army Engineer Research and Development Center, Vicksburg, MS. Technical Report ERDC/EL TR-WRP-RE-21.

The wetlands engineering handbook presents methods for monitoring and evaluating success. Authors emphasize that local expertise and databases for particular wetland types must be used together with the guide to ensure monitoring plans for a specific project are effectively developed. Chapter eight of this report provides a guide for developing evaluation criteria and monitoring projects for wetland restoration and creation. Also presented is guidance for monitoring and success evaluation on basic monitoring concepts, assessing wetland hydrology, evaluating soils and vegetation, and fauna usage. The authors also outline an approach to determining project goals and evaluation criteria, basic considerations related to monitoring, provide detailed information on how to assess wetland structure and function regarding hydrology, soils, vegetation, and fauna (e.g., macroinvertebrates, birds and fish). Additional information needed on assessment, monitoring, and evaluating success are described within this report.

Raposa, K. B. and C. T. Roman. 2001. Monitoring nekton in shallow estuarine habitats. A Protocol of the Long Term Monitoring Program at Cape Cod National Seashore. 39 pp. Narragansett Bay National Estuarine Research Reserve Prudence Island, RI 02872 and National Park Service, Graduate School of Oceanography, University of Rhode Island, Narragansett, RI. Contact information: Kenny@gso.uri.edu http://www.nature.nps.gov/im/monitor/protocoldb.cfm

Author Abstract. Long term monitoring of estuarine nekton has many practical and ecological benefits but efforts are hampered by a lack of standardized sampling procedures. This study develops a protocol for monitoring nekton in shallow (< 1 m) estuarine habitats for use in the Long term Coastal Monitoring

Program at Cape Cod National Seashore. Sampling in seagrass and salt marsh habitats is emphasized due to the susceptibility of each habitat to anthropogenic stress and to the abundant and rich nekton assemblages that each habitat supports. Extensive sampling with quantitative enclosure traps that estimate nekton density is suggested. These gears have a high capture efficiency in most habitats and are small enough (typically 1 m^2) to permit sampling in specific microhabitats. Other aspects of nekton monitoring are discussed, including seasonal sampling considerations, sample allocation, station selection, sample size estimation, parameter selection, and associated environmental data sampling. Developing and initiating long term nekton monitoring programs will help track natural and human-induced changes in estuarine nekton over time and advance our understanding of the interactions between nekton and the dynamic estuarine environments.

Sasich, J. 1998. Monitoring Effectiveness of Forest Practices and Management Systems: Study Design Guidelines, Procedures and Methods. Northwest Indian Fisheries Commission, Spokane, WA. Contact information: Phone # (360) 438-1180. http://www.nwifc.wa.gov/TFW/documents/mws.html

The purpose of this document is to provide the framework, under the Timber Fish Wildlife (TFW) Monitoring Program Plan, for evaluating the control of fine and coarse sediment delivered to the aquatic resource from mass wasting. This document provides guidance for developing a monitoring plan, procedures for conducting evaluations, and methods of evaluation. The document is organized into two parts. Part I discusses considerations in designing a monitoring project such as general considerations for monitoring, consideration in mass wasting processes, site scale evaluation, evaluation of multiple practices and management, and quality assurance. Part II outlines the procedure and methods necessary to conduct a TFW monitoring project such as scale versus watershed scale monitoring, monitoring approaches and monitoring report. See report for additional information on monitoring planning and methods used.

Shafer, D. J. and D. J. Yozzo. 1998. National Guidebook for Application of Hydrogeomorphic Assessment of Tidal Fringe Wetlands. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi. Technical Report WRP-DE-16.

Authors described in the regional guidebook the hydrogeomorphic (HGM) approach used for assessing tidal wetlands. The procedures used to assess wetland functions in relation to regulatory, planning or management programs are described. The Application Phase includes characterization, assessment analysis, and application components. Characterization describes the wetland ecosystem and the surrounding landscape, describes the planned project and potential impacts, and identifies wetland areas to be assessed. Assessment and analysis involves collecting field data that is needed to run the assessment models and calculating the functional indices for the wetland assessment areas under the existing conditions.

The Tidal Wetland HGM Approach Application Phase involves determining the wetland assessment area (WAA) and the indirect wetland assessment area (IWAA) and, determining wetland type. The boundaries of the area and the type of tidal wetland to be assessed are identified. The WAA is the wetland area impacted by a proposed project. The WAA defines specific boundaries where many of the model variables are ascertained and directly contributes to calculations for other variables (e.g., maximum aquatic and upland edge).

Methods for determining WAA are discussed in detail in the procedural manual of the HGM Approach. The IWAA is any adjacent portions of hydrologic unit that may not be affected by the project directly but indirectly affected through hydrologic flow alterations. Wetland types are determined by comparing the hydroperiod, salinity regime, and vegetation community structure with those described in the wetland type profiles for each region. Plant communities react to change in the environment (e.g., salinity and hydrologic alterations) so are considered good indicators of a wetland type. Descriptions of the vegetation present, salinity levels, and hydrological conditions for each wetland type are presented in each regional wetland type profile. To determine the salinity regime of an area, one can refer to available references on salinity and or wetland distribution. Data collected on average salinity or the range of salinity helps to sort each site into one of the four categories of the Cowardin system.

Shafer, D. J., B. Herczeg, D. W. Moulton, A. Sipocz, K. Jaynes, L. P. Rozas, C. P. Onuf and W. Miller. 2002. Regional Guidebook for Applying the Hydrogeomorphic Approach to Assessing Wetland Functions of Northwest Gulf of Mexico Tidal Fringe Wetlands, U.S. Army Engineer Research and Development Center, Vicksburg, MS. Technical Report ERDC/EL TR-02-5.

This manual is designed to provide practitioners with guidelines for monitoring and assessing wetland functions. The manual outlines protocols used for collecting and analyzing data needed to assess wetland functions in the context of a 404 permit review or comparable assessment setting. When assessing tidal fringe wetlands in the northwestern Gulf of Mexico the researcher must define the assessment objectives by stating the purpose (e.g., assessment determines how the project impacts wetland functions); characterize the project area by providing a description of the structural characteristics of the project area (e.g., tidal flooding regime, soil type, vegetation and geomorphic setting); use screen for redflags; define the wetland assessment area; collect field data using a 30-m measuring tape, quadrats and color infrared aerial photography; analyze field data; and apply assessment results. This document provides additional detail information on criteria selection and methods used for assessing tidal fringe wetlands.

Twilley, R. R. and V. H. Rivera-Monroy. 2003. Developing Performance Criteria Using Simulation Models of Mangrove Ecosystem Restoration: A Case Study of the Florida Coastal Everglades. Center for Ecology and Environmental Technology, University of Louisiana at Lafayette, Lafayette, LA. Contact information: rtwilley@louisiana.edu.

Author Abstract. The design and goals mangrove restoration projects should account for three major functions of mangroves: hydrology, biogeochemistry, and community ecology. There are global, regional and local factors that can explain patterns of regulator gradients, and hydroperiod that account for the diversity of these functions across a variety of environmental settings. Simulation models of these functions that can account for this diversity have been developed to evaluate the restoration of mangroves in the Florida coastal Everglades. These restoration measures; and monitoring these criteria can help in adaptive management and assessment programs by testing hypotheses of system degradation. Hydrologic performance criteria include soil regulators, particularly soil salinity, surface topography of mangrove landscape, and hydroperiod, including both the frequency and duration of flooding. In the estuary, performance criteria should include salinity of the bay, tidal amplitude, and conditions of freshwater discharge (included in the salinity value). The most important

performance measures of the biogeochemistry function of mangroves should include soil resources (bulk density, total nitrogen and phosphorus), and soil accretion. Community ecology should include performance criteria for both the mangrove and the estuary. Mangrove criteria include forest dimension analysis (transects and/or plots), sapling recruitment, leaf area index, and faunal relationships. In the estuary the habitat function of mangroves can be evaluated with growth rate of key species, habitat suitability analysis, isotope abundance of indicator species and bird census. There are several other performance criteria described for each of the three functions, but require more intensive investment of time and resources. The list of criteria can be modified depending of what characteristics of the models presented that describe the restoration goals during the restoration planning process.

U.S. EPA. 1992. Monitoring Guidance for the National Estuary Program. United States Environmental Protection Agency, Office of Water, Office of Wetlands, Washington D.C. EPA Report 842-B-92-004.

This document provides guidance on the design, implementation, and evaluation of the required monitoring programs. It also identifies steps to be taken when developing and implementing estuarine monitoring programs and provides technical basis for discussions on the development of monitoring program objectives, the selection of monitoring program components, and the allocation of sampling effort.

Some of the criteria listed for developing a monitoring program and described in this document include: monitoring program objectives, performance criteria, establish testable hypotheses, selection of statistical methods, alternative sampling designs, use of existing monitoring programs, and evaluate monitoring program performance. Additional information on guidelines for developing a monitoring program is described in this document.

U.S. EPA.. 1993. Volunteer Estuary Monitoring: A Methods Manual. 176 pp. In Ohrel, R. L., Jr., and K. M. Register (eds.), a Methods Manual. U.S. Environmental Protection Agency, Washington, D.C., Office of Water. EPA Report- 842-B-93-004. http://www.epa.gov/owow/estuaries/monitor/.

This document presents information and methodologies specific to estuarine water quality. Information presented in the first eight chapters include: understanding estuaries and what makes them unique; impacts to estuarine habitats and human's role in solving the problems; guidance on how to establish and maintain a volunteer monitoring program; guidance for working with volunteers and ensuring that they are well-positioned to collect water quality data safely and effectively; ensuring that the program consistently produces high quality data; and managing the data and making it readily available to data users. Also presented are water quality measures that determine the condition of the estuary: physical (e.g., substrate texture), chemical (e.g., dissolved oxygen) and biological parameters (e.g., plant and animal presence and abundance). The importance of each parameter and methods used to monitor the conditions are described in a gradual process. Proper quality assurance and quality control techniques must also be described in detail to ensure that the data are beneficial to state agencies and other data users.

Wenner, E. L. and M. Geist. 2001. The National Estuarine Research Reserves Program to Monitor and Preserve Estuarine Waters. *Coastal Management* 29:1-17.

The National Estuarine Research Reserve (NERR) sites in 1992 coordinated a program that would attempt to identify and track short-term variability and long-term changes in representative estuarine ecosystems and coastal watersheds. Water quality parameters that were monitored include: pH, conductivity, temperature, dissolved oxygen, turbidity, and water level. Standardized protocols were also used at each site so that sampling, processing, and data management techniques were consistent among sites. Statistical techniques are being used to identify periodicity in water quality variables. Periodic regression analysis indicated that diel periodicity in dissolved oxygen is a larger source of variation than tidal periodicity at sites with less tidal amplitude. Authors of this document stress how understanding the functions of estuaries and how they change over time will help predict how these systems respond to change in climate and anthropogenic sources.

APPENDIX III: LIST OF MANGROVE EXPERTS

The experts listed below have provided their contact information so practitioners may contact them with questions pertaining to the restoration or restoration monitoring of this habitat. Contact information is up-to-date as of the printing of this volume. The list below includes only those experts who were 1) contacted by the authors and 2) agreed to submit their contact information. Some of those listed also reviewed the associated habitat chapter. In addition to these resources, practitioners are encouraged to seek out the advice of local experts as well faculty members and researchers at colleges and universities. Engineering, planning, and landscape architecture firms also have experts on staff or contract out the services of botanists, biologists, ecologists, and other experts whose skills are needed in restoration monitoring. These people are in the business of providing assistance in restoration and restoration monitoring and are often extremely knowledgeable in local habitats and how to implement projects on the ground. Finally local, state, and Federal environmental agencies also house many experts who monitor and manage coastal habitats. In addition to the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the Army Corps of Engineers (ACE), Fish and Wildlife Service (FWS), and the United States Geologic Survey (USGS) are important Federal agencies to contact for assistance in designing restoration and monitoring projects as well as potential sources of funding and permits to conduct work in coastal waterways.

Perry Gayaldo
NOAA Restoration Center
1315 East West Highway
Silver Spring, MD 20910-3282
301-713-0174
perry.gayaldo@noaa.gov

Roy R. "Robin" Lewis III
Ecologist and Wetland Scientist
Lewis Environmental Services, Inc.
PO Box 5430
Salt Springs, FL 32134-5430
Street Address: 23797 NE 189th Street
Salt Springs, FL 32134
LESRRL3@AOL.COM

Alfredo Quarto
Mangrove Action Project
PO Box 1854
Port Angeles, WA 98362-0279
alfredo@mangroveactionproject.org

GLOSSARY

Abiotic - non-living

Adaptive management - a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form–"active" adaptive management–employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.

Aerobic - (of an organism or tissue) requiring air for life; pertaining to or caused by the presence of oxygen

Algae - simple plants that are very small and live in water through photosynthesis, algae are the main producers of food and oxygen in water environments

Allochthanous - carbon that is formed outside of a particular area as opposed to an autochthanous carbon that is produced within a given area

Alluvial plain - the floodplain of a river, where the soils are alluvial deposits carried in by overflowing river

Alluvium - any sediment deposited by flowing water, as in a riverbed, floodplain, or delta

Alternate hypothesis - a statement about the values of one or more parameters usually describing a potential change

Anaerobic - living in the absence of air or free oxygen; pertaining to or caused by the absence of oxygen

Anoxic - without oxygen

Anthropogenic - caused by humans; often used when referring to human induced environmental degradation

Apical - the tips of the plants

Aquatic - living or growing in or on water

Asset mapping - a community assessment research method that provide a graphical representation of a community's capacities and assets

Assigned values - the relative importance or worth of something, usually in economic terms. Natural resource examples include the value of water for irrigation or hydropower, land for development, or forests for timber supply (see held values).

Attitude - an individual's consistent tendency to respond favorably or unfavorably toward a given attitude object. Attitudes can be canvassed through survey research and are often defined utilizing scales ranging from positive to negative evaluations.

Backwater - a body of water in which the flow is slowed or turned back by an obstruction such as a bridge or dam, an opposing current, or the movement of the tide

Baseline measurements - a set of measurements taken to assess the current or pre-restoration condition of a community or ecosystem

Basin morphology - the shape of the earth in the area a coastal habitat is found

Benefit-cost analysis - a comparison of economic benefits and costs to society of a policy, program, or action

Benthic - on the bottom or near the bottom of streams, lakes, or oceans

Bequest value - the value that people place on knowing that future generations will have the option to enjoy something

Biogenic - produced by living organisms

Biomass - the amount of living matter, in the form of organisms, present in a particular habitat, usually expressed as weight- per-unit area

Blackwater streams - streams that do not carry sediment, are tannic in nature and flow through peat-based areas

Brackish - water with a salinity intermediate between seawater and freshwater (containing from 1,000 to 10,000 milligrams per liter of dissolved solids)

Calcareous - sediment/soil formed of calcium carbonate or magnesium carbonate due to biological deposition or inorganic precipitation

Canopy formers - plants that form a diverse vertical habitat structure

Carnivores - organisms that feed on animals

Catchment - the land area drained by a river or stream; also known as "watershed" or "drainage basin"; the area is determined by topography that divides drainages between watersheds

Causality - or causation, refers to the relationship between causes and effects: i.e., to what extent does event 'A' (the cause) bring about effect 'B'

Coastal habitat restoration - the process of reestablishing a self-sustaining habitat in coastal areas that in time can come to closely resemble a natural condition in terms of structure and function

Coastal habitat restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring coastal habitat restoration project performance

Cognitive mapping - a community assessment research method used to collect qualitative data and gain insight into how community members perceive their community and surrounding natural environment

Cohort studies - longitudinal research aimed at studying changing in a particular subpopulation or cohort (e.g., age group) over time (see longitudinal studies)

Community - all the groups of organisms living together in the same area, usually interacting or depending on each other for existence; all the living organisms present in an ecosystem

Community (human) - a group of people who interact socially, have common historical or other ties, meet each other's needs, share similar values, and often share physical space; A sense of "place" shaped by either natural boundaries (e.g., watershed), political or administrative boundaries (e.g., city, neighborhood), or physical infrastructure

Computer-assisted telephone interviewing (CATI) - a system for conducting telephone survey interviews that allows interviewers to enter data directly into a computer database. Some CATI systems also generate phone numbers and dial them automatically.

Concept mapping - community assessment research method that collects data about how community members perceive the causes or related factors of particular issues, topics, and problems

Content validity - in social science research content validity refers to the extent to which a measurement (i.e., performance standard) reflects the specific intended domain of content (i.e., stated goal or objective). That is, how well does the performance standard measure whether or not a particular project goal has been met?

Contingent choice method - estimates economic values for an ecosystem or environmental service. Based on individual's tradeoffs among sets of ecosystems, environmental services or characteristics. Does not directly ask for willingness to pay; inferred from tradeoffs that include cost as an attribute.

Contingent valuation method (CVM) - used when trying to determine an individual or individuals' monetary valuation of a resource. The CVM can be used to determine changes in resource value as related to an increase or decrease in resource quantity or quality. Used to measure non-use attributes such as existence and bequest values; market data is not used.

Coral reefs - highly diverse ecosystems, found in warm, clear, shallow waters of tropical oceans worldwide. They are composed of marine polyps that secrete a hard calcium carbonate skeleton, which serves as a base or substrate for the colony.

Coralline algae - algae that contains a coral-like, calcareous outer covering

Cost estimate - estimates on costs of planning and carrying out a project. Examples of items that may be included in a cost estimate for a monitoring plan may be personnel, authority to provide easements and rights-of-way, maintenance, labor, and equipment.

Coulter counter - a device that measures the amount of particles in water

Coverage error - a type of survey error that can occur when the list – or frame – from which a sample is drawn does not include all elements of the population that researchers wish to study

Cross-sectional studies - studies that investigate some phenomenon by taking a cross section (i.e., snapshot) of it at one time and analyzing that cross section carefully (see longitudinal studies)

Crowding - in outdoor recreation, crowding is a form of conflict (see outdoor recreation conflict) that is based on an individual's judgment of what is appropriate in a particular recreation activity and setting. Use level is not interpreted negatively as crowding until it is perceived to interfere with one's objectives or values. Besides use level, factors that can influence perceptions of crowding include participant's motivations, expectations, and experience related to the activity, and characteristics of those encountered such as group size, behavior, and mode of travel.

Cryptofauna - tiny invertebrates that hide in crevices

Cultch - empty oyster shells and other materials that are on the ground and used as a place of attachment

Culture - a system of learned behaviors, values, ideologies, and social arrangements. These features, in addition to tools and expressive elements such as graphic arts, help humans interpret their universe as well as deal with features of their environments, natural and social.

Cyanobacteria - blue-green pigmented bacteria; formerly called blue-green algae

Dataloggers - an electronic device that continually records data over time

Deepwater swamps - forested wetlands that develop along edges of lakes, alluvial river swamps, in slow-flowing strands, and in large, coastal-wetland complexes. They can be found along the Atlantic and Gulf Coasts and throughout the Mississippi River valley. They are distinguished from other forested habitats by the tolerance of the dominant vegetation to prolonged flooding.

Demersal - bottom-feeding or bottom-dwelling fish, crustaceans, and other free moving organisms

Detritivorous - the practice of eating primarily detritus

Detritus - fine particles of decaying organic and inorganic matter fomed by excrement and by plant and animal remains; maybe suspended in water or accumulated on the bottom of a water body

Diatoms - any of a class (Bacillariophyceae) of minute planktonic unicellular or colonial algae with silicified skeletons that form shells.

Direct impacts - the changes in economic activity during the first round of spending. For tourism this involves the impacts on the tourism industries (businesses selling directly to tourists) themselves (see Secondary Effects)

Dissolved oxygen - oxygen dissolved in water and available to aquatic organisms; one of the most important indicators of the condition of a water body; concentrations below 5 mg/l are stressful and may be lethal to many fish and other species

Dominant species - a plant species that exerts a controlling influence on or defines the character of a community

Downwelling - the process of build-up and sinking of surface waters along coastlines

Driving forces - the base drivers that play a large role in people's decision making processes and influence human behavior. Societal forces such as population, economy, technology, ideology, politics and social organizations are all drivers of environmental change.

Duration - a span or interval of time

Ebb - a period of fading away, low tide

Echinoderms - any of a phylum (Echinodermata) of radially symmetrical coelomate marine animals including the starfishes, sea urchins, and related forms

Economic impact analysis - used to estimate how changes in the flow of goods and services can affect an economy. Measure of the impact of dollars from outside a defined region/area on that region's economy. This method is often used in estimating the value of resource conservation.

Ecosystem - a topographic unit, a volume of land and air plus organic contents extended aerially for a certain time

Ecosystem services - the full range of goods and services provided by natural ecological systems that cumulatively function as fundamental life-support for the planet. The life-support functions performed by ecosystem services can be divided into two groups: production functions (i.e., goods) and processing and regulation functions (i.e., services).

Emergent plants - water plants with roots and part of the stem submerged below water level, but the rest of the plant is above water; e.g., cattails and bulrushes

Environmental equity - the perceived fairness in the distribution of environmental quality across groups of people with different characteristics

Environmental justice - a social movement focused on the perceived fairness in the distribution of environmental quality among people of different racial, ethnic or socio-economic groups

Ephemeral - lasting a very short time

Epifaunal - plants living on the surface of the sediment or other substrate such as debris

Epiphytes - plants that grow on another plant or object upon with it depends for mechanical support but not as a source of nutrients

Estuary - a part of a river, stream, or other body of water that has at least a seasonal connection with the open sea or Great Lakes and where the seawater or Great Lakes water mixes with the surface or subsurface water flow, regardless of the presence of man-made structures or obstructions.

Eukaryotic - organisms whose cells have a nucleus

Eulittoral - refers to that part of the shoreline that is situated between the highest and lowest seasonal water levels

Eutrophic - designating a body of water in which the increase of mineral and organic nutrients has reduced the dissolved oxygen, producing an environment that favors plant over animal life

Eutrophication - a natural process, that can be accelerated by human activities, whereby the concentration of nutrients in rivers, estuaries, and other bodies of water increases; over time this can result in anaerobic (lack of oxygen) conditions in the water column; the increase of nutrients stimulates algae "blooms; " as the algae decays and dies, the availability of dissolved oxygen is reduced; as a result, creatures living in the water accustomed to aerobic conditions perish

Evapotranspiration - a term that includes water discharged to the atmosphere as a result of evaporation from the soil and surface-water bodies and by plant transpiration

Existence value - the value that people place on simply knowing that something exists, even if they will never see it or use it

Exotic species - plants or animals not native to the area

Fauna - animals collectively, especially the animals of a particular region or time

Fecal coliforms - any of several bacilli, especially of the genera *Escherichia*, found in the intestines of animals. Their presence in water suggests contamination with sewage of feces, which in turn could mean that disease-causing bacteria or viruses are present. Fecal coliform bacteria are used to indicate possible sewage contamination. Fecal coliform bacteria are not harmful themselves, but indicate the possible presence of disease-causing bacteria, viruses, and protozoans that live in human and animal digestive systems. In addition to the possible health risks associated with them, the bacteria can also cause cloudy water, unpleasant odors, and increased biochemical oxygen demand.

Fetch - the distance along open water or land over which the wind blows

Fishery dependent data - data on fish biology, ecology and population dynamics that is collected in connection with commercial, recreational or subsistence fisheries.

Flooding regime - pattern of flooding over time

Floodplain - a strip of relatively flat land bordering a stream channel that may be overflowed at times of high water; the amount of land inundated during a flood is relative to the severity of a flood event

Flora - plants collectively, especially the plants of a particular region or time

Fluvial - of, relating to, or living in a stream or river

Focus group - a small group of people (usually 8 to 12) that are brought together by a moderator to discuss their opinions on a list of predetermined issues. Focus groups are designed to collect very detailed information on a limited number of topics.

Food chain - interrelations of organisms that feed upon each other, transferring energy and nutrients; typically solar energy is processed by plants who are eaten by herbivores which in turn are eaten by carnivores: sun –> grass –> mouse –> owl

Food webs - the combined food chains of a community or ecosystem

Frequency - how often something happens

Fronds - leaf-like structures of kelp plants

Function - refers to how wetlands and riparian areas work – the physical, chemical, and biological processes that occur in these settings, which are a result of their physical and biological structure

Functional habitat characteristics - characteristics that describe what ecological service a habitat provides to the ecosystem

Gastropods - any of a large class (Gastropoda) of mollusks (as snails and slugs) usually with a univalve shell or none and a distinct head bearing sensory organs

Geomorphic - pertaining to the form of the Earth or of its surface features

Geomorphology - the science that treats the general configuration of the Earth's surface; the description of landforms

Habitat - the sum total of all the living and non-living factors that surround and potentially influence an organism; a particular organism's environment

Hard bottom - the floor of a water body composed of solid, consolidated substrate, including reefs and banks. The solid floor typically provides an attachment surface for sessile organisms as well as a rough three-dimensional surface that encourages water mixing and nutrient cycling.

Hedonic pricing method - estimates economic values for ecosystem or environmental services that directly affect market prices of some other good. Most commonly applied to variations in housing prices that reflect the value of local environmental attributes.

Held values - conceptual precepts and ideals held by an individual about something. Natural resource examples include the symbolic value of a bald eagle or the aesthetic value of enjoying a beautiful sunset (see assigned values).

Herbivory - the act of feeding on plants

Holdfasts - a part by which a plant clings to a flat surface

Human dimensions - an multidisciplinary/ interdisciplinary area of investigation which attempts to describe, predict, understand, and affect human thought and action toward natural environments in an effort to improve natural resource and environmental stewardship. Disciplines within human dimensions research is conducted include (but are not limited to) sociology, psychology, resource economics, geography, anthropology, and political science.

Human dominant values - this end of the natural resource value continuum emphasizes the use of natural resources to meet basic human needs. These are often described as utilitarian, materialistic, consumptive or economic in nature.

Human mutual values - the polar opposite of human dominant values, this end of the natural resource value continuum emphasizes spiritual, aesthetic, and nonconsumptive values in nature

Hydric soil - a soil that is saturated, flooded, or ponded long enough during the growing season to develop anaerobic conditions that favor the growth and regeneration of hydrophytic vegetation; field indicators of hydric soils can include: a thick layer of decomposing plant material on the surface; the odor of rotten eggs; and colors of bluish–gray, gray, black, or sometimes gray with contrasting brighter spots of color

Hydrodynamics - the motion of water that generally corresponds to its capacity to do work such as transport sediments, erode soils, flush pore waters in sediments, fluctuate vertically, etc. Velocities can vary within each of three flow types: primarily vertical, primarily bidirectional and horizontal, and primarily unidirectional and horizontal. Vertical fluxes are driven by evapotranspiration and precipitation. Bidirectional flows are driven by astronomic tides and wind-driven seiches. Unidirectional flows are downslope movement that occurs from seepage slopes and floodplains.

Hydrogeomorphology - a branch of science (geology) that studies the movement of subsurface water through rocks, either as underground streams or percolating through porous rocks.

Hydrology - the study of the cycle of water movement on, over and through the earth's surface; the science dealing with the properties, distribution, and circulation of water

Hydroperiod - depth, duration, seasonality, and frequency of flooding

Hydrostatic pressure - the pressure water exerts at any given point when a body of water is in a still motion

Hypersaline - extremely saline, generally over 30 ppt salinity (average ocean water salinity)

Hypoxic - waters with dissolved oxygen less than 2 mg/L

IMPLAN - a micro-computer-based input-output (IO) modeling system (see Input-output model below). With IMPLAN, one can estimate 528 sector I-O models for any region consisting of one or more counties. IMPLAN includes procedures for generating multipliers and estimating impacts by applying final demand changes to the model.

Indirect impacts - the changes in sales, income or employment within the region in backward-linked industries supplying goods and services to tourism businesses. The increase in sales of linen supply firms that result from more motel sales is an indirect effect of visitor spending.

Induced impacts - the increased sales within the region from household spending of the income earned in tourism and supporting industries. Employees in tourism and supporting industries spend the income they earn from tourism on housing, utilities, groceries, and other consumer goods and services. This generates sales, income and employment throughout the region's economy.

Infauna - plants that live in the sediment

Informed consent - an ethical guideline for conducting social science research. Informed consent emphasizes the importance of both accurately informing research participants as to the nature of the research and obtaining their verbal or written consent to participate. The purpose, procedures, data collection methods and potential risks (both physical and psychological) should be clearly explained to participants without any deception.

Infralittoral - a sub-area of the sublittoral zone where upward-facing rocks are dominated by algae, mainly kelp

Input-output model (I-O) - an input-output model is a representation of the flows of economic activity between sectors within a region. The model captures what each

business or sector must purchase from every other sector in order to produce a dollar's worth of goods or services. Using such a model, flows of economic activity associated with any change in spending may be traced either forwards (spending generating income which induces further spending) or backwards (visitor purchases of meals leads restaurants to purchase additional inputs -- groceries, utilities, etc.). Multipliers may be derived from an input-output models (see multipliers).

Instrumental values - the usefulness of something as a means to some desirable human end. Natural resource examples include economic and life support values associated with natural products and ecosystem functions (see non-instrumental values).

Intergenerational equity - the perceived fairness in the distribution of project costs and benefits across different generations, including future generations not born yet

Interstices - a space that intervenes between things; especially one between closely spaced things

Intertidal - alternately flooded and exposed by tides

Intrinsic values - values not assigned by humans but are inherent in the object or its relationship to other objects

Invasive species - a species that does not naturally occur in a specific area and whose introduction is likely to cause economic or environmental harm

Invertebrate - an animal with no backbone or spinal column; invertebrates include 95% of the animal kingdom

Irregularly exposed - refers to coastal wetlands with surface exposed by tides less often than daily

Lacunar - a small cavity, pit, or discontinuity

Lacustrine - pertaining to, produced by, or formed in a lake

Lagoons - a shallow stretch of seawater (or lake water) near or communicating with the sea (or lake) and partly or completely separated from it by a low, narrow, elongate strip of land

Large macroalgae - relatively shallow (less then 50 m deep) subtidal algal communities dominated by very large brown algae. Kelp and other large macroalgae grow on hard or consolidated substrates forming extensive three-dimensional structures that support numerous flora and fauna assemblages.

Large-scale commercial fishing - fishing fleets that are owned by corporations with large capital investments, and are highly mobile in their global pursuit of fish populations

Littoral - refers to the shallow water zone (less than 2 m deep) at the end of a marine water body, commonly seen in lakes or ponds

Longitudinal studies - social science research designed to permit observations over an extended period of time (see trend studies, cohort studies, and panel studies)

Macrofauna - animals that grow larger than 1 centimeter (e.g., animals exceeding 1 mm in length or sustained on a 1 mm or 0.5 mm sieve)

Macroinvertebrate - animals without backbones that can be seen with the naked eye (caught with a 1 mm^2 mesh net); includes insects, crayfish, snails, mussels, clams, fairy shrimp, etc

Macrophytes - plant species that are observed without the aid of an optical magnification e.g., vascular plants and algae

Mangroves - swamps dominated by shrubs that live between the sea and the land in areas that are inundated by tides. Mangroves thrive along protected shores with fine-grained sediments where the mean temperature during the coldest month is greater than 20º C, which limits their northern distribution.

Marine polyps - refer to the small living units of the coral that are responsible for secreting calcium carbonate maintaining coral reef shape

Market price method - estimates economic values for ecosystem products or services that are bought and sold in commercial markets

Marshes (marine and freshwater) - coastal marshes are transitional habitats between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water tidally or seasonally. Freshwater species are adapted to the short- and long-term water level fluctuations typical of freshwater ecosystems.

Mast - the nuts of forest trees accumulated on the ground

Measurement error - a type of survey error that occurs when a respondent's answer to a given question is inaccurate, imprecise, or cannot be compared to other respondent's answers

Meiofauna - diverse microorganisms that are approximately between .042 mm and 1 mm in size

Meristematic - the ability to form new cells that separate to form new tissues

Mesocosm - experimental tanks allowing studies to be performed on a smaller scale

Metadata - data that describes or provides background information on other data

Microfauna - animals that are very small and best identified with the use of a microscope, such organisms include protozoans and nematodes

Microinvertebrates - invertebrate animals that are so small they can only be observed with a microscope

Micro-topography - very slight changes in the configuration of a surface including its relief and the position of its natural and man-made features

Migratory - a creature that moves from one region to another when the seasons change

Morphology - the study of structure and form, either of biological organisms or features of the earth surface

Mottling - contrasting spots of bright colors in a soil; an indication of some oxidation or ground water level fluctuation

Mudflat - bare, flat bottoms of lakes, rivers and ponds, or coastal waters, largely filled with organic deposits, freshly exposed by a lowering of the water level; a broad expanse of muddy substrate commonly occurring in estuaries and bays

Multipliers - capture the size of the secondary effects in a given region, generally as a ratio of the total change in economic activity in the region relative to the direct change. Multipliers may be expressed as ratios of sales, income or employment, or as ratios of total income or employment changes relative to direct sales. Multipliers express the degree of interdependency between sectors in a region's economy and therefore vary considerably across regions and sectors

Nanoplankton - plankton of minute size, generally size range is from 2 to 20 micrometers

Native - an animal or plant that lives or grows naturally in a certain region

Nearshore - nearshore waters begin at the shoreline or the lakeward edge of the coastal wetlands and extend offshore to the deepest lakebed depth contour, where the thermocline typically intersects with the lake bed in late summer or early fall

Nekton - free-swimming aquatic animals (such as fish) essentially independent of wave and current action

Non-instrumental values - something that is valued for what it is; a good of its own; an end in itself. Natural resource examples include aesthetic and spiritual values found in nature (see instrumental values)

Non-market goods and services - goods and services for which no traditional market exists whereby suppliers and consumers come together and agree on a price. Many ecosystem services and environmental values fall under this category

Non-point source - a source (of any water–carried material) from a broad area, rather than from discrete points

Nonresponse error - a type of survey error that occurs when a significant proportion of the survey sample do not respond to the

questionnaire and are different from those who do in a way that is important to the study

Non-use values - also called "passive use" values, or values that are not associated with actual use, or even the option to use a good or service

Norms - perceived standards of acceptable attitudes and behaviors held by a society (social norms) or by an individual (personal norms). Serve as guideposts for what is appropriate behavior in a specific situation.

Nuisance species - undesirable plants and animals, commonly exotic species

Null hypothesis - a statement about the values of one or more parameters usually describing a condition of no change or difference

Nutria - a large South American semiaquatic rodent (*Myocastor coypus*) with webbed hind feet that has been introduced into parts of Europe, Asia, and North America

Nutrient - any inorganic or organic compound that provides the nourishment needed for the survival of an organism

Nutrient cycling - the transformation of nutrients from one chemical form to another by physical, chemical, and biological processes as they are transferred from one trophic level to another and returned to the abiotic environment

Octocorals - corals with eight tentacles on each polyp. There are many different forms that may be soft, leathery, or even those producing hard skeletons.

Oligohaline - an area of an estuary with salinities between 0.5 and 5.0 ppt

Oligotrophic - a water body that is poor in nutrients. This refers mainly to lakes and ponds

One-hundred year flood - refers to the floodwater levels that would occur once in 100 years, or as a 1.0 percent probability per year

Opportunity cost - the cost incurred when an economic decision is made. This cost is equal to the benefit of the most highly valued alternative that would have been gained if a different decision had been made. For example, if a consumer has $2.00 and decides to purchase a sandwich, the economic cost may be that consumer can no longer use that money to buy fruit.

Option value - the value associated with having the option or opportunity to benefit from some resource in the future

Organic - containing carbon, but possibly also containing hydrogen, oxygen, chlorine, nitrogen, and other elements

Organic material - anything that is living or was living; in soil it is usually made up of nuts, leaves, twigs, bark, etc.

Osmotic stress - water stresses due to differences in salinity between an organism and its aquatic environment

Outdoor recreation conflict - defined as behavior of an individual or group that is incompatible with the social, psychological or physical goals of another person or group

Oyster beds - dense, highly structured communities of individual oysters growing on the shells of dead oysters

Panel studies - longitudinal research that studies the same set of people through time in order to investigate changes in individuals over time (see longitudinal studies)

Pelagic - pertaining to, or living in open water column

Personal area network (PAN) - a computer network used for communicating between computer devices (including telephones and personal digital assistants) and a person

Petiole - the stalk of a leaf, attaching it to the stem

pH - a measure of the acidity (less than 7) or alkalinity (greater than 7) of a solution; a pH of 7 is considered neutral

Phenology - refers to the life stages a plant/algae experiences (e.g., shoot development in kelp)

Physiographic setting - the location in a landscape, such as stream headwater locations, valley bottom depression, and coastal position. Similar to geomorphic setting.

Physiography - a description of the surface features of the Earth, with an emphasis on the mode or origin

Phytoplanktivores - animals that eat planktonic small algae that flow in the water column

Phytoplankton - microscopic floating plants, mainly algae that are suspended in water bodies and are transported by wave currents because they cannot move by themselves swim effectively against a current.

Piscivorous - feeding on fish

Planktivorous - eating primarily plankton

Plankton - plant and animal organisms, generally microscopic, that float or drift in water

Pneumatocysts - known as gas bladders or floaters that help the plant stay afloat such as the bladders seen in the brown alga *Macrocystis*

Pneumatophores - specialized roots formed on several species of plants occurring frequently in inundated habitats; root is erect and protrudes above the soil surface

Polychaete - a group of chiefly marine annelid worms armed with setae, or bristles, extending from most body segments

Population - a collection of individuals of one species or mixed species making up the residents of a prescribed area

Population list - in social science survey research, this is the list from which the sample is drawn. This list should be as complete and accurate as possible and should closely reflect the target population.

ppt - parts per thousand. The salinity of ocean water is approximately 35 ppt

Precision - a statistical term that refers to the reproducibility of the result or measurement. Precision is measured by uncertainty and is usually expressed as the standard error or some confidence interval around the estimated mean.

Prop roots - long root structures that extend midway from the trunk and arch downward creating tangled branching roots above and below the water's surface, such as the mangrove *Rhizophora*

Propagules - a structure (cutting, seed, spore, rhizome, etc.) that causes the continuation or increase of a plant, by sexual or asexual reproduction

Protodeltaic - similar in form to the early stages of delta formation

Pseudofeces - material expelled by the oyster without having gone through the animal's digestive system

Quadrats - are rectangular, or square shaped instruments used to estimate density, cover and biomass of both plants and animals

Quality assurance/quality control plan - a detailed plan that describes the means of data collection, handling, formatting, storage, and public accessibility for a project

Random utility models - a non-market valuation technique that focuses on the choices or preferences of recreationists among alternative recreational sites. Particularly appropriate when substitutes are available to the individual so that the economist is measuring the value of the quality characteristics of one or more site alternatives (e.g., a fully restored coastal wetland and a degraded coastal wetland).

Receiving water bodies - lakes, estuaries, or other surface waters that have flowing water delivered to them

Recruitment - the process of adding new individuals to a population or subpopulation (as of breeding individuals) by growth, reproduction, immigration, and stocking; also a measure (as in numbers or biomass) of recruitment

Redox potential - oxidation-reduction potential; often used to quantify the degree of electrochemical reduction of wetland soils under anoxic conditions

Reference condition - set of selected measurements or conditions of minimally impaired waterbodies characteristic of a waterbody type in a region

Reference site - a minimally impaired site that is representative of the expected ecological conditions and integrity of other sites of the same type and region

Reflectance - The ratio of the light that radiates onto a surface to the amount that is reflected back

Regime - a regular pattern of occurrence or action

Reliability - the likelihood that a given measurement procedure or technique will yield the same result each time that measure is repeated (i.e., reproducibility of the result) (see Precision)

Remote sensing - the process of detecting and monitoring physical characteristics of an area by measuring its reflected and emitted radiation and without physically contacting the object

Restoration - the process of reestablishing a self-sustaining habitat that in time can come to closely resemble a natural condition in terms of structure and function

Restoration monitoring - the systematic collection and analysis of data that provides information useful for measuring restoration project performance at a variety of scales (locally, regionally, and nationally)

Rhizome - somewhat elongate usually horizontal subterranean plant stem that is often thickened by deposits of reserve food material, produces shoots above and roots below, and is distinguished from a true root in possessing buds, nodes, and usually scale-like leaves

Riparian - a form of wetland transition between permanently saturated wetlands and upland areas. These areas exhibit vegetation or physical characteristics reflective of permanent surface of subsurface water influence. Lands along, adjacent to, or contiguous with perennially and intermittently flowing rivers and streams, glacial potholes, and the shores of lakes and reservoirs with stable water levels are typically riparian areas. Excluded are such sites as ephemeral streams or washes that do not exhibit the presence of vegetation dependent upon free water in the soil.

Riverine - of, or associated with rivers

Riverine forests - forests found along sluggish streams, drainage depressions, and in large alluvial floodplains. Although associated with deepwater swamps in the SE United States, riverine forests are found throughout the US and do not exhibit prolonged flooding.

Rocky shoreline - extensive hard bottom littoral habitats on wave-exposed coasts

RVD (recreational visitor day) - one RVD is defined as 12 hours of use in some recreational activity. This could be one person using an area for 12 hours, or 2 people using an area for 6 hours each, or any combination of people and time adding to 12 hours of use.

Salinity - the concentration of dissolved salts in a body of water; commonly expressed as parts per thousand

Salt pans - an undrained natural depression in which water gathers and leaves a deposit of salt on evaporation

Sample - in social science survey research, this is a set of respondents selected from a larger population for the purpose of a survey

Sampling designs - the procedure for selecting samples from a population and the subsequent statistical analysis

Sampling error - a potential source of survey error that can occur when researchers survey only a subset or sample of all people in the population instead of conducting a census. To minimize this error the sample should be as representative of the population as possible.

Satisfaction - in outdoor recreation, satisfaction is defined as the difference between desired and achieved goals. Can be measured through surveys of recreation participants.

SAV (submerged aquatic vegetation) - marine, brackish, and freshwater submerged aquatic vegetation that grows on soft sediments in sheltered shallow waters of estuaries, bays, lagoons, and lakes

Seasonality - the change in naturally cycles, such as lunar cycles and flooding cycles, from one season to the next

Secondary data - information that has already been assembled, having been collected for some other purpose. Sources include census reports, state and federal agency data, and university research.

Secondary effects - the changes in economic activity from subsequent rounds of re-spending of tourism dollars. There are two types of secondary effects: indirect effects and induced effects.

Sector - a grouping of industries that produce similar products or services. Most economic reporting and models in the U.S. are based on the Standard Industrial Classification system (SIC code). Tourism is more an activity or type of customer than an industrial sector. While hotels (SIC 70) are a relatively pure tourism sector, restaurants, retail establishments and amusements sell to both tourists and local customers. There is therefore no simple way to identify tourism sales in the existing economic reporting systems, which is why visitor surveys are required to estimate tourist spending.

Sediment porewater - water in the spaces between individual grains of sediment

Seiches - a sudden oscillation of the water in a moderate-size body of water, caused by wind

Seine - a net weighted at the bottom with floats at the top so it remains vertical in the water. A seine can be towed behind a boat or smaller versions, attached to poles, may be operated by hand.

Senescence - the growth phase in a plant or plant part (as a leaf) from full maturity to death, also applies to winter dormancy

Sessile - plants that are permanently attached or established; animals that do not freely move about

Simple random sampling (SRS) - in survey research, when each member of the target population has an equal change of being selected. If a population list exists, SRS can be achieved using a computer-generated random numbers.

Small-scale commercial fishing - fishing operations that have relatively small capital investment and levels of production, and are more limited in terms of mobility and resource options (compared to large-scale operations). Terms that are commonly used to describe small-scale fishermen include native, coastal, inshore, tribal, peasant, artisanal, and traditional.

Social capital - describes the internal social and cultural coherence of society, the norms and values that govern interactions among people and the institutions in which they are embedded

Social impact assessment (SIA) - analysis conducted to assess, in advance, the social consequences that are likely to follow from specific policy actions and alternatives. Social impacts in this context refers to the consequences to human populations that alter the ways in which people live, work, play, relate to one another, organize and generally cope as members of society.

Social network mapping - community assessment research method used to collect, analyze, and graphically represent data that describe patterns of communication and relationships within a community

Socioeconomic monitoring - tracking of key indicators that characterize the economic and social state of a community

Soft bottom - loose, unconsolidated substrate characterized by fine to coarse-grained sediment

Soft shoreline - sand beaches, dunes, and muddy shores. Sandy beaches are stretches of land covered by loose material (sand), exposed to and shaped by waves and wind.

Stakeholders - individuals, groups, or sectors that have a direct interest in and/or are impacted by the use and management of natural resources in a particular area, or that have responsibility for management of those resources

Statistical protocol - a method of a analyzing a collection of observed values to make an

inference about one or more characteristic of a population or unit

Strands - a diffuse freshwater stream flowing through a shallow vegetated depression on a gentle slope

Structural habitat characteristics - characteristics that define the physical composition of a habitat

Subsistence - describes the customary and traditional uses of renewable resources (i.e., food, shelter, clothing, fuel) for direct personal/family consumption, sharing with other community members, or for barter. Subsistence communities are often held together by patterns of natural resource production, distribution, exchange, and consumption that helps maintain a complex web of social relations involving authority, respect, wealth, obligation, status, power and security.

Subtidal - continuously submerged; an area affected by ocean tides

Supralittoral region - is that area which is above the high tide mark receiving splashing from waves

Target population - the subset of people who are the focus of a survey research project

Taxa - a grouping of organisms given a formal taxonomic name such as species, genus, family, etc. (singular form is taxon)

Temporal - over time

Thermocline - the region in a thermally stratified body of water which separates warmer oxygen-rich surface water from cold oxygen-poor deep water and in which temperature decreases rapidly with depth

Tide - the rhythmic, alternate rise and fall of the surface (or water level) of the ocean, and connected bodies of water, occurring twice a day over most of the Earth, resulting from the gravitational attraction of the Moon, and to a lesser degree, the Sun

Topography - the general configuration of a land surface or any part of the Earth's surface, including its relief and the position of its natural and man–made features

Transect - two types of transects, point and line. Point intercept transect methods is performed by placing a point frame along a set of transect lines. Line transects are when a line is extended from one point to the next within the designated sample area

Transient - passing through or by a place with only a brief stay or sojourn

Transit - a surveying instrument for measuring horizontal and vertical angles; appropriate to help determine actual location of whale surfacing. It contains a small telescope that is placed on top of a tripod.

Travel cost method (TCM) - TCM is used to estimate monetary value of a geographical site in its current condition (i.e., environmental health, recreational use capacity, etc.) by site-users. Individuals or groups report travel-related expenditures made while on trips to single and multiple recreational sites. Market values are used.

Trend studies - longitudinal research that studies changes within some general population over time (see longitudinal studies)

Trophic - refers to food, nutrition, or growth state

Trophic level - a group of organisms united by obtaining their energy from the same part of the food web of a biological community

Turf - cover (the ground) with a surface layer of grass or grass roots

Unconsolidated - loosely arranged

Utilitarian value - valuing some object for its usefulness in meeting certain basic human needs (e.g., food, shelter, clothing). Also see human-dominant values

Validity - refers to how close to a true or accepted value a measurement lies

Vibracore - refers to a high frequency, low amplitude vibration, coring technique used for collecting sediment samples without disrobing the sample

Viviparous - producing living young instead of eggs from within the body in the manner of nearly all mammals, many reptiles, and a few fishes; germinating while still attached to the parent plant

Water column - a conceptual volume of water extending from the water surface down to, but not including the substrate. It is found in marine, estuarine, river, and lacustrine systems.

Watershed - surface drainage area that contributes water to a lake, river, or other body of water; the land area drained by a river or stream

Willingness-to-pay - the amount in goods, services, or dollars that a person is willing to give up to get a particular good or service

Zonation - a state or condition that is marked with bands of color, texture, or plant species

Zooplanktivorus - animals that feed upon zooplankton

Zooplankton - free-floating animals that drift in the water, range from microscopic organisms to larger animals such as jellyfish

References

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