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.)

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.

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 8: RESTORATION MONITORING OF SOFT SHORELINE HABITATS

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INTRODUCTION

Soft shoreline habitats are composed of soft substrates such as mud, sand, and gravel found along the coast. According to Cowardin et al. (1979), these habitats are composed of unconsolidated substrates with less than 75 percent areal cover of stones, boulders, or bedrock and less than 30 percent vegetative cover other than pioneer species. For the purpose of this document, habitats composed of cobble-gravel will not be addressed. This chapter primarily discusses sandy beaches, mudflats, and sandflats.

SANDY BEACHES

Sandy beaches (Figure 1) are land covered by loose material with minimal vegetation, extending landward from the low water line to the place where there is distinct change in material or physical features (Brown et al. 1990; Finkl 2004; USEPA 2004a).

Beaches are influenced by various environmental factors including changes in oceanic and riverine activity as well as ocean salinity. For example, the natural erosion process caused by waves and tides influences the physical features of beaches. These factors are responsible for the extraordinary high hydric deficit (minimum moisture levels) of such beaches. These environmental factors also make a sandy beach one of the most inhospitable places for life forms (Marquinez Garcia et al. 2003).

Vegetation found along sandy beaches is also minimal because plant seeds are not able to settle and establish themselves. However, plant species living in habitats immediately connected with beaches such as dunes include:

Beach wild rye (e.g., *Leymus mollis*)
Beach bur (e.g., *Franseria chamissonis*)
Black sage (e.g., *Salvia mellifera*), and
Beach salt bush (e.g., *Atriplex leucophylla*)

Figure 1. Sandy beaches on Midway Island in the Pacific Ocean. Photo courtesy of NOAA Office of Response and Restoration.

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Organisms primarily found in beach habitats include:

Amphipods
Crustaceans
Polychaetes, and
Bivalves

Sandy beaches and other soft shoreline habitat types not only support plants and animals by providing shelter, breeding, nursery, and feeding grounds, but these habitats, particularly beaches, support many tourist-related activities. Florida, California, Virginia, Hawaii, the Caribbean, and other parts of the world have developed hotels, resorts (Figure 2), and vacation homes along beach waterfronts that assist in increasing the tourist industry (discussed further in Chapter 14 - Human Dimensions of Coastal Restoration). Beach-related activities that generally support coastal tourism include:

- Marinas
- Recreational fishing
- Water sports (e.g., using jet skis and canoes)
- Beach sports (e.g., volleyball)
- Restaurants and bars
- Snorkeling
- Kayaking
- Sun bathing (Figure 3), and
- Viewing of marine mammals, waterfowl, and shorebirds

Although sand dunes are not discussed in detail in this chapter, it is important to understand the close link dunes have with sandy beaches (Figure 4).

The first stage of dune construction is the embryonic dune, sometimes known as "yellow dune" or primary dune (Figure 5). Yellow dunes develop closest to the beach and form by ripples or raised sand surfaces of the upper beach or by a seaward fringe at the foot of tall dunes (The European Habitats Directive: Natura 2000 code 2110[3]).

The next phase of dune construction is commonly known as "white dune" or secondary dune (Figure 5), and is typically characterized by the presence of European beachgrass (*Ammophila arenaria*). This species has been introduced on the West coast of the United States to help stabilize sand on dunes and beaches since the

Figure 2. Public boat ramps allow easy access to recreational fisheries. Photo courtesy of W.B. Folsom, NOAA National Marine Fisheries Service. http://www.photolib.noaa.gov/fish/images/big/fish1125.jpg

Figure 3. Sun bathers on a sandy beach along the Northern Shore of Oahu, Hawaii. Photo courtesy of Andrew Mason, NOAA National Centers for Coastal Ocean Science.

[3] The "Habitats" Directive (Council Directive 92/43/EEC of May 21, 1992 on the conservation of natural habitats and of wild fauna and flora) is a European Union legislative instrument that establishes a common framework for the conservation of wild animal and plant species and natural habitats. One of its main products is the creation of a network of special areas of conservation, called Natura 2000, to "maintain and restore, at favorable conservation status, natural habitats and species of wild fauna and flora of Community interest" (EEC 1992).

Figure 4. Beach and dunes in the Cantabric Sea. La Lanzada Beach, Pontevedra, Spain. Photo courtesy of Spanish Ministry of Environment.

early 1900s (Knudson 1917; Barbour and Johnson 1977; Crook 1979a, b). This invasive species has threatened coastal sand dunes in the eastern and western United States, displacing native dune species and significantly altering the morphology of dune systems that it invades. White dunes are considered the first "true" stage of a real dune, which contributes to the landscape consisting of sand hills (i.e., cordons of dunes).

MUDFLATS AND SANDFLATS

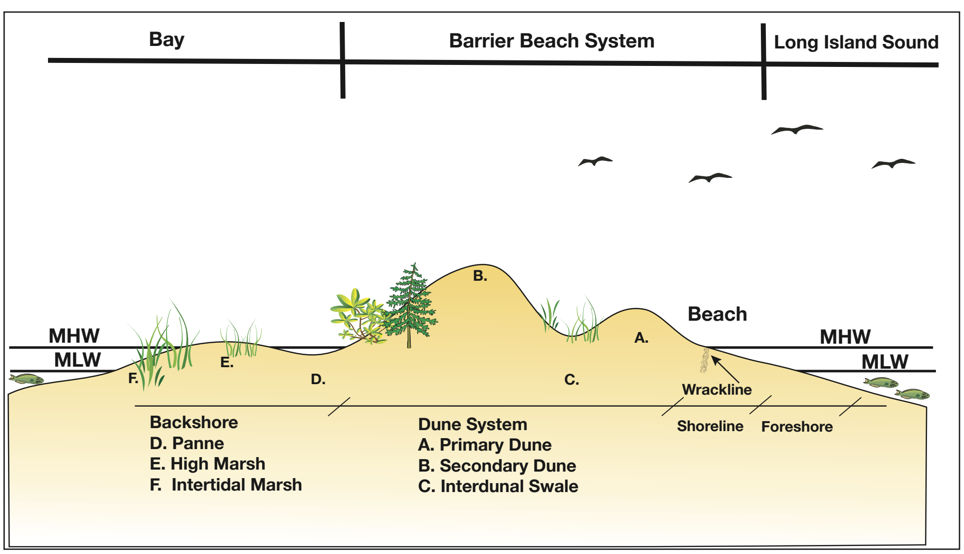
Mudflats and sandflats (Figure 6) can be found around the high or low watermarks in tidal and intertidal zones. These habitat types develop along gently sloping coastal areas where sediment is available, in areas without strong wave action, and in moderately sheltered coastal inlets and bays where diurnal tides are present (i.e., covered twice daily by tides) (Brown et al. 1990; Hardie and Shinn 1986; Morelock 2000).

There are many sources that provide a good description of mudflats and sandflats such as the European Economic Community's (EEC) "Natura 2000" Habitat Network. The general description of these habitats is that it:

- Consists of fine-grained sediment (sand and mud)
- Connects to seas and/or associated lagoons, and
- Is not covered by sea water at low tide

These habitat types are widely distributed along both coasts of the United States; the Atlantic coast of Europe, particularly around the North Sea; and other parts of the world. Mudflats and sandflats *constantly* covered by water at low tide are not discussed in this chapter but are discussed in Chapter 7 - Restoration Monitoring of Soft Bottom Habitats. Chapter 9 - Restoration Monitoring of Submerged Aquatic Vegetation, Chapter 10 - Restoration Monitoring of Coastal Marhes, and Chapter 11 - Restoration Monitoring of Mangroves also refer

Figure 5. Cross-section of an idealized beach, dune, and marsh system, including the different types of dunes (A, B) adjacent to the shoreline, where beaches are situated. Drawing modified from USEPA Long Island Sound Office.



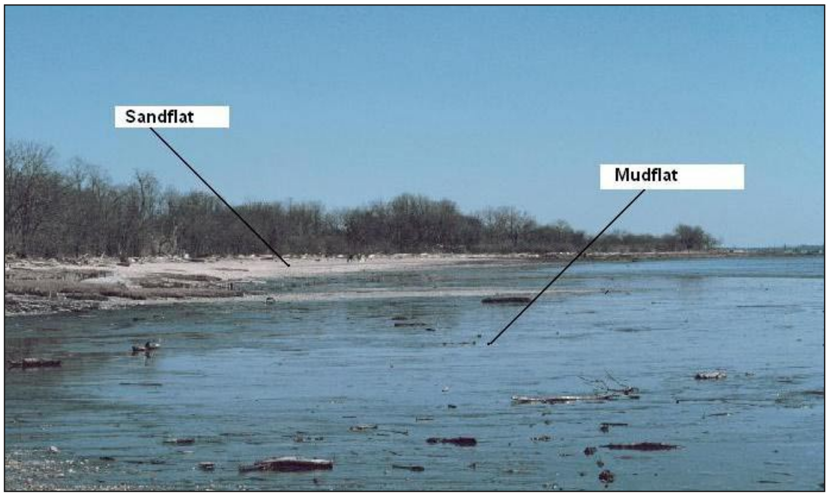


Figure 6. Mud and sand flats of the Delaware River. Photo courtesy of NOAA Restoration Center. NOAA Central Library http://www.photolib.noaa.gov/habrest/r0020104.htm

to soft shoreline habitats because of their close linkage to these habitat types. Soft shoreline habitats for instance provide the substrate upon which marsh, dune, and mangrove vegetation develop.

Mudflats

Mudflats are found in low energy coastal environments and consist mainly of silts, clays, and some sand particles, and they often contain high organic content. Larger mudflats are found in estuaries where the riverine dynamic is lower allowing fine grained sediments to settle. Where there is a strong riverine dynamic, mudflats are created only within the most inner parts of estuaries and in areas adjacent to channels (Marquinez et al. 2003). In areas toward the mouth of estuaries where salinity and wave energy are higher, however, the amount of sand increases, therefore sandflats are more likely to develop.

Mudflats are linked by physical processes and may be dependent on other coastal habitats which help provide sediment such as soft cliffs. These soft cliffs commonly appear in the natural sequence of habitats between subtidal channels and vegetated salt marshes. In large estuaries, mudflats can be several miles wide and commonly form the largest part of the intertidal area of estuaries. For example, about 531,000 hectares of tidal estuarine wetlands exist in Great Britain of which 267,800 hectares are tidal sandflats and mudflats (Davidson and Buck 1997).

Although mudflats are not as popular as beaches with regard to tourist activities, they are very important to the ecological community because they provide rich organic matter for plants and animals to utilize as food. Important plant species found in muddy habitats and other associated habitats include:

- Seagrass (e.g., *Spartinia anglica* and *Zostera* spp.)
- Blunt spike rush (e.g., *Eleocharis obtusa*)
- Bull rush (e.g., *Scirpus* spp.), and
- Mangroves (e.g., *Avicennia* and *Rhizophora*)

Organisms commonly found in mudflats include:

- Molluscs (e.g., oysters and mussels)
- Annelids (e.g., worms), and
- Anthropods (crabs and shrimp) (Moore et al. 1968; Peterson and Peterson 1979)

Different species of birds feed and/or nest in these habitats. For instance, wading birds such as great egret (*Casmerodius albus)* and great blue heron (*Ardea herodias*) feed on small fish, while shorebirds such as clapper rail (*Rallus longirostris)* and piping plover (*Charadrius semipalmatus*) feed on amphipods and insects found on the sediment surface (Soots and Parnell 1975; Recher 1966).

Sandflats

Sandflats tend to develop towards the outer, more exposed shores and offshore banks and bars. They provide substrates that support marsh vegetation in estuaries and other tidal inlets. Sandy foreshores act as constructive pathways that assist in the formation of sand dunes (Doody 2003). The larger sand flats in bigger estuaries are created mainly near the mouth of estuaries, where the high riverine dynamic is more favorable for course-grained (e.g., sand) deposition than fine sediment (e.g., mud) deposition (Marquinez et al. 2003).

HUMAN IMPACTS TO SOFT SHORELINE HABITATS

Soft shoreline habitats experience tremendous pressures from human-induced impacts in the coastal zone, including:

- Habitat loss
- Reduced sediment supply due to erosion
- Changes in sediment patterns
- Changes in wave patterns
- Pollution
- Increased nutrient loads
- Sea level change, and
- Harvesting of animals (e.g., lugworms for fishing)

These impacts can be categorized into three groups: physical disturbances, coastal erosion, and pollution.

Physical Disturbance

Many areas along soft shores are exposed to disturbances as a result of construction during coastal development (Burger 1988). On mudflats in New Jersey, for example, birds moved farther along the beach and out onto mudflats when construction activities and demolition took place. As a result, bird populations were altered and other mobile animals migrated to more suitable areas. In addition, sessile or slow moving organisms in the area under construction were killed during the process, thus resulting in reduced numbers of certain benthic species.

In areas where ports and other industrial-related development is involved, large expanses of tidal flats can be destroyed. Dams, offshore sand extraction, maintenance dredging (in estuaries), and protection of eroding cliffs can reduce both sediment supply to the coast and high erosion rates. Offshore structures such as breakwaters can also restrict long-shore drift as well as change sediment and wave patterns. The construction of artificial barriers (Figure 7) may restrict tidal flow, thereby destroying tidal flats and negatively affecting plant growth and animals that rely on these habitats for food (Davidson et al. 1991).

In some cases, increased urbanization (e.g., as a result of hotels, marinas, water sports, etc.) on exposed sandy beaches can cause detrimental effects to animals living in this habitat such as the disruption and damage to bird nesting areas and crustaceans for ghost crabs (*Ocypode cordimana*) (Barros 2001). Researchers have observed that the number of burrows made by ghost crabs was fewer on urban beaches than on non-urban beaches. Thus, urbanization along beaches destroys habitats for crabs and other species of animals occupying the shoreline and causes a decline in the number of organisms (Barros 2001). Human trampling and use of off-road motor vehicles also disturbs and in some cases kills benthic communities. For example, trampling and motor vehicles may completely uproot plants from the sediment or damage the plant structure, thereby disrupting its normal growth process. Many of these organisms are food sources for other species such as birds or fishes. If the habitat is disturbed and the

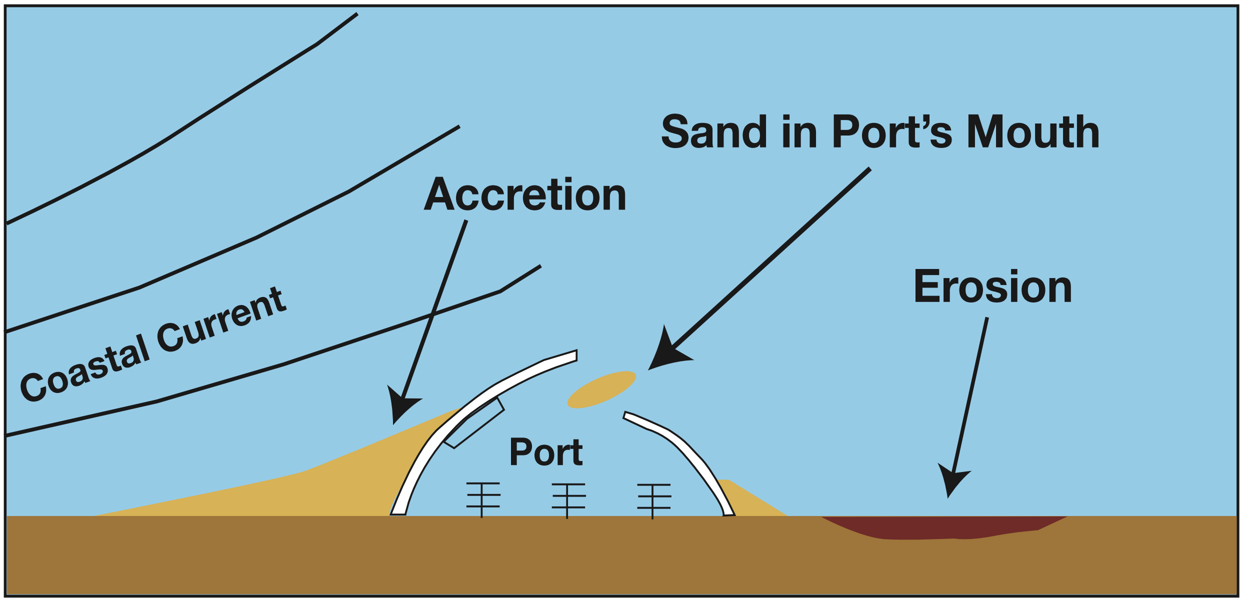


Figure 7. An artificial barrier interrupts coastal currents, thus interrupting the transportation of sand along the near shoreline. Diagram courtesy of the Spanish Ministry of Environment.

number of benthic organisms is significantly reduced, then there may be a shift in fish or bird populations within that specific area.

Mechanical devices used for cleaning beaches can unintentionally destroy soft shoreline habitats by disturbing the vegetative growth on areas of the beach closest to dunes. For example, mechanical beach raking can be harmful to aquatic vegetation, nesting birds, sea turtles, and other types of aquatic life. Beach raking not only prevents the natural re-vegetation process, but also uproots the very few species of plants that colonize sandy habitats, therefore causing the shore to be more vulnerable to erosion (USEPA 2004b).

Coastal Erosion

Coastal erosion is one of the largest socio-economic problems that challenge states and localities. It is always accompanied with shoreward recession of the shoreline and loss of land area. Erosion can cause significant economic losses, social problems, and ecological damages. The problem of erosion may extend hundreds of kilometers along large deltas and may have transboundary implications. In the United States, beach erosion is caused primarily by human-induced sand removal from beaches. Activities that involve the removal of sand include dredging of ship cannels without sand bypassing (i.e., placing sand from where it was originally removed) and sand entrapment by jetties (i.e., rock walls built to keep sand from entering ship channels), groins[4] seawalls, and dams. Construction of ship channels in Port Canaveral, Florida is an example of sand removal from beaches when the dredged sand is not bypassed (Douglas 2002). Throughout the construction of this channel, more than eight million cubic yards were dredged and dumped in deep waters away from the beach. Additional sand was dredged each year to maintain the depths needed for ship clearance (Douglas 2002). Severe beach erosion was also seen on Assateague Island in Ocean City, Maryland as a result of inlet jetties. A sufficient amount of sand was trapped on the updrift[5] side of the jetty and deposited in deep water, resulting in severe erosion and destruction of the downdrift[6] of the barrier island (Douglas 2002).

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[4] A low artificial wall-like structure extending from the land to seaward to prevent coast erosion.
[5] The opposite direction to the main long shore movement of beach material.
[6] The main direction in which shoreline materials such as sand are moved.

In other areas outside the United States such as the Mediterranean, coastal erosion has been a longstanding, large-scale issue around the deltaic areas (e.g., the Nile and Po River deltas, and smaller deltas such as for the Albanian River). It has also been a major issue at smaller scales, especially at the municipal and tourist resort beaches along the more densely developed northern Mediterranean coast, following the flux of people to the coast and the sudden increase of the tourism industry. According to the *Atlas of the Italian Beaches* (Fierro and Ivaldi 2001), 27 percent of the Italian beaches - which constitute 61 percent of the Italian coastline - are receding, 70 percent are in equilibrium, and only 3 percent are expanding as a result of sediment deposition or accumulation (i.e., prograding). In pocket beaches however, it could be a local phenomenon affecting only local residents and/or the tourism industry (Özhan 2002).

Pollution

Pollution as a result of industrial discharges can also impact plants and animals along soft shores. For instance, chemicals in industrial discharges can affect meiofauna in mudflats (Mohd Long 1987). A study showed that the density of meiofauna was significantly lower nearest the points of discharge, closest to the shore. Organochlorine pesticide residue runoff was also found in mudflats in Texas where wintering shorebirds are found. Pesticide residues including dichlorodiphenyldichloroethylene (DDE), dieldrin, and toxaphene were detected on shorebirds. Ninety-five percent of shorebirds were exposed to some level of DDE, 13 percent were exposed to dieldrin, and 22 percent were exposed to toxaphene. Levels of DDE increased in all shorebirds from October to December, with potentially hazardous levels accumulating in some long-billed dowitchers (*Limnodromus scolopaceus*) and American avocets (*Recurvirostra americana*) (White et al. 1983). In addition, pesticide residues and other agricultural chemicals may be potentially dangerous to birds and other organisms by inhibiting them to feed and grow, which can result in high mortality rates.

Freshwater flows due to human activities and discharges of sewage effluents may also affect animal and plant communities by reducing environmental quality, such as altering salinity levels and nutrient regimes (Lercari and Defeo 2003). Studies have shown that freshwater canal discharges can negatively affect resident macrobenthos on an exposed sandy beach by lowering salinity, beach width, swash width, and slope. Macrobenthos abundance, biomass, species richness, diversity, and evenness were also significantly reduced closest to the source of disturbance and in areas where salinity was lower (Lercari and Defeo 2003).

Hazardous substance spills can also significantly impact beach communities. Oil spills that occur on beaches, for instance, may negatively affect animals such as birds, crustaceans, and invertebrates that utilize this habitat. In some cases, birds may be covered with oil while attempting to feed on marine organisms in oil-contaminated shallow waters. Once covered with oil, birds become exhausted because of the excess energy they exert while trying to free themselves from the oil-contaminated water. As a result, mobility is often reduced and their bodies subside, causing them to drown.

One of the most well known oil spill events is the *Exxon Valdez* oil spill in Prince William Sound, Alaska in 1989 (Peterson 2000). This spill event negatively affected animal and plant species in many shoreline habitats including sandy beaches and sandflats (Peterson 2000). Following the oil spill, scavenging terrestrial birds such as bald eagles and northwestern crows in the intertidal zone either died or experienced reproductive losses; pigeon guillemots showed reduced feeding on organisms such as sand eels and capelin, and therefore migrated to more suitable feeding areas (Peterson 2000).

Figure 8. Dredgers throwing sand into a nourishment restoration project. Photo courtesy of Bert Visser's Directory of Dredgers. http://www.dredgers.nl

RESTORATION EFFORTS

Restoration efforts for beaches involve beach fills and cleanup, as well as sand nourishment (Figure 8) particularly in eroded areas. Beach nourishment is a method to counteract beach erosion by dredging sand from offshore and then pumping it onto the beach (Nelson 1993). This process, however, may not always be favorable to the ecosystem and may result in short-term decline in animal numbers, biomass, and diversity (Peterson et al. 2000; Rumbold et al. 2001). Nourishment, referred to here, is performed to restore eroded beaches closest to its natural state. Other types of nourishment include:

- Recycling shingle[7] (i.e., coarse gravel) and/or sand by accumulating material and moving it from the accumulated area to the eroding area
- Bypassing sediment, sand, shingle, and
- Using dredged material to re-create tidal sandflats/mudflats and/or create saltmarshes

Such restoration efforts can be expensive and may require funding from various sources. For example, government agencies such as the National Oceanic and Atmospheric Administration (NOAA) provide funding and scientific expertise to help protect, manage, and restore coastal and marine habitats. Under NOAA, the Coastal Services Center has developed a guidance document entitled "Beach Nourishment: A Guide for Local Governments" to help state and local organizations make knowledgeable decisions regarding beach nourishment (see http://www.csc.noaa.gov/opis/html/descrip.htm). Additional publications regarding beach restoration are: Nordstrom 2000; MMS 2001; Greene 2002; and Dean 2003.

Mudflats, on the other hand, are restored primarily to support seagrass, mangrove, and marsh vegetation that might have been degraded due to human activities such as dredging. In some cases when mudflats are eroded or otherwise degraded, marsh vegetation found in these habitat types also declines. Once marsh vegetation is reduced, the number of organisms that feed on grass species or shorebirds occupying grass areas is also reduced. Efforts to restore the mudflat depend on the reason for degradation and goals of the project. An important goal is to restore the hydrological functionality of the habitat. This may involve raising the elevation of the flat, increasing tidal flow to support plant growth which in turn supports many other

[7] A term for coarse beach material, a mixture of gravel, pebbles and larger material.

organisms, and planting vegetation on degraded mudflat areas.

Assuming that all the physical conditions affecting the site remain the same, successful restoration relies on increasing sediment availability. A key question for success in relation to bird usage is the speed and type of colonization by invertebrates and plants, notably *Zostera* spp. Where there is abundant sediment either naturally or as a result of sediment recharge, physical structures can be employed to increase the rate of sedimentation. The methods applied, to some extent, depend on whether the aim is to move the habitat seaward, maintain the existing position of the flats (by raising the level of the surface), or to allow re-creation on former tidal land. Each method chosen for restoration purposes may be used separately or in combination with other approaches designed to improve sea defenses (through beach nourishment) and/or re-create saltmarshes by managed realignment. In addition to re-creating the tidal flats, the extent of recolonization by invertebrates and seagrass species such as *Zostera* can be enhanced. This design may be done mainly to improve seagrass usage by wintering and migratory waterfowl in marshes, mudflats, and sandy beaches (Doody 2003).

The three principle approaches to restoring sandy beaches, sandflats, and mudflats are:

- Moving the habitat seaward by encouraging the accumulation of sediment on the foreshore through a variety of techniques, including the construction of polders[8]
- Maintaining the existing shoreline using various methods including beach nourishment, and
- Retreating the habitat landward by altering a flood-protected area to allow flooding (i.e., managed realignment)

MONITORING

In order to obtain the support of government agencies (local, state, and federal) and community members for restoration of soft shoreline habitats, practitioners must develop an understanding of the ecological role of the various plants and animals within the habitat. Once the practitioner has obtained this information through monitoring and review of previous studies of the area, it can be presented to government agencies and the community to gain their support (discussed further in Chapter 14).

Before restoration is performed, monitoring should be performed not only to understand the ecological role of plants and animals present in the habitat, but also to gather baseline information on the habitat's conditions. This helps to determine whether the habitat is suitable for restoration and what factors may affect progress of the project. For example, some mudflat or sandy areas may not be suitable for restoration if the original impacts that degraded the habitat are ongoing and cannot be mitigated through restoration efforts. Monitoring is also performed during restoration to allow practitioners to detect any changes that may have occurred such as whether the habitats are stable, whether erosion or alteration are occurring due to human-induced or natural pressures, and whether modifications can made to improve the project. Post-restoration monitoring is done to determine whether the project accomplished the goals that were set. Surveys should be considered when performing any coastal restoration monitoring, as these surveys can provide detailed information on threatened coastal areas and help identify measures to be incorporated into the restoration plan (Wise and Kraus 1993; Tyler and McHattie 1999).

[8] An area of low-lying land that has been reclaimed from a body of water and is protected by dikes.

STRUCTURAL CHARACTERISTICS OF SOFT SHORELINE HABITATS

This section presents the structural characteristics of soft shoreline habitats that may be applicable to restoration monitoring. The characteristics described below refer to the physical and hydrological features of the habitat. They may be potential parameters to gather baseline information and monitor restoration efforts as they may influence soft shoreline restoration projects. Not all of these structural characteristics, however, are expected to be measured or monitored in every restoration project. Additional information is provided to help educate the reader on the ecology of soft shoreline habitats.

Structural characteristics of these habitats include:

Physical

- Habitat created by soft substrates
- Topography/Geomorphology
- Sediment grain size
- Wind speed and direction
- Organic content
- Turbidity

Hydrological

- Waves
- Coastal and littoral currents
- Tides/Hydroperiods
- Water sources

As these structural characteristics can influence soft shoreline restoration efforts, practitioners should first monitor them to ensure conditions are favorable for restoration success and determine how these parameters can potentially affect restoration progress.

PHYSICAL

Habitat Created by Soft Substrates

Sandy beaches, as previously mentioned in the introduction, are land areas covered by loose material (sand) extending over a wide range of area (Brown et al. 1990; Finkl 2004). Beaches and other soft shoreline habitat types range from intertidal beaches to mudflats that are comprised generally of unconsolidated sediment (Finkl 2004). Beaches are formed when sand or other loose materials are deposited along the shore by waves or currents that are influenced by winds. Sand particles may be suspended in seawater and transported by currents flowing parallel to the beach as waves break at the shore. The shape of a beach is influenced by both constructive and destructive waves, and whether the material is sand or other materials, such as shingle (Bascom 1980). Constructive waves transport material further up the beach shore, whereas destructive waves transport beach material down the beach and out to sea. The backwash of the waves continuously removes material, thus forming a gently sloping beach (Bascom 1980).

Mudflats (Figure 9) and sandflats however form along slightly sloping coastal areas where sediment is available and wave energy is low. Sediment deposited above high tide (i.e., the supratidal zone) is often inundated during spring or storm tides in both mudflats and sandflats. This zone can be divided into vegetated and non-vegetated intertidal mudflats and/or sandflats (Morelock 2000). The ecological community of mudflats may rely on other habitats such as saltmarshes because bacteria and fungi affiliated with marshes break down marsh plants and help replenish mudflat sediments. In return, mudflats disperse wave energy, which helps prevent erosion of saltmarshes and flooding in low-lying areas. Mudflats contain high biological productivity and an abundance of organisms, but low diversity with few rare species (Reise 1985).

Sampling and Monitoring Methods

Digital Shoreline Mapping System - There are various methods to map shorelines to

Figure 9. Tidal mudflat with *Spartina*. Photo courtesy of South Florida Water Management District. http://www.sfwmd.gov/org/wrp/wrp_ce/2_wrp_ce_info/photos/hires/sl_inlet_spartina.jpg

show their past and present conditions. The Digital Shoreline Mapping System (DSMS) for example, has been used to determine historical shorelines from maps and provide clarity in aerial photographs (Thieler and Danforth 1994). This system allows researchers to quantify and analyze various sources of error during the mapping procedure. It also allows baseline information to be gathered on the habitat's condition before restoration is performed. This helps to determine whether restoration will be suitable at a potential site (Thieler and Danforth 1994). It also allows for one person to perform shoreline mapping in a small lab using computer hardware and software. The DSMS produces shoreline position data that correspond with geographic information systems (GIS).

Digital Shoreline Analysis System - The Digital Shoreline Analysis System (DSAS) is used to calculate shoreline rates-of-change from a sequence of shoreline data in a GIS. Using this system at selected times throughout the restoration project can help track changes and identify factors that may prevent restoration progress towards achieving a naturally sustainable habitat. The combined use of DSMS and DSAS can provide accurate shoreline positions and erosion rates (Thieler and Danforth 1994). The use of mathematical models along with referred tools can also help in the prediction of shoreline evolution.

Other field methods, data collection, and analysis procedures for monitoring changes in soft shoreline physical features include: aerial photography, satellite imagery, profile surveys, and bathymetric (hydrographic) records (Gorman et al. 1998). Aerial photographs and satellite images can serve as base maps to interpret landform changes and quantify shoreline movement, both of which can help track restoration progress over time.

Profile surveys, which can be obtained from government agencies and universities, can be used to assess shoreline changes along and across the shore (Gorman et al. 1998).

Bathymetric data for a specific project may be plotted using State Plane coordinates[9], while hydrographic data from federal agencies such as the United States Geological Survey (USGS), United States Army Corps of Engineers (USACE), and NOAA may be provided in latitude/longitude coordinates.

Long-term data collected using methods discussed previously can be used to evaluate natural and human-induced changes to a coastal system that can affect restoration progress including storm history, seasonality, wave climate and engineering changes (i.e. large and small scale landform changes) (Gorman et al. 1998).

[9] A coordinating system that separates the U.S. states, Puerto Rico, and U.S. Virgin Islands into over 120 numbered zones. Each zone has a designated code number that identifies the projection parameters for the region.

Topography/Geomorphology

Although soft shoreline habitats are usually flat, strong wind-induced waves and currents transporting sediment (mud or sand) can cause substrates to accumulate and form mount-like characteristics such as sand bars and mud banks (Purandara et al. 1996). Sandy shores, however, have a gradual slope as a result of constant wave action. For example, sandy beaches have a relatively smooth profile and are basically straight or gently curved (Russell 1958). Geomorphic features (Figure 10) relating to processes that form and shape beaches (Finkl 2004) include:

- Berm - the near horizontal part of the beach landward of the sloping foreshore
- Berm crest - the seaward limit of the berm
- Beach face - berm crest to low tide waterline, in the swash zone[10]
- Trough - extended depressions or sequence of depressions along the lowered beach or in the offshore zone that may be exposed at low water, and
- Longshore bar - an elongate, partially submerged, and sand ridge or ride which may be exposed at low water (Finkl 2004)

Muddy shores on the hand, appear relatively flat most of the time (Eltringham 1971) and form during calmer wave periods (Pethick 1996). Changes in frequency of wave events, the tidal regime, and sediment availability can affect the habitat's elevation and the pattern of its profile. If sediment availability decreases, lower deposition rates will result. Therefore, mudflats do not completely recover from erosion before the next wave activity occurs. This can result in a decrease in surface elevation (Pethick 1996). If erosion occurs, vegetation such as mangroves may withdraw along the coastline when landward sand is transferred, covering the mudflat, and smothering vegetation (Cohen and Lara 2003). As part of a soft shoreline restoration plan, practitioners must devise a strategy that will successfully restore the habitat structure to a naturally sustainable habitat supporting vegetation growth and a large number of organisms. Human activities may also cause changes in soft shoreline habitats (discussed in "Human Impacts to Soft Shoreline Habitats" section of this chapter). For instance, dredging of canals may alter water flow and cause an increase or decrease in the slope of the mudflat, which may in turn disrupt benthic communities.

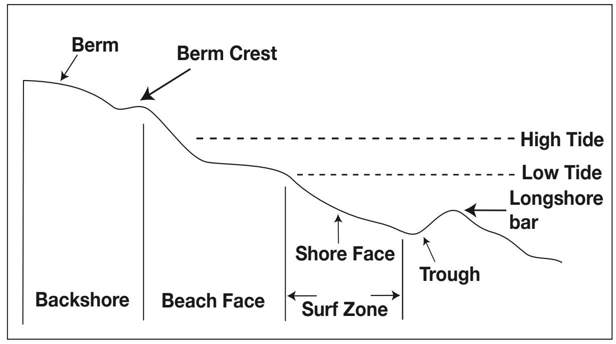

Figure 10. Geomorphic features of a beach. Diagram courtesy of Felicity Burrows, NOAA National Centers of Coastal and Ocean Science

Sampling and Monitoring Methods

Environmental Sensitivity Index (ESI) - In the United States, NOAA's ESI mapping is commonly used to map and gather information on coastal sensitivity, biological resources, and human use of these habitat types (Finkl 2004). The maps identify sensitive resources and are used to create mitigation plans prior to an oil or chemical spill to minimize the damage if such an event occurs. The ESI maps also include geomorphology of shoreline types which can assist in identifying hazards during a spill event affecting progress towards restoring soft shoreline habitats. These maps are assembled in both paper and digital formats to be easily accessed by various coastal managers and restoration practitioners. The maps provide a consistent approach for mapping coastal

[10] The area of a beach where water rushes up following the breaking of a wave.

geomorphology as well as consistent color schemes and symbolization for coastal habitats (Finkl 2004).

Airborne (Light Detection and Ranging) LIDAR - A LIDAR device may also be used to map and monitor shoreline topography through surveys (Gibeaut et al. 2001; Woolard et al. 2003). For restoration purposes, this method may be used in pre-monitoring and post-monitoring of soft shoreline geomorphology. LIDAR surveys integrate a scanning laser, a device that records aircraft motion, and global positioning system (GPS) receivers. LIDAR can be used to survey beaches and collect data points less than one meter apart from one another. These devices also help create detailed beach topographic models and soft shoreline characterizations. Many organizations, such as NOAA's Coastal Services Center, use LIDAR to map coastal topography in the United States by using a GPS reference frame to obtain LIDAR data. Collected data is used not only to determine coastal topography and elevation, but also to assess erosion, storm damage, inlet migration, beach nourishment, and shoreline stabilization (Gibeaut 2001; Fitzgerald et al. 2003).

Video digital imagery - Charge-Coupled-Device (CCD) video digital imagery can be used to assess beach width, bluff erosion, geomorphology, and seismic structures (Rindell and Hollarn 1998). The CCD images can help to identify changes from events such as landslides. This system can rapidly be constructed for natural disaster assessment following storms, floods, or other coastal disturbances that can affect restoration progress (Rindell and Hollarn 1998). Video digital imaging systems can provide continuous and automated data collection on beach bathymetry as well. Shoreline features are identified using an automated system with full-color imagery and an objective discriminator function to define the boundary of the shoreline. Shoreline elevation is calculated in a model using concurrent tide and wave information. The model combines the effects of wave set-up[11] and water movements (Aarninkhof et al. 2003). In some cases, video imagery may be more time- and cost-efficient than aerial photography.

Sediment

Grain size

Sediment grain size is a distinct feature of soft shoreline habitats. Sandy habitats contain substrate that may be calcareous or terrigenous in origin and coarser than mud. Sandy sediments dominate in relatively high energy environments. Muddy habitats contain some sand particles but are composed mainly of silt and clay and found in waters with low energy (Sanders 1958; Cowardin et al. 1979). Silt contains very fine inorganic particles that are normally held in place at the surface of the mud with minimum water movement (Eltringham 1971). Clay is basically hydrated aluminum silicate with iron and other impurities (Eltringham 1971). Because mud sediments are composed of fine grains, they can be easily transported and deposited by low energy waves.

Both sand and mud environments support a number of species of organisms that prefer different grain sizes. For example, meiofauna in intertidal sandflats are mainly small interstitial organisms (i.e., they prefer spaces between particles). The interstitial spaces provide oxygenation to deeper sediments so that meiofauna can live at broader sediment depths (McIntyre 1969). In mudflats, however, meiofauna are larger than those species limited to surface sediments and found burrowed just below the surface (McIntyre 1969; Peterson and Peterson 1979). These burrowing animals help aerate the sediment and increase the flow of seawater by creating holes that act as passage ways. Changes in grain size which may result from coastal activities such as dredging can disrupt ecological communities in soft shoreline habitats and affect restoration progress in these areas.

[11] When waves break on a beach and produce a rise in the mean water level above the still-water elevation of the sea.

Basin for materials

Sand and mud particles may act as sinks for not only nutrients but pollutants. As the particles in mud are much finer than those in sand, mud particles are able to retain pollutants for longer periods. Land runoff and industrial discharges can seep into sediments and alter the benthic community by killing some of the organisms. Collecting sediments and analyzing metals, organics, other substances, and benthic organisms within the sediment can help determine factors affecting the habitat's ecological communities and whether restoration efforts would be appropriate for a particular area.

Figure 11. A push corer being inserted in the sediment using the manipulator arm of *Alvin*, a remotely operated vehicle (ROV) from Woods Hole Oceanographic Institution. Similar plastic tubes can be introduced manually in the sediment by diving or simply walking in an intertidal flat. Photo courtesy of NOAA Ocean Explorer.

Sampling and Monitoring Methods

Push corer instruments - Push corer instruments (Figure 11) can be used to collect both sand and mud samples because they can easily penetrate through soft sediments (USEPA 1984; USEPA 1998). The practitioner places the instrument on the surface of the sediment and drives it into the sediment to the point marked on the push core where gravity sucks the sample into the container and the sample is then pulled from the surrounding sediment. A vacuum device may also be attached to the push core to extract sediment deeper than two meters. Push core tubes can then be cut at the water-substrate interface and sealed to prevent disruption of the sediment (USEPA 1984; USEPA 1998). Piston corer samplers also use both gravity and hydrostatic pressure to collect sediment samples. As the instrument penetrates the sediment, an internal piston remains at the level of the sediment-water interface to prevent sediment compression (USACE 1996).

Remote Sensing - To quantify sediment grain size distribution, remote sensing methods can be used prior to restoration in order to gather baseline information on the grain size of the habitat (Rainey et al. 2003). In some cases, remote sensing can also be done during and after restoration to determine whether there was any change in grain size distributions that might influence the functioning of that habitat (e.g., ability to support plant and animal communities). Remote sensing platforms can take measurements within the short-wave infrared (SWIR) band that generally ranges from 0.8-1 microns (µm). The timing of image attainment with regard to tidal cycles and sediment moisture content is considered significant for identifying spectral differences between sand and mud particles, therefore providing precise mapping of estuarine sediment distributions (Rainey et al. 2003).

A more common instrument to assess sediment grain size is a sieve. Sieve methods include press sieving and wet sieving (USEPA 2001). Press sieving involves pressing down on sediments using paddles and then recording visible matter such as organisms, shell fragments, gravel, and debris collected on the screen (USEPA 2001). Wet sieving involves rotating sediments and water within a sieve. Water is added to the sieve to assist in separating larger and smaller particles. The particles are then sieved and retained for measurement. In most cases, sand particles may not have to be sieved because they are composed of larger, coarser grains. After being retrieved from the shoreline, sand and mud samples are deposited into sample containers. The weight of sediment preserved on each sieve is measured and converted into a percentage of the total sediment sample (USEPA 2001).

Wind speed and direction

Winds plays a role in transporting sand and mud particles and can influence the geomorphology of the soft shoreline. Once winds transport sediment from one position to the next, the original sediment location becomes relatively flat or eroded while the new location is elevated. The direction and speed of the wind can also play a significant role in geomorphological changes. For example, high-speed winds continuously blowing in the same direction can result in severe erosion of a particular area. Winds can also influence wave movement and affect the stability of animals living in soft shoreline habitats (Norkko et al. 2002). Waves, combined with winds, are significant to the formation of habitats, particularly on sandy shores. In sandy habitats, for example, the greater the wind speed, the higher the waves, and the greater the angle when waves hit a beach, the more sand is transported. Once sand is transported during high–speed winds and intense wave action (e.g., during storms), the area on the beach from where sand was transported becomes flat. Sand will eventually re-accumulate on the shore over time, but at a slow and gradual rate.

Sampling and Monitoring Methods

Cup anemometer and windwane - Monitoring wind speed and direction allows practitioners to assess the frequency and rate at which soft substrate is transported. Two instruments used to measure wind speed and direction are a cup anemometer and a windvane. These instruments are usually placed at about 6.5 meters high (Abuodha 2000) and data can be recorded, processed, and stored in a programmable datalogger.

Other commercial instruments such as a wind direction sensor can provide a single output of the wind direction angle. The advantage to using a wind direction sensor is that it reduces errors and minimizes friction.

Organic content

Organic content in sediment greatly influences the plant, animal, and microorganism populations. For instance, decomposed organic material provides nutrients to benthic organisms. Microorganisms utilize the organic matter and recycle nutrients so that they can provide food for other organisms (Trimmer et al. 1998). In high energy regions where sandy habitats such as beaches and sandflats) are typically found, organic matter levels are relatively low (Eagle 1973) and consist mainly of detritus resulting from decayed macroalgae, feces, and animal remains (Hayward 1994). Since organic content is low in these areas, very few species of animals are found there.

In intertidal mudflats, however, organic content is much higher than in sandy habitats (Rae and Bader 1960; Cowardin et al. 1979). As mudflats are found in relatively low energy regions, these habitats accumulate large quantities of organic matter and therefore experience higher rates of biomass decomposition. Sources of organic material in mudflats include:

- Human sources (effluent, runoff, food and waste from aquaculture, and degraded petroleum hydrocarbons)
- Natural sources (plankton and detritus), and
- Organic material such as benthic microalgae (diatoms and euglenoids)

As a result, plant and animal species abundance is greater in mudflats than in sandy habitats.

Sampling and Monitoring Methods

There are various methods to sample sediments, many of which are discussed in the "Sediment: *Sampling and Monitoring Methods*" section of this chapter. Methods to assess total phosphorus involve extracting the phosphorus from sediments with 1 N (i.e., one mole per liter) hydrochloric acid after ignition at high temperatures (550ºC) or by digesting the sample with sulphuric acid-potassium persulphate at 135ºC in a sealed pressure vessel (Aspila et al. 1976). Organic phosphorus can be determined by the difference in phosphorus content of the 1 N hydrochloric acid extract measured before and after ignition of the dry sediments at 550ºC (Aspila et al. 1976). The level of orthophosphate - a salt of phosphoric acid - is determined by using a standard technical AutoAnalyzer II. These methods can successfully measure inorganic, organic, and total phosphorus in sediments (Aspila et al. 1976).

Another technique used to analyze organic content in sediment, particularly nutrients such as carbon and nitrogen, is acidification**.** The sediment samples are dried and acidified with 10 percent hydrochloric acid to eliminate all carbonates. The samples are then dried again and analyzed for carbon and nitrogen. Data collected from organic/nutrient analyses of sediment samples can indicate whether organic levels have increased or decreased significantly over time. For example, an increase in nutrients may be an indication of agricultural runoff, causing increased algal growth which then reduces oxygen levels.

Turbidity

Turbidity is a water quality parameter referring to the water clarity, or the amount of light penetrating through the water column. The greater the amount of total suspended solids or sediments (TSS) in the water, the more muddy or cloudy the water appears and the higher the measured turbidity. Clay, silt, and sand particles from soils of soft shoreline habitats are common suspended solids. Wave energy circulates the sediments throughout the water column which eventually settle to the bottom. When there is frequent strong wave action along a soft shoreline, the water column is generally turbid because sediments are in constant motion. The water column in muddy habitats, however, is generally more turbid than sandy habitats because the mud grains are finer and easily distributed throughout the water. Thus, the turbidity of the water can be an indication of the sediment type that creates the soft shoreline habitat (i.e., sand creates less turbid waters than mud). Changes in turbidity may also affect the ecological community of soft shoreline habitats. Macroalgae in turbid waters, for instance, receive minimum sunlight and therefore may be unable to photosynthesize. As a result, productivity is low which in turn, affects the animal community that relies on macroalgae as a food source.

Measuring and Monitoring Methods

Secchi disc - The depth of light penetration in the water column can be measured using a secchi disc (Figure 12). It is a painted disc attached to a cord. The disc is 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 an increasing amount of light is absorbed. The depth at which the disc can no longer be seen is the depth at which the light is being completely absorbed as it passes down and back up through the water column. Three measurements are usually recorded at each location.

Turbidimeter - There are also many commercial instruments that can be used to measure turbidity. A turbidimeter, for example, measures water turbidity by passing a beam of light

Figure 12. A Secchi disc is taken out of the water after a depth reading in a study of Poplar Island, Maryland. Photo courtesy of Chris Doley, NOAA Restoration Center.

through the sample and measuring the quantity of light scattered by particulate matter (Rogers et al. 2001). The turbidity measurements are then displayed in nephelometer turbidity units (NTUs) (USEPA 1983; Rogers et al. 2001).

HYDROLOGICAL

Waves

Soft shoreline habitats, particularly those composed of sand, are influenced by wave height and period, as well as fetch[12] of the wave. The height and period of a wave correlate with the strength and fetch of the wind that produces it. For instance, the longer the fetch, the greater the increase in wavelength and period (Brown et al. 1990). Short fetches cause waves to be higher, whereas longer fetches cause lower wave heights.

Wave energy (from minor to extreme) also influences soft shoreline characteristics and is primarily responsible for sediment transportation. The movement of waves is driven primarily by kinetic and potential energy (Brown et al. 1990). Kinetic energy refers to the energy of particle motion; potential energy is the displacement of the sea surface in relation to wave height (Brown et al. 1990). Wave energy is considered directly proportional to wave height. The total wave energy per unit area is represented as:

$$E = 125\ H^2\ \text{ergs. cm}^{-2}$$

E = energy in ergs
H = height
ergs = unit of energy

In shallower waters, wave energy is dissipated through friction with bottom sediments and additional energy is lost as waves break on shorelines or other objects. In contrast, waves that approach the shore in deeper waters retain greater energy which can cause shoreline erosion.

Although wave energy is generally low in muddy shores, when storms or other forces increase wave action, mud banks may form

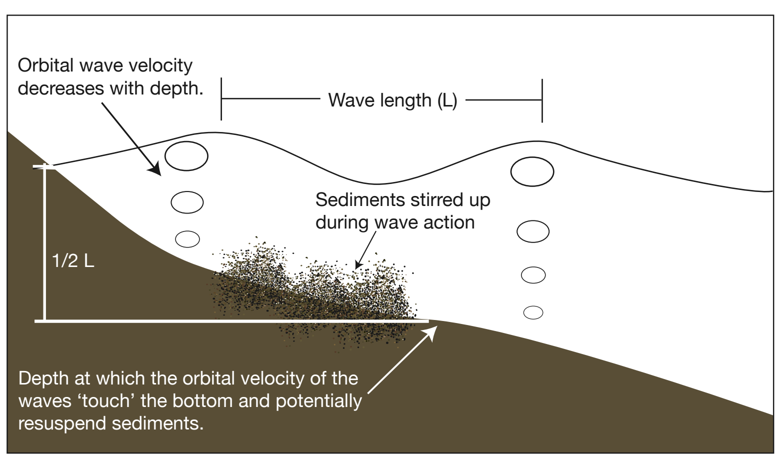

Figure 13. Wave in motion stirs up sediments as it approaches the shore, causing an increase in turbidity. Diagram courtesy of Felicity Burrows, NOAA National Centers for Coastal and Ocean Science.

[12] The distance over open water wind travels to generate waves.

as sediment accumulates. Differences in wave energy levels also influence what species of plants and animals are found in these habitats, depending on their ability to tolerate high or low wave exposure. For example, the substrate material on sandy shores is exposed to extreme washing action of waves which reduces organic content, thus organisms in this area must be able to tolerate and survive under low organic content conditions (Norkko et al. 2002). Because wave energy can influence the physical characteristics of these habitat types, their plant and animal communities, and restoration efforts, monitoring wave energy should be considered during the project planning process.

Waves influence not only sediment transport and shoreline geomorphology, but also the distribution of pollutants. The effects of wave and tidal occurrences on spilled oil penetration on tidal flats and the influence of the penetrated oil on seawater infiltration were studied with the use of a tidal flat simulator (Cheong and Okada 2001). Oil penetrated sediments by tidal movement only, whereas seawater infiltrated sediments by wave action and tidal fluctuation. In addition, infiltration of seawater was lessened by penetrated oil. Furthermore, penetrated oil may reduce seawater infiltration in sediments, causing oxygen, nutrients, and organic matter reductions, which affect the abundance of benthic organisms in tidal flats (Cheong and Okada 2001).

Measuring and Monitoring Methods

Pressure gauges - Bottom-mounted pressure gauges can be used to measure wave pressure and direction (Smith 2002), and sensors can be used to measure wave height. Pressure gauges may be mounted on platforms to measure the depth from the sea surface to the gauge and determine wave directions (Smith 2002).

Wave buoys - Wave buoys (Figure 14) fixed at certain locations in the ocean use electronic sensors to measure wave height, wave direction, and time period between waves (Davies 1996). As this monitoring method may be relatively expensive for restoration practitioners, information about wave conditions may be obtained in some instances from other research efforts in proximity to the restoration site. This encourages collaborative efforts between researchers and practitioners. In areas where wave energy is low, such as sand and mudflats, the measurement of wave energy should not be a priority when assessing restoration progress. Other sources that describe methods for measuring wave energy as well as wave direction, height, and periods include: Draper et al. 1974; Middleton et al. 1978; Fu et al. 1987; Brumley et al. 1983; AshokKumar and Diwan 1996; Tortell and Awosika 1996; Terray et al. 1999; and Yang et al. 2004.

Coastal and Littoral Currents

Coastal currents are offshore currents that flow generally parallel to the shoreline in the deeper

Figure 14. A three-meter NOAA buoy collects weather data by measuring wave height and period, as well as other weather parameters such as wind speed and direction. Photo courtesy of NOAA National Data Buoy Center.

water beyond and near the surf zone. They are not related intrinsically to waves and the resulting surf, but may relate to tides, winds, or the distribution of large oceanic circulations. In contrast, littoral (i.e., relating to the seashore, especially the intertidal zone) currents occur in the littoral zone and result primarily from wave action such as long shore currents or rip currents (USACE 1984).

Littoral processes include the interaction of waves, currents, winds, tides, sediments, and other materials near the shoreline. These currents flow either parallel to the shoreline (longshore currents) or perpendicular to the shoreline (rip currents or undertow) and travel in one primary direction. For example, in the Fire Island National Seashore Park in Patchogue, New York, littoral currents generally run in an east-west direction (NPS 2004). Together with waves, winds, and tides, littoral currents transport coastal materials towards and away from beaches. Such materials, collectively referred to as littoral drift, include sand, gravel, other sediments, and organic material. Littoral transport is the movement of littoral drift in the littoral zone by waves and currents. Depending on the rate and direction of littoral transport, beaches erode, accrete (i.e. expand), or remain relatively stable.

Structures that extend perpendicular to shorelines interfere with natural littoral processes and sediment transport. For example, groins are constructed to control or modify littoral transport. Such structures block the nearshore movement of littoral materials and cause “up-current” beaches to accrete. Although groins may increase deposition on up-current beaches, they effectively steal sediments from down-current beaches, intensifying erosion in those areas. Coastal currents may also displace high quantities of sand along the shoreline. It is important to know the direction of those currents and measure the amount of sand transported throughout the year.

Measuring and Monitoring Methods

Current profilers - Commercial instruments such as current profilers have generally been used to obtain information about the speed and direction of currents. The most commonly-used current profilers are acoustic Doppler current profilers (ADCPs) (Figure 15). This instrument uses underwater sound to measure vertical profiles of horizontal currents. The ADCPs are generally moored in the open sea, but they can also be mounted aboard survey vessels.

Tides/Hydroperiods

Mudflats and sandflats are mostly exposed to very low tides compared to sandy beaches, but each of these habitat types is inundated during high tides (Cowardin et al. 1979). Hydroperiods (i.e., fluctuating water levels) play a significant role in modifying the physical structure of soft shorelines and in the distribution and abundance of plant and animal communities. As a result of changes in water level fluctuations and increased inundation periods, mobile animals that are used to lower water fluctuations may migrate to more suitable locations, thus opening a niche for other species preferring the more inundated conditions. In other cases,

Figure 15. Image of a typical four-beam acoustic Doppler current profiler (ADCP) sensor head. The ADCP measures the speed and direction of ocean currents using the principle of “Doppler shift.” Photo courtesy of NOAA Ocean Explorer.

inundated waters may cause animals and plants to die because they are not able to tolerate flooded conditions. During restoration of some habitats (e.g., mudflats), hydroperiods may be restored in order to support plant and animal communities that were initially found in that particular area. Continuous flushing of nutrients and other materials by fluctuating water levels is necessary to distribute nutrients and make them available to organisms. Flushing can also help prevent the accumulation of nutrients and other materials that may contaminate the habitat and disrupt the habitat's ecological community. However, if flushing is increased in areas such as mudflats that are accustomed to low energy wave action, animal and plant abundance may decline.

Sediment transport and accretion are also influenced by fluctuating waters. Slower water fluctuations reduce sediment transportation rates, particularly for coarser grains. Since grain size in muddy shores is finer, less energy is required to suspend and transport silt and clay materials. Sediment accretion due to water level fluctuation may also affect the survival and growth of some vegetative species such as mangroves. For instance, when mangrove seedlings are planted on mudflats they may experience an increase in mortality rates with increasing sediment accretion. As a result, mangrove growth declines (Terrados et al. 1997).

Measuring and Monitoring Methods

Tide gauges - A tide gauge is a mechanical device that is usually placed on piers or pilings to record water levels (IOC 1985; Emery and Aubrey 1991). This instrument may consist of a datalogger that reads and stores data from different sensors and a modem that communicates with a computer (IOC 1985). The elevation of the water level sensor should be determined from a stable bench mark and calibrated at regular intervals to ensure accurate water level measurements.

Water Sources

Water quality is a significant parameter that affects soft shoreline plant and animal communities. The source of water inflow can influence nutrient concentrations, toxins, and ultimately the number of organisms living there. The chemical concentration and physical characteristics of water near soft shoreline habitats can be influenced by various environmental factors, including:

- Tides/hydroperiods
- Currents
- Groundwater, and
- Human inputs (e.g., runoff from upstream land use)

In some cases when runoff - which may include freshwater, nutrients, sediment, or pollutants - from upland areas enters soft shoreline habitats, it can reduce the number of organisms occupying the habitat or alter behavioral patterns of some organisms (Levings and McDaniel 1976; Mohd Long 1987; Rao 1987; Lercari and Defeo 2003). In other cases, groundwater flowing through sandy beaches (and in some cases, mudflats) to coastal waters is considered a source of nutrients that supports the biological productivity of coastal waters (Nakasone et al. 1998). Also in several areas, freshwater flowing over intertidal, estuarine mudflats may attract waterbirds, especially ducks and geese, probably because the water source for preening and drinking is near their feeding grounds (Ravenscroft and Beardall 2003). Freshwater inflows, however, may not be utilized by some organisms and may cause ecological changes to occur in soft shoreline habitats. Large amounts of freshwater discharges may also form deeply-cut creeks in narrow mudflats that may not be suitable for most waterbirds (Ravenscroft and Beardall 2003).

Measuring and Monitoring Methods

Water quality measurements and water source evaluation should be considered when developing a restoration monitoring plan because these factors can have a tremendous impact on restoration success. If polluted runoff continues to enter soft shoreline habitats, the quality of the habitat deteriorates. In most cases, restoration practitioners may not be able to correct this problem but should, at a minimum, be able to identify factors that contributed to unsuccessful restoration.

Monitoring methods that may be used directly in the field to obtain immediate measures include commercial pH meters, oxygen meters, and turbidity readers. Samples should be taken at designated locations to ensure that certain parameters that cannot be measured in the field are measured or determined in the laboratory (e.g., nutrient concentrations, heavy metals, etc.). Samples should also be properly contained, transported, and stored in the laboratory for preservation purposes.

A good reference for monitoring water sources is the *Standard Methods for the Examination of Water and Wastewater*, a joint publication by the American Public Health Association, American Water Works Association, and Water Environment Federation that covers all aspects of water and wastewater analysis techniques. The United States Environmental Protection Agency (USEPA) approved the 20th Edition of this manual for regulatory applications (Clesceri et al. 1998).

CHEMICAL

Salinity levels can influence the distribution of plants and animals in sandflats and mudflats. For example, mangroves are considered salt-tolerant plants. Hypersaline conditions (greater than 35 ppt) can, however, affect productivity by preventing mangrove terminal buds from developing (Koch and Snedaker 1997) (see Chapter 9 - Restoration Monitoring of Mangroves). Also different species of seagrasses tolerate different salinity levels (Lirman and Cropper 2003). Those species of seagrass that tolerate relatively lower salinity levels may result in low productivity if salinity levels increase significantly. Some factors that may be responsible for increase in salinity levels include industrial and agricultural inputs (see Chapter 7 - Restoration Monitoring of Submerged Aquatic Vegetation). Because of the effect salinity may have on plants and animal distribution, it should be monitored in tidal areas exposed to changes in salinity levels.

Sampling and Monitoring Methods

Hydrometer - A hydrometer can be placed into a tall flask containing the water sample. Salinity is determined by taking a reading of the position of the water surface at the bottom of the meniscus (Rogers et al. 2001). Hydrometers are typically calibrated for use at a specific temperature and a conversion chart is usually provided in order to estimate salinities at different temperatures (Rogers et al. 2001).

Refractometer - A refractometer is a hand-held instrument that measures the bending of light between dissolved salts as it passes through the water sample. To measure salinity, one or two drops of the sample are put onto the prism. The observer holds the cover down, faces the instrument toward the light and looks at the scale through the eye piece to determine the salinity (Rogers et al. 2001).

FUNCTIONAL CHARACTERISTICS OF SOFT SHORELINE HABITATS

In most cases, the goal of many restoration projects is to restore the habitat to a functioning and naturally sustainable state which supports plants and animals. These functions include:

Biological

- Providing habitat and shelter for plants, fish, and invertebrates
- Providing breeding and feeding grounds for many marine species
- Assisting in providing food for marine organisms by contributing to primary productivity
- Providing refuge from predation for benthic invertebrates

Physical

- Affects transport of suspended/dissolved material
- Alters turbidity

If the health of the habitat is degraded in any way, it can affect the functioning of the habitat. Understanding how the habitat functions is important to restoring it successfully. Monitoring should be performed to determine whether the habitat is functioning efficiently and to track progress throughout the restoration project.

In the section below, some of the biological and physical functions performed by soft shoreline habitats are discussed. Also provided are methods to sample, measure, and monitor several functional parameters affiliated with the functional characteristics described. Not all of these functional characteristics, however, are expected to be measured for every restoration project. This information is provided to illustrate the importance of the habitat and the role each characteristic plays. The methods discussed here are just a few of the methods that can be used.

BIOLOGICAL

Provides Habitat and Shelter

Different types of shoreline habitats support various plant and animal species that can tolerate a constantly changing environment. Tidal flats, for instance, whether they are accreting or not, are important in contributing to the productivity of estuaries. They help support the food web within the tidal embayment and therefore play a critical role in both fisheries and wildlife conservation. The high productivity associated with tidal waters and flats also helps to support spawning and juvenile stages of many important commercial and recreational fish species such as flounders, snappers, and groupers.

Vegetation commonly found along soft shorelines includes mostly herbaceous vascular, plankton, and algal species that are washed in with tides. For example, eelgrass (*Zostera marina*) (Figure 16) is an important plant found in mudflats and sandflats and, commonly lives in the mid-upper shore. Eel grass provides important grazing for a variety of herbivores including ducks and geese. It also contributes to the stability of tidal flats, a characteristic which they share with another species of seagrass called widgeon grass (*Ruppia maritime*) that is found in the intertidal zone. Seagrass species, in general, play an important role in coastal wetlands by providing oxygen, food, shelter, and nursery areas for a wide variety of marine species, and by helping to stabilize shorelines.

Not only are species of grass found in soft shoreline habitats but other vascular plants such as mangroves (e.g., *Rhizophora* spp.) (Figure 17) are commonly found along mudflats.

On sandy beaches, however, there is typically very little vegetation found as it is hard for plants

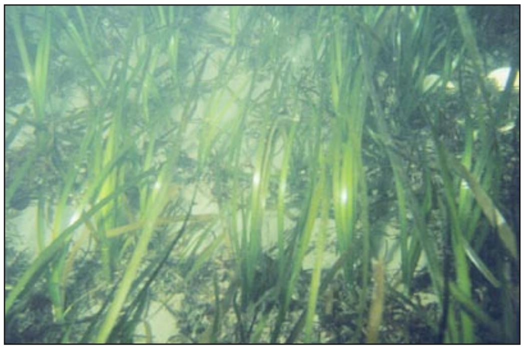

Figure 16. Left: Bed of eelgrass (*Zostera marina*). Photo courtesy of USEPA Dive Team. Right: A plug of eelgrass (*Zostera marina*) just before it is transplanted. Note the u shaped "staple" that is used to secure it to the bottom. Photo credit: Jay Preshoso. Photo courtesy of NOAA Narragansett Bay Eelgrass Restoration Project.

to establish themselves and seeds have difficultly settling in the sand. There are, however, a few species of amphipods, crustaceans, polychaetes, and bivalves adapted to this habitat type.

Some vegetative species that are seen in areas near sandy beaches, especially in dunes immediately linked to the beach, are:

Beach wild rye (e.g., *Leymus mollis*)
Beach bur (e.g., *Franseria chamissonis*)
Beach salt bush (e.g., *Atriplex leucophylla)*
Dune beach grass (e.g., *Ammophilia spp.)* (Figure 18)
Lizard tail (*Eriophyllum confertiflorum)*
Saw palmetto *(*e.g., *Serenoa repens),* and
Sea fig (e.g., *Carpobrotus edulis)* (Slattery 1996)

In the United States, European beachgrass (*Ammophila arenaria*) has been used in beach and dune restoration. This species, however, is invasive and has outgrown other native plants in dunes throughout the East coast, Great Lakes, Washington, and Oregon. *Carpobrotus edulis* (known as hottentot fig or highway ice plant or sea fig) is also considered an invasive plant along dunes and beaches in California. It is therefore important to consider invasive species when monitoring restoration efforts particularly if non-local plants are used. Successful management of coastal sand dunes in the United States requires the control of aggressive species such as European beachgrass. The spread of this and other invasive species can be controlled

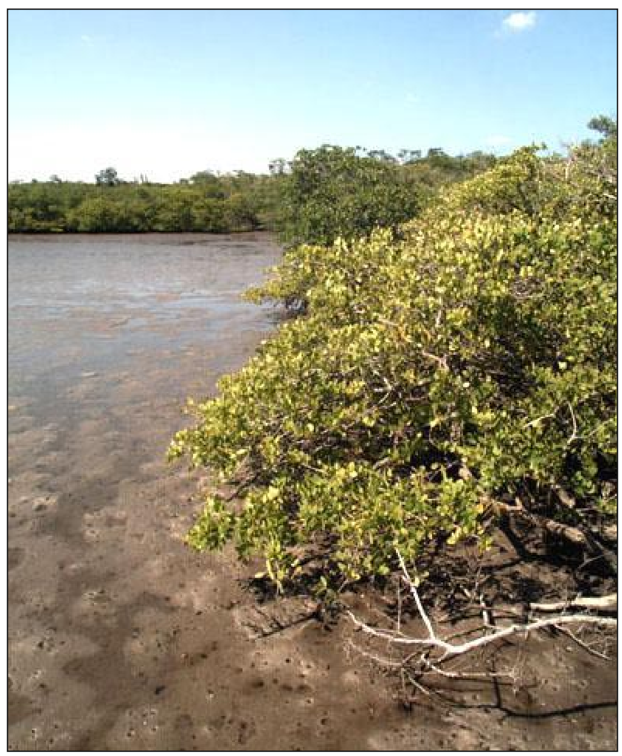

Figure 17. Mangroves bordering a mudflat. Photo courtesy of United States Geological Survey, South Florida. http://sofia.usgs.gov/virtual_tour/images/photos/wlak/ak_mangroves.jpg

Figure 18. Dune beach grass (*Ammophilia spp.*). Photo courtesy of S. Muller, NOAA National Estuarine Research Reserve Collection. http://www.photolib.noaa.gov/nerr/nerr0786.htm

by manually removing the plant. This type of control requires ongoing treatment and is labor intensive. Control should be emphasized until eradication techniques are refined.

Animals found along the soft shoreline may vary depending on the sediment texture and grain size such as fine-grained mud or coarse-grained sand. Mudflats and sandflats support a large number of invertebrates such as amphipods, polychaetes, bivalves, and oligochaetes in the sediment surface. Typical densities on predominantly muddy shores for mud snails (*Hydrobia* sp.) and burrowing amphipods (*Corophium volutator*) may be up to 100,000 and 60,000 individuals per square meter, respectively (Barnes 1974). Segmented worms such as ragworm (*Nereis diversicolor*) and lugworm (*Arenicola marina*), which are found on more sandy shores, are also often abundant and particularly important as prey for wintering wading birds.

Other animals found in soft shoreline habitats include:

- Crustaceans (e.g., amphipods, mysids, ghost shrimp, and crabs) (Figure 19)
- Invertebrates (e.g., mud snails, oligochaetes, and polychaetes)
- Molluscs such as bivalves (e.g., oysters, *Crassostrea;* clams *Corbicula;* and zebra mussels, *Dreissena polymorpha*)
- Shorebirds (e.g., sandpiper, *Calidris pusilla* and red knot, *C. canutus*), and
- Fishes

(Note: Species distribution will vary based on salinity. For instance, zebra mussels, oligochaetes, and some species of ghost shrimp are found primarily in freshwater.)

Provides Breeding Grounds

Organisms such as crustaceans such as American horseshoe crab (*Limulus polyphemus*) and birds such as piping plover (*Charadrius melodus*) use soft shoreline habitats as breeding grounds. The male American horseshoe crab courts with females by attaching themselves to the back of the female's shell using pincher-like appendages called pedipalps. The female crab then drags the attached male up the beach and constructs holes in the sand to lay eggs. Male crabs then fertilize the eggs. Waves at high tide wash up the shore and distribute eggs all along the shoreline where they lay exposed (Rudloe 1980). Other species of crabs, such as fiddler crabs (*Uca* spp.), also use soft shoreline habitats as breeding grounds (Figure 20). Male fiddler crabs attract females to the mudflats by waving their claws, signaling females in the breeding grounds (Oliviera et al. 2000). The female crab then approaches the

Figure 19. Female blue crab (*Callinectes sapidus*) occupying soft shoreline. Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0838.htm

male and burrows underground to mate. After the mating process, the female crab remains underground for approximately two weeks to incubate the eggs.

Birds such as piping plovers seek a suitable nesting territory just before breeding. Once a site has been selected, the male and female birds then perform courtships with each other. The two birds develop depressions in the sand near the high beach for nests (USFWS 1997). The eggs and the young are camouflaged by grasses and sand present to lessen the chance of predation. In some cases, however, nests are disturbed by storm tides, predators, or intruding humans before the eggs can hatch (USFWS 1997).

Provides Feeding Grounds

Soft shoreline habitats, especially mudflats, are important feeding grounds for many animals because they provide greater biomass resources than sandy habitats. Bacteria and diatoms present between sand grains support the soft shoreline habitat food web by recycling nutrients and providing food for microscopic protozoans, crustaceans, invertebrate larvae, and roundworms (Berrill and Berrill 1981). Crustaceans such as fiddler crabs, for example, use their claws to scrape the surface of the sediment while placing sediment particles into their mouth to retrieve organic matter.

Figure 20. Male fiddler crab (*Uca* spp.) inhabiting a mudflat. Photo courtesy of USGS, South Florida. http://sofia.usgs.gov/virtual_tour/images/photos/wlak/ak_malefidcrab.jpg

Sandy beaches, mudflats and sandflats are especially important in providing feeding areas for a variety of waterfowl, particularly migratory waders. These waders depend on the availability of suitable invertebrate prey that live in or on the surface of the sediment. In the low intertidal zones of beaches where there is protection against intense heat and freezing temperatures, concentrations of small invertebrates such as amphipods, isopods, polychaete worms, and clams are very high (Larsen and Doggett 1990). Shorebirds (Figure 21) also feed on invertebrates (e.g., clams and polychaetes), molluscs (e.g., snails), as well as crustaceans (e.g., crabs) by picking or probing in the mud or sand along the water's edge.

Sea turtles, fishes, and other animals feed on other small animals (e.g., polychaetes), seagrasses (e.g., *Zostera*) found in these habitats, and algae which may be washed ashore by tides and waves. Seagrass beds can provide food for a smaller number of herbivores, most notably grazing ducks and geese (discussed in Chapter 9 "Restoration Monitoring of Submerged Aquatic Vegetation"). The importance of the habitat for waterfowl is reflected in the number of sites identified as nationally and internationally significant for this group of species. Seagrasses in soft shoreline habitats are also an important source of food and shelter for the young stages of many fish and crustacean species, some of which serve as food for commercially-valuable fishery species (Doody 2003).

Provides Refuge from Predation

Many organisms such as crustaceans and other invertebrates seek refuge within sediments to avoid being preyed upon by larger organisms such as birds and fish that primarily capture prey on or just beneath the sediment surface. For example, the staghorn sculpin fish (*Leptocottus*

Figure 21. Sandpiper searching for food along a Gulf of Mexico beach in Biloxi, Mississippi. Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of NOAA Central Library. http://www.photolib.noaa.gov/coastline/line2589.htm

armatus), known as opportunistic feeders, prey mainly on ghost shrimp (*Callianassa californiensis*) and blue mud shrimp (*Upogebia pugettensis*). These shrimps avoid being preyed upon by burrowing in sediments to depths deep enough where predators cannot reach them (Armstrong et al. 1995). Migratory shorebirds also forage over intertidal shores, preying on crabs and worms. For example, the American golden plover (*Pluvialis dominica*), black-billed plover *(P. squatarola*), ruddy turnstone (*Arenaria interpres*), and whimbrel (*Numenius phaeopus*) have been seen foraging on species of fiddler crabs (*Uca uruguayensis*) in soft shoreline habitats (Iribarne and Martinez 1999). Similar to shrimps and other types of crustaceans and invertebrates, crabs burrow into the sediment to avoid predation once they sense a threat. In some cases, prey may still be captured because the sediment is soft, as predators such as birds are able to probe into the sediments to obtain prey, or the prey may be captured before they can burrow into the sediment.

Sampling and Monitoring Methods

Birds - Aerial surveys can be used to determine bird numbers. Practitioners observe and record the numbers, location, and species of birds. The data collected from multiple surveys can be compared to determine whether any changes have occurred in species type or bird numbers (i.e., the number of birds nesting, breeding, and feeding patterns) over time (King and Michot 2002). Nesting sites of colonial waterbirds can be identified using color infrared aerial photography (Kingsbury 2001). The sites are displayed by digital imagery in GIS software such as ESRI's ArcView. This method allows researchers to perform temporal and aerial assessments of colonial waterbird breeding activities. ArcView allows the user to query, analyze, and view information about the colonial waterbirds. Practitioners can customize the software to observe the information at different scales to show species distribution, areal extent of the nesting areas, and population trends for long periods (Kingsbury 2001).

Transect methods can also be used for monitoring birds along the shoreline. Transect counts may vary depending on species type and whether an index of relative abundance or absolute abundance is needed (Mannan and Meslow 1980). A relative abundance index represents the number of birds per kilometer of transect, while an absolute abundance represents the density of birds per square kilometer. To determine a relative abundance index, practitioners travel along the transect beside the shoreline for a particular distance and count the number of individuals detected. The resulting index represents the number of detections per unit distance traveled (Gibson 1971). Absolute abundance can be measured using fixed-width transects in which practitioners move along a transect and count the birds detected within a fixed-width strip on either side of the transect (Government of British Columbia 1997). Bird densities may be determined by dividing the number of birds detected by the area of the transect strip.

Invertebrates - A multiple tube sampler can be used to sample benthic and pelagic invertebrates (Euliss et al. 1992). This sampling device consists of clear acrylic tubes that are arranged in the shape of a square and placed 25 centimeters apart from one another. Each tube is sharpened so that it can penetrate into the sediment (Euliss et al. 1992). The device is lowered into the water and pushed about 10-15 centimeters into the sediment. The sediment type will, however, influence the depth in which this device will be inserted. A standard five centimeter pressure plug is then used to cover the tube with an air-tight seal. Once sealed, the tubes are shaken back and forth to separate sediment (Euliss et al. 1992).

Invertebrates can also be sampled using a standard core sampler or collected by hand within quadrats (Boer and Prins 2002). Organisms assessed using quadrats are usually large enough to be seen by the naked eye. Parameters measured generally include:

- Composition
- Biomass
- Abundance
- Density or percentage of target species
- Predator to prey ratio
- Target species size
- Species richness
- Species-rank abundance, and
- Biomass/abundance ratio

Quadrat replicates may be taken along a transect or various transects at fixed intervals along the shore. Other instruments used to sample sediment and macrofauna include dredge (Figure 22), sled, or grab samplers (Brown et al. 1990).

Fish - There are various types of nets that can be used to sample fish, such as seine nets, lift nets and gill nets. Seine nets are composed of a bunt (i.e., bag or lose netting) and long ropes used to pull it out of the water. The nets contain floats to keep the top part afloat and weights to keep the bottom of the net submerged to prevent the fish from escaping from the net-enclosed area. Fish caught in the net are then identified and counted (Hart and Reynolds 2002).

Lift nets consist of a bag-shaped structure with the opening facing upwards while the bottom of the bag remains submerged. Fish that swim over the opening of the bag are then enclosed as persons holding the net lift it out of the water.

Figure 22. Hand dredging on a mudflat in Metal Bank site, Philadelphia, Pennsylvania. Photo courtesy of NOAA Office of Response and Restoration.

Gill nets can also be used to sample fish. The mesh size of the net varies depending on the size of the targeted fish species. Fish are captured when they swim into the invisible mesh net and struggle to escape. As they struggle, they become entangled within the net (Hart and Reynolds 2002). Practitioners then separate the fish from the nets so that they can be identified and counted.

Contributies to Primary Productivity

Primary productivity in both mud and sandy shores is primarily from benthic macrophytes, benthic macroalgae, and phytoplankton biomass and supports many animals (Peterson and Peterson 1979). Chlorophyll concentration is measured to determine the abundance of phytoplankton which contributes to most plant production in estuaries and oceans. This measurement allows practitioners to determine whether the vegetative species growing in these habitats are productive. Low productivity in a habitat that usually has substantial vegetation can be an indication of insufficient nutrients to support plant growth and therefore can affect animal abundance. Mudflats particularly receive organic input from other coastal vegetation that have high rates of primary production. These include marsh plants such as *Spartina, Juncus*, seagrasses such as *Halodule, Zostera*, and mangroves. (Odum 1959; Keefe 1972). In some areas, higher levels of primary production vary between benthic algae and phytoplankton (Marshall et al. 1995). In the Chesapeake Bay, near intertidal mudflats, for example, higher primary productivity was due primarily to benthic algae (Marshall et al. 1995). Whether benthic algae, benthic macrophytes, or phytoplankton is the main source of high primary productivity, each of these vegetative species provides a large supply of nutrients to benthic fauna occupying soft shoreline habitats.

Sampling and Monitoring Methods

Fluorometer - A sample fluorometer can be used to estimate phytoplankton biomass by measuring chlorophyll. This is an underwater instrument that projects a beam of blue light into the water column and then measures the amount of red light absorbed by chlorophyll in the suspended algae (Moldaenke et al. 1992; Xia et al. 1997). Chlorophyll concentrations are measured by first collecting water samples and extracting chlorophyll in 90 percent acetone along with the help of a mechanical tissue grinder (Arar and Collins 1997). The chlorophyll concentration is then determined from the absorbance of light measured in a spectrophotometer and compared to estimates made using the sample fluorometer.

PHYSICAL

The primary physical functions of soft shoreline habitats include alteration of turbidity and, transportation of sediment and dissolved materials by means of waves, currents, tides and hydroperiods. These parameters have been discussed with the associated structural characteristics in this chapter.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The following matrices present the structural and functional characteristics of soft shoreline habitats suitable for restoration monitoring. These matrices are not exhaustive, but represent those elements most commonly used in restoration monitoring strategies. These parameters have been recommended by experts in soft shoreline habitat restoration as well as in the literature on soft shoreline restoration and ecological-monitoring literature. The closed circle (●) denotes a parameter that should be considered in monitoring restoration performance. Parameters with an open circle (❍) may also be measured depending on specific restoration goals.

Parameters to Monitor the Structural Characteristics of Soft Shoreline Habitats

	Structural Characteristics				
	Physical		**Hydrological**		**Chemical**
Parameters for Monitoring	Sediment grain size	Topography/ Geomorphology	Tides/ Hydroperiod	Wave energy	pH, salinity, toxics, redox, Dissolved oxygen
Hydrological					
Physical					
Shear force at sediment surface				❍	
Water level fluctuation over time			●		
Chemical					
Salinity (in tidal areas)			❍		❍
Soil/Sediment					
Physical					
Basin elevations		❍			
Geomorphology (slope, basin cross section)		●	●		
Organic content	●		●		
Percent sand, silt, and clay	●				
Sedimentation rate and quality	❍	❍	❍		

Parameters to Monitor the Functional Characteristics of Soft Shoreline Habitats

Parameters	Functional Characteristics: Biological – Contributes to primary production	Biological – Provides breeding grounds	Biological – Provides feeding grounds	Biological – Provides refuge from predation	Physical – Affects transport of suspended/dissolved material	Physical – Alters turbidity
Geographical						
Acreage of habitat types	●	●	●	●	●	●
Biological						
Plants						
Species, composition, and % cover of:						
Algae	❍	❍	❍	❍	❍	❍
Herbaceous vascular	❍	❍	❍	❍	❍	❍
Invasive species		❍	❍	❍		
Interspersion of habitat types		❍	❍	❍	❍	❍
Plant health (herbivory damage, disease[13])			❍			
Biological						
Animals						
Species, composition, and abundance of:						
Birds		●	●	●		
Fish		❍	❍	❍		
Invasive species			❍	❍	❍	❍
Invertebrates		●	●	●		
Hydrological						
Physical						
Fetch					❍	❍
Shear force at sediment surface					❍	❍
Trash			❍		❍	❍
Water level fluctuation over time		●	●	●	●	●
Chemical						
Chlorophyll concentration	❍		❍		❍	❍
Salinity (in tidal areas)	❍	❍	❍			
Toxics		❍	❍			
Soil/Sediment						
Physical						
Geomorphology (slope, basin cross section)		●	●	●	●	●
Sediment grain size (OM[15]/sand/silt/clay/gravel/cobble)					❍	❍
Sedimentation rate and quality					❍	❍
Chemical						
Organic content in sediment			❍		❍	❍
Pore water salinity (in tidal areas)	❍					

[13] Organic matter.

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APPENDIX I: SOFT SHORELINE HABITATS 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. Wherever possible, web addresses or other contact information has been included in the reference to assist readers in 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.

Cheong, C. J. and M. Okada. 2001. Effects of spilled oil on the tidal flat ecosystem - evaluation of wave and tidal actions using a tidal flat simulator. World Water Congress: Part 2-Industrial Wastewater and Environmental Contaminants. *Water Science & Technology* 43:171-177.

Author Abstract. The purpose of this study is to clarify the effects of wave and tidal actions on the penetration of spilled oil stranded on tidal flats and to evaluate the influence of the penetrated oil on seawater infiltration using tidal flat simulator. A simulator used was composed of tidal flat, wave maker, tide controlling device, temperature controlling system, and computer controlling system. The infiltrations of seawater and fuel oil C into tidal flats were visualized using transparent glass beads as tidal flat sediments. Penetration behaviour of the spilled oil into the sediments was significantly different from that of seawater. Seawater infiltrated into the sediments both by wave action and tidal fluctuation, while fuel oil C penetrated by tidal movement only. The infiltration of seawater was reduced by penetrated oil. This result indicates that the penetrated oil diminishes infiltration of seawater into the sediments and thus results in the reduction in the supply of oxygen, nutrients, and organic matter to the benthic organisms in tidal flat.

Collins, M. 1996. The high-frequency in situ measurement of coastal zone processes, p. 521. In Duursma, E. (ed.), Conference on the Coastal Change, Bordomer-95. Proceedings Jointly Organized by the Intergovernmental Oceanographic Commission of UNESCO (IOC) and Bordomer organization (France), Bordeaux (France), 10-16 February 1995 Workshop Report. Intergovernmental Oceanographic Commission. Paris 105 Supplemental. UNESCO, Paris, France.

Author Abstract. The understanding of coastal zone processes has been approached (by oceanographers, geologists, and engineers) on a variety of scales, both temporally and spatially. Hence, on the one hand, beach stability constitutes part of an overall sediment transport system incorporating: riverine inputs, sometimes ephemeral; the onshore-offshore transport of material, and the loss of sediment through submarine canyons, intercepting the adjacent continental shelf or shoreline. At the same time, there is a need to understand the response of beach profiles to extreme events such as short-term effects. Such process-response mechanisms, on the basis of scale extrapolation, control the evolution and development of the associated coastal morphology. Sediment transport mechanisms, at various scales, have been investigated using a variety of techniques including field measurements and (1D, 2D and 3D) numerical modelling. In some cases, conventional instrumentation and modelling has been used; in others, specifically-designed experimentation or instrumentation has been utilized. Against a background of the development of regional course-grain (conceptual) sediment transport model for a section of the coastline and inner continental shelf of southern England, a bottom-mounted tripod system (TOSCA) has been developed. The system was designed to examine the movement of shingle, under combined wave and current activity, in water depths of up to 20 m. Hydrodynamic conditions were monitored using electromagnetic meters (currents) and pressure sensors (waves). Movement of the sediment particles was detected using SGN self-generated noise), caused by interparticle collision. For comparison, regional patterns of movement were identified on the basis of: sea bed sampling; geophysical (side-scan sonar) surveying; and the numerical modelling of hydrodynamic conditions. A high-frequency monitoring system, similar to TOSCA, has been used on adjacent sandy beaches. The resuspension of sand has been related here to the presence of "wave groups" and, in comparable laboratory studies, to pore pressure fluctuations. Following the description of integrated fieldwork, modelling and laboratory programmes, designed to understand process-response processes and parametise the boundary conditions for models, consideration will to be given to: (i) the utilization of site-specific measurements to large-scale sections of the coastline; and (ii) extrapolation of short-term measurements of extreme events to long-term coastal evolution. The scientific objectives described affect utilization of the coastal zone with particular reference to the artificial replenishment of beaches and dredging activities.

Danufsky, T. and M. A. Colwell. 2003. Winter shorebird communities and tidal flat characteristics at Humboldt Bay, California. *Condor* 105:117-129.

Author Abstract. We examined winter (November-January) shorebird use at 19 sites around Humboldt Bay, California, an important site for nonbreeding shorebirds. We analyzed species richness (number of species), species densities, and incidences (presence/absence) in relation to habitat characteristics (tidal flat width, channelization, standing water, timing of tidal ebb, and sediment particle size). We included site area in analyses of incidence, and site area and substrate heterogeneity in the species richness analysis. We observed a total of 19 species, 8-16 at individual sites, and this variation correlated with substrate heterogeneity. Substrate particle size correlated positively with Sanderling (*Calidris alba*) incidence and negatively with American Avocet (*Recurvirostra americana*) incidence. Amount of standing water correlated positively with Whimbrel (*Numenius phaeopus*) and negatively with dowitcher (*Limnodromus griseus* and *L. scolopaceus*) incidence. Width of tidal flat correlated negatively with Whimbrel incidence. Sites at which tides ebbed earliest had higher incidences of Whimbrel and Sanderling and higher densities of Long-billed Curlew (*Numenius americanus*), but lower yellowlegs (*Tringa melanoleuca* and *T. flavipes*) densities. The amount of channelization correlated positively with curlew densities. These habitat relationships suggest that alteration of tidal flats at Humboldt Bay and elsewhere in coastal habitats has the potential to adversely affect patterns of shorebird distribution.

Dernie, K. M., M. J. Kaiser, E. A. Richardson and R. M. Warwick. 2003. Recovery of soft sediment communities and habitats following physical disturbance. *Journal of Experimental Marine Biology and Ecology* 285-286:415-434.

Author Abstract. Physical disturbance in soft sediment habitats disrupts the sediment structure and can lead to the death or emigration of resident biota. Current methods used to quantify the response of benthic assemblages to physical disturbance are time consuming and expensive, requiring the analysis of a time series of samples to ascertain the time taken for a disturbed area to converge on a condition similar to that found in adjacent control areas (the recovery time). Researchers designed an experiment that studied the effects of two intensities of physical disturbance on both the habitat and fauna of a sheltered sand flat to ascertain whether the recovery of the biota could be predicted from physical attributes of the habitat. Benthic community recovery from the lower intensity disturbance occurred within 64 days of the disturbance, whereas recovery after higher intensity disturbance did not occur until 208 days post-disturbance at this site. Sediment granulometry and percentage organic content did not alter as a result of the disturbance in either treatment. However, the depth of water that remained in the disturbed pits decreased with time, and correlated with the temporal changes in community structure. Although this was the most crude physical parameter measured it best described the recovery process of the fauna and may encapsulate the entire suite of other more subtle habitat changes that occur at the same time. By quantifying the persistence of physical features in different soft sediment habitats it might be possible to develop a more amenable and rapid framework for assessing the longevity of the effects of physical disturbance.

Dolphin, T. J., T. M. Hume and K. E. Parnell. 1995. Oceanographic processes and sediment mixing on a sand flat in an enclosed sea, Manukau Harbour, New Zealand. *Marine Geology* 128:169-181.

Author Abstract. Studies of oceanographic and sedimentary processes on intertidal sandflats in an enclosed sea were undertaken to gain better understanding of the factors controlling the mixing and dispersal of sediment bound contaminants. Understanding interactions between wave action and sediment transportation will aid in restoration monitoring techniques for soft shoreline habitats. Field investigations included a 90-day process experiment during which wind, waves, tidal currents, tides, depth of disturbance, and sand flat morphology were measured, and 27 months of sand flat profile monitoring. Sediment entrainment by strong spring tidal currents is restricted to the middle and lower regions of the sand flat which are inundated during the peak tidal flows. The upper 2-3 cm of sediment is re-worked across the middle and upper sand flat by mild storm wave events (H sub(s) = 70 cm), which occurred four times during the 90-day experiment. Numerous ridges and runnels in the upper sandflats are wave-formed features and are maintained by the lack of currents of sufficient magnitude to re-work the features. The ridge and runnel morphology is testimony to large infrequent storm events which re-work the sediment to depths of 20 cm. Such storms are an important mechanism for the release of contaminants and were recorded on 3 occasions in the 27 month profile record.

Dugan, J. E., D. M. Hubbard, D. L. Martin, J. M. Engle, D. M. Richards, G. E. Davis, K. D. Lafferty and R. F. Ambrose. 2000. Macrofauna communities of exposed sandy beaches on the southern California mainland and Channel Islands, pp. 339-346. In Browne, D. R., K. L. Mitchell, and H. W. Chaney (eds.), Proceedings of the Fifth California Islands symposium. United States Department of the Interior, Minerals Management Service, Pacific OCS Region, Camarillo, CA.

Author Abstract. Exposed sandy beaches are important intertidal habitats and coastal resources in southern California. A high proportion of the mainland coast (74%, 93%, and 66% of Santa Barbara, Ventura, and Los Angeles counties, respectively) is sandy beach, much of which is heavily used by humans. Lower proportions of the California Channel Island coasts are sandy (52%, 33%, and 14% of San Miguel, Santa Rosa, and Santa Cruz islands, respectively). Island beaches receive little direct human disturbance and some are important rookeries for pinnipeds and nesting birds. Recent studies used similar methods to sample macrofauna and other factors on 36 sandy beaches of the southern California mainland and Channel Islands. Monitoring of physical characteristics, macrophyte wrack, and selected macrofauna species occurs only on Santa Rosa Island beaches. The beaches sampled were primarily modally intermediate morphodynamic types. Species richness, abundance, and biomass of macrofauna inhabiting exposed sandy beaches in southern California were high compared to values reported for similar beaches of other regions. Species richness was higher on mainland beaches than on island beaches. Species richness and abundances of selected taxa were positively correlated with macrophyte wrack cover. Beach grooming practices that remove wrack may have significant impacts on macrofauna communities. Understanding how sandy beaches support macrofauna as well as other species of the ecological community will aid in the development of restoration monitoring plans.

Dugan, J. E. and A. McLachlan. 1999. An assessment of longshore movement in *Donax serra* Roeding (Bivalvia: Donacidae) on an exposed sandy beach. *Journal of Experimental Marine Biology and Ecology* 234:111-124.

Author Abstract. Peak abundances of intertidal populations of a donacid bivalve, *Donax serra*, occur 10-23 km from major river mouths along exposed sandy beaches of log-spiral bays on the coast of southeast Africa. Post-settlement eastward movement of *D. serra* from areas of spat settlement by prevailing longshore currents has been suggested as the mechanism which results in the observed population distributions. To estimate the net rates of longshore movement in intertidal *D. serra* on one of these exposed beaches, we developed and used a novel technique. A metal detector was used to track net change in the positions of intertidal juvenile and adult clams (37-67 mm shell length, 1-3 + years) with aluminum tags glued to the shells over a 3-month period during the austral fall and winter. Estimated net longshore movement of tagged clams ranged from 0.19 to 0.80 m day^{-1}. The net movement of tagged clams was primarily to the east along the beach but the direction of longshore movement varied during the study. Net rates of longshore movement were not correlated with clam size. The burrowing rates and the condition of recaptured tagged individuals were not significantly different from untagged clams after 2 months. The results of this study suggest that average longshore movement rates of intertidal clams, > 1 year of age, along the beach are low and the animals are relatively sedentary. The technique developed and used here to estimate net longshore movement rates in *D. serra* allowed us to successfully recapture and track tagged individuals with very minimal disturbance to the intertidal habitat and associated fauna. Use of this novel technique could potentially enhance investigations of post-settlement movement, growth, zonation, competitive interactions and other aspects of the ecology of mobile soft sediment macrofauna. Understanding faunal use of sandy beaches will be useful for developing efficient management and restoration monitoring plans.

Fischer, R. L., K. R. Slocum, J. E. Anderson and J. E. Perry. 1998. Use of Digital Multispectral Video for Littoral Zone Applications. NTIS, Springfield, VA. NTIS accession number: ADA354816.

Author Abstract. Digital multispectral videography was obtained over Parramore Island, VA in an effort to extract information concerning vegetation communities, micro elevation changes, soil texture, and soil moisture conditions. These information categories would then be used to assist in tactical near-shore decisions, such as cross country mobility, avenues of approach, bivouac sites, and landing areas, and to also provide greater insight concerning environmental management activities within installation natural resource communities. Flightlines extending from the open ocean to the bayside lagoons were collected at both 0.25 meter and 0.5 meter ground spatial resolution. Through image analysis and ground truth verification, the multispectral videography was successful in separating the basic ecological communities of seaside beach, undulating dune-ridge/valley complex, maritime forest, salt marsh, tidal flat, and bays.

Frid, C. L. J., W. U. Chandrasekara and P. Davey. 1999. The restoration of mud flats invaded by common cord-grass (*Spartina anglica*, CE Hubbard) using mechanical disturbance and its effects on the macrobenthic fauna. *Aquatic Conservation: Marine and Freshwater Ecosystems* 1:47-61.

Author Abstract. The growth of the common cord-grass, *Spartina anglica,* across many temperate coastlines has resulted in a reduction in the extent of tidal flats. Its colonization has reduced the abundance of macrobenthic fauna and hence has had a direct effect on the feeding of shorebirds. Although the use of chemical methods has proven successful in controlling *Spartina* swards on tidal flats, factors such as environmental and human health concerns have stimulated a search for alternative control methods. However, any such control method must not impact the macrobenthic fauna. The effectiveness of a physical disruption to control *Spartina* swards on tidal flats was investigated in the saltmarsh at Lindisfarne NNR, UK. The sediment was disturbed by a light-weight tracked vehicle until the *Spartina* swards were dislodged and buried within the sediment. The post-disturbance dynamics of the infauna in the disturbed area was investigated 1, 12, 31, 92 and 384 days after the disturbance. In spite of the drastic change brought about in the flora, there was no evidence that the infauna were impacted by the disturbance at any sampling time. Two possible mechanisms to explain the absence of changes in the abundance of the infauna are discussed with special reference to the unconsolidated nature of the sediment and the high mobility of the adult infauna. The abundance of *Spartina* swards in the disturbed area was lower than that in the undisturbed area. Physical disturbance to *Spartina* swards by the tracked vehicle seems to be an appropriate method for its control in tidal flats which obviates the need, with associated financial costs and environmental risks, of chemical control.

Garcia-Mora, M. R., J. B. Gallego-Fernandez and F. Garcia-Novo. 2000. Plant diversity as a suitable tool for coastal dune vulnerability assessment. *Journal of Coastal Research* 16:990-995.

Author Abstract. The investigation reported here is concerned with the use of plant diversity measures for coastal dune monitoring. The original set of recorded plant species on dune systems was broken into 3 functionally homogeneous groups, which allow ecological comparisons among foredune vegetation on a much wider sense than traditional taxonomic approaches. Plant diversity was measured both, as species richness and as the rate of species number increase with area. Plant diversity values were tested as a dependent variable of a coastal dune vulnerability index. Increasing coastal dunes vulnerability, caused by natural or human events, lowered the rate of species increase with area within the plant functional

type associated to prograding foredunes. Results suggest that plant diversity within this functional type, measured as the slope of the species-area curve, may be used as a management tool for predicting coastal dune vulnerability.

Govender, Y. and M. R. Jury. 2000. Long-term Monitoring of South Africa's Coral Coast as Part of C-Goos, p. 1. The Tenth Southern African Marine Science Symposium (SAMSS 2000): Land, Sea and People in the New Millennium, Abstracts.

Author Abstract. To improve management of the north coast of South Africa where coral reefs are present, a long-term monitoring project is proposed to quantify and understand the: diversify of marine species in the coral reefs; dynamic behaviour of sandy beaches; diversify of vegetation in the coastal dune forests; human uses and impacts; and potential for limited development. The bi-annual observational program at Mabibi will include measurement of: sand height along three transects; near-surface wind profiles; near-shore currents using drifting drogues; sea and air temperature and soil moisture; swell height and period bio-diversify assessment of coral species; bio-diversify assessment of dune vegetation; vehicular, pedestrian, and snorkeling traffic. In addition soil and water samples will be collected for analysis of fertility and pollution. Demographic surveys of local communities, visiting tourists, conservation officers and private developers will be conducted. The following Key Questions will be addressed: is the near-shore ocean circulation wave, wind, or current driven? And does the net longshore drift display seasonal, synoptic, and tidal cycles; how is dune vegetation de-stabilized and overtopped by blown sand from the incessant NE winds; how will human pressure arising from local consumption, visitors from Sodwana and coastal developments alter the ecosystem.

Irish, J. L. and C. Truitt. 1995. Beach fill storm response at Longboat Key, Florida: Sand wars, sand shortages and sand-holding structures, pp. 103-117. In Tait, L. S. (ed.), Proceedings of the 1995 National Conference on Beach Preservation Technology. Florida Shore and Beach Preservation Association, Tallahassee, FL, USA.

Author Abstract. Over two million cubic meters of compatible sand were placed in the spring of 1993 to restore the severely eroded Gulf beaches of Longboat Key, Florida. The fill section begins just north of New Pass and extends north for over 14 km. The source of the borrow material was the ebb shoal at New Pass on the south and at Longboat Pass on the north end of the Key. The conditions imposed as part of the several regulatory permits for the project defined an overall monitoring program which included periodic beach profile surveys. The surveys were performed using conventional hydrographic surveying techniques. Three additional surveys were performed to supplement the required monitoring and to evaluate an alternate surveying technique. These surveys were conducted using the Scanning Hydrographic Operational Airborne Lidar Survey (SHOALS) system, developed by the United States Army Engineer Waterways Experiment Station. The SHOALS system collected very detailed bathymetry along an 8 km section of the restored beach, producing a 4 m by 4 m uniform horizontal grid with measured depths from 1 m to 9 m. The initial fill adjustment during the first project year appeared to be dominated by storm events. A goal of the present effort was to evaluate the beach response to the wave climate during the second year monitoring. Directional wave information was collected throughout the period in order to quantify any significant storm activity and relate any observed beach changes.

Jackson, N. L. 1999. Evaluation of criteria for predicting erosion and accretion on an estuarine sand beach, Delaware Bay, New Jersey. *Estuaries* 22:215-223.

Author Abstract. Predicting erosion and accretion of sand beaches in estuaries is important to managing shoreline development and identifying potential relationships between biological productivity and beach change. Wave, sediment, and profile data, gathered over twenty-nine days on an estuarine sand beach in Delaware Bay, New Jersey, were used to evaluate the performance of four criteria that predict beach erosion and accretion due to wave-induced cross-shore sediment movement. Each criterion defines a relation, between a wave and sediment parameter, and includes a coefficient that discriminates beach erosion and accretion events. Relations, based on small-scale laboratory and field data, were evaluated for predicting erosion or accretion at the study site. Significant wave heights at the study site, monitored near high water, ranged from 0.08 to 0.52 m with periods of 2.4 to 12.8 s. Median grain sizes of sediments on the beach foreshore, gathered at low water, ranged from 0.33 to 0.73 mm. All four criteria showed a clustering of erosion and accretion events. Relations derived from small-scale laboratory data were better predictors of erosion on the profile at the field site than those derived from field data gathered on exposed ocean environments. The planar profile and dominance of incident waves of low height and short period are similar to laboratory conditions characterized by initial planar beach slopes and monochromatic waves. Decreasing the value of the empirical coefficient to account for the differences in the magnitude of wave energy and grain size increases the performance of the criteria tested to predict erosion of the profile.

Jaramillo, E., A. McLachlan and J. Dugan. 1995. Total sample area and estimates of species richness in exposed sandy beaches. *Marine Ecology Progress Series* 119:311-314.

Author Abstract. Recent studies have shown that macroinfaunal species richness of exposed sandy beaches increases from reflective to dissipative conditions. To analyse if this trend is affected by sampling strategies (primarily area sampled), we compared results from surveys carried out in different beach types of South Africa, Australia, and Chile. Total area sampled in those surveys was 4.5 m^2. The percentage of species predicted for each beach increased in relation to an increase in total sampling area. Only at a total sample area of 4 m^2 were most (> 95%) of the species present collected. Sampling areas of 1 m^2 and 2 m^2 result in average underestimations of nearly 40% and 20% of the species, respectively. Beaches harbouring the highest number of species (the most dissipative ones) need to be sampled more extensively to collect most of the species, as compared with beaches having lower species richness. A bibliographic survey showed that most of the studies carried out on sandy beaches have been based upon sampling areas considerably smaller than 4 to 4.5 m^2, suggesting that in many of the studies the sandy beach macrofauna was under-sampled.

Jutte, P. C., R. F. Van Dolah and P. T. Gayes. 2002. Recovery of benthic communities following offshore dredging, Myrtle Beach. *South Carolina Shore & Beach* 70:25-30.

Author Abstract. The Myrtle Beach Renourishment Project placed more than 6 million cu yd of sand on approximately 25 miles of beaches in the northern portion of South Carolina. The project was divided into three phases due to its large size. Nearshore dredging for the first phase occurred in 1996. More than 2.6 million cu yd of sandy sediments were removed to approximately 1 m below grade by a hopper dredge. Replicate benthic infaunal and sediment samples were collected quarterly from the borrow area and an undredged reference area from November 1995 until February 1998, with supplemental sampling occurring in February 1999. Sediment measurements were made of silt/clay, sand, $CaCO_3$, and organic matter content. Sediment composition at the borrow area underwent significant changes in sand, silt/clay, and $CaCO_3$ following dredging activity. Organic matter content at the borrow site was elevated after dredging occurred, with effects persisting throughout the study period. Biological effects at the dredged site, based on temporal and spatial comparisons, included altered diversity indices (H', J', and species richness), shifts in general taxonomic composition, and changes in numerically dominant species. The benthic infaunal assemblage in the borrow area recovered to pre-dredging conditions, showing signs of enhancement, within 27-30 months after dredging. The relatively rapid recovery of the dredged area was attributed to the use of hopper dredges that leave shallow dredged furrows separated by relatively undisturbed areas of sediment and biota.

McLachlan, A. 1996. Physical factors in benthic ecology: Effects of changing sand particle size on beach fauna. *Marine Ecology Progress Series* 131:205-217.

Author Abstract. This paper reports on the disposal of diamond mine tailings on a Namibian sandy beach. Coarse sand in the tailings greatly increases the grain size of the affected parts of the beach and thereby provides the opportunity to assess the effects of changing sand grain size on a beach when other physical variables are kept constant. Elizabeth Bay (Namibia) is 4 km long and was originally composed of fine sand which, exposed to moderate to heavy wave action, produced a log spiral bay with a dissipative beach. Tailings disposal in the centre of the bay has increased mean sand particle size from original values of 110 to 160 mu m to present values of 500 to 800 mu m with a concomitant conversion of beach morphodynamic state from dissipative to intermediate. Surveys of the 2 ends of the bay, which are relatively unaffected by disposal, and of an undisturbed similar bay nearby revealed intertidal benthic macrofauna communities with 15 to 20 species occurring in high abundance (24,120 to 129,276/m). In 3 transects in the affected area, species richness was 8 to 12 per transect and abundance was 640 to 4,710/m. Beds of the large sand mussel *Donax serra* have disappeared from the affected sector of the bay and peracarids typical of finer sands have been replaced by a more robust species. Regression analysis revealed significant correlations between community parameters (species richness and abundance) and both beach slope and particle size; ANOVA confirmed the significantly lower abundances of fauna in the affected areas. Smothering effects appeared to be localised and limited. This study has supported the hypothesis that an increase in sand particle size (on a beach where tide range and wave energy have remained constant) results in a change in beach state and a decrease in species richness and abundance.

Miller, D. L., M. Thetford and L. Yager. 2001. Evaluation of sand fence and vegetation for dune building following overwash by hurricane Opal on Santa Rosa Island, Florida. *Journal of Coastal Research* 17: 936-948.

Author Abstract. Santa Rosa Island, a barrier island located in the panhandle of Florida, was severely impacted by hurricane Opal's 3-4 m tidal surge in October 1995. Rapid reestablishment of the fragmented dune system through sand accumulation and stabilization is essential for many wildlife and plant species and protection of coastal structures against storm surge. Comparisons of sand accumulation rates for two biodegradable materials, three-fence orientations and non-fenced controls were assessed in a secondary dune position. Effect of winter and spring planting without supplemental water on survival and growth of nursery-grown sea oats and bitter panicum was monitored within the dunes. Wood and Geojute material sand fences in three orientations were installed at six sites. Sand accumulation associated with these fence material/orientation combinations and non-fenced controls was measured twice a year (1996-99). There were no significant differences in sand accumulation between Geojute and wood fences at most positions for the first eight months. Following this, Geojute degraded and its accumulated sand was no more than that of the controls 18 months after installation. Sand accumulation did not differ significantly among wood fence configurations at most distances from the fence. Through time the straight-conventional wood and perpendicular-wood fence treatments had consistently higher sand accumulation values compared to unfenced controls. While survival of transplanted sea oats and bitter panicum was not effected by season of planting, growth varied with planting season.

Moragwa, G. and J. Seys. 1995. Monitoring Waterbirds as Indicators of Ecosystem Health. Sustainable Development of Fisheries in Africa, Kenya, 211 pp. FISA, Nairobi Kenya.

Author Abstract. The universality and high mobility of birds makes them very easy to monitor since their presence or absence can act as an early warning system in assessing ecosystem health. From January 1994 to March 1995, regular counts of wetland birds were conducted in six major creek systems between Gazi-bay and the Sabaki river mouth. Spatial patterns showed that shorebirds were best represented (23) followed by large wading birds (15) then gulls and terns (10). Of these species, twenty were common in all the studied areas, while the rest had a more restricted distribution. In total, sixty species were encountered. Mida creek and Sabaki River mouth (Kenya) were the most important bird areas with 79% of the total numbers and 80% of the species respectively. In the marine environment, birds are on top of the food web and thus can indicate the presence of lower trophic groups. Local fishermen have been known to use sea gulls and terns to locate the presence of large schools of fish. Temporal patterns carried out in Mida Creek and Gazi Bay using boat surveys showed that piscivores were dominant in Gazi Bay, while benthivores were dominant in Mida Creek. Abiotic and geomorphological characteristics of the creeks were found to determine the relative abundance of different trophic groups of birds. The tidal flats exposed during low tide had the highest densities due to the feeding activity of many shorebirds and large waders. Food availability in terms of small benthic organisms (Mollusca, worms) tended to be higher in fine sediments than in coarse ones while sands banks were favorite habitats for certain crab species which are prey for birds such as crab plovers *Dromas ardeola*. Mangroves played a critical role for the safety of many species during high tide.

Nel, R., A. McLachlan and D. Winter. 1999. The effect of sand particle size on the burrowing ability of the beach mysid *Gastrosaccus psammodytes* Tattersall. *Estuarine, Coastal and Shelf Science* 48:599-604.

Author Abstract. Laboratory studies on the burrowing rates of the mysid shrimp, *Gastrosaccus psammodytes*, in a series of well-sorted sediments, determined whether (1) burial times were dependent on grain size and (2) if natural population distribution may be influenced by grain size on beaches. Assessing sediment particle size in relation to fauna activity will help practitioners understand soft shoreline use and contribute to developing an effective restoration monitoring plan. Burial times were tested in nine well-sorted sediments with grain size ranging from 90 to 2000 mu m. Large individuals (i.e., gravid females) were used. *G. psammodytes* burrowed fastest in 125-1000 mu m sand with mean burial times less than 1.6 s. Burial time increased to approximately 2 s in 90-125 mu m sand. *G. psammodytes* could not burrow in grain sizes coarser than 1000 mu m. *G. psammodytes* has been reported to occur on beaches with grain sizes ranging from 90 to 500 mu m but are uncommon on beaches with coarser sand. It appears that population distribution may be influenced by grain size that is probably not related to the animals' burial time ability, but rather their inability to burrow completely into coarse sand. Indirectly, grain size may also influence the morphodynamic state of a beach and therefore food availability since coarse-grained beaches tend to be reflective with little surf production.

Ohsaka, Y. and Y. Koshiishi. 1998. Effects of covering a tidal flat with sand for stock enhancement of tonguefish: A feasibility study at Ariake Sound in Kyushu, Japan, pp. 105-114. In. Howell, W. H., B. J. Keller, P. K. Park, J. P. McVey, K. Takayanagi, and Y. Uekita (eds.), Nutrition and Technical Development of Aquaculture.

Author Abstract. Ariake Sound is characterized by a high tidal range of about 6 m at the innermost part, and is known to have high productivity of commercially important species. However, the production of certain species has shown decreasing trends due to overfishing and deterioration in environmental conditions. Tonguefish are important species for gill net and trawl fisheries in this sound because of their high commercial values, but the annual catch of *Cynoglossus abbreviatus* has been decreasing markedly during the last decade. We assumed that covering the muddy tidal flat with sand as a means of habitat restoration would enhance the stock of these fish. In order to study the effects of sand covering on growth and survival of tonguefish *C. abbreviatus* and *C. joyneri* juveniles, we carried out periodic samplings by small beam trawl at the innermost part of the sound. A sand-covered area made in 1991, at about the lowest low water level, to increase the production of short-neck clams was selected as the survey area. The gear was towed along the lines set on the sand-covered area and a nearby muddy area as a control. The periodic samplings revealed that occurrence of *C. abbreviatus* in the sand-covered area increased with growth, but was not the case for *C. joyneri.* Since the larger juveniles of *C. abbreviatus* changed their prey animals from copepods to gammarids and mysids which were known to be abundant in the sandy area, it was suggested that covering the mud with sand provided beneficial effects at least for the growth and survival of this species.

Parikh, A. and N. Gale. 1998. Vegetation monitoring of created dune swale wetlands, Vandenberg Air Force Base, California. *Restoration Ecology* 6:83-93.

Author Abstract. A monitoring program was established on San Antonio Terrace at Vandenberg Air Force Base to compare vegetation development at two created wetland sites and six nearby natural wetlands. The reference wetlands were chosen to represent a range of habitats in dune swale wetlands on the Terrace. Vegetation in the reference wetland plant communities varies from low-growing herbaceous marsh species with open canopies to closed canopies dominated by shrub or tree species. Transects and plots for long-term vegetation monitoring were established in all the wetlands, stratified by plant communities in the reference wetlands and by geomorphic location in the newly created wetlands. Quantitative vegetation and environmental data were collected at all the sites; measures included species distributions, species cover, and topographical elevations. Over the first three years of monitoring, variations in groundwater depth at different geomorphic locations in the created wetlands resulted in a variety of physical conditions for plant growth. In the first year, more than 100 plant species were observed, the majority being natives. During the next two years, species richness at the created wetland sites remained relatively stable and was higher than at the reference sites. Statistical comparisons of vegetation parameters by analysis of variance and hierarchical clustering exhibited patterns of increasing similarity between the created and reference wetlands. Long-term monitoring will be continued to track the progress of vegetation at the created sites, and to assess their development relative to the reference wetlands.

Pickart, A. J., L. M. Miller and T. E. Duebendorfer. 1998. Yellow bush lupine invasion in northern California coastal dunes: Ecological impacts and manual restoration techniques. *Restoration Ecology* 6:59-68.

Author Abstract. We studied the ecological effects of the invasion of coastal dunes by *Lupinus arboreus* (yellow bush lupine), an introduced species, and used the results to develop manual restoration techniques on the North Spit of Humboldt Bay. Vegetation and soil data were collected in five vegetation types representing points along a continuum of bush lupine's invasive influence. We collected data on the number and size of shrubs, vegetation cover, and soil nutrients. One set of plots was subjected to two restoration treatments: removal of lupine shrubs only, or removal of all nonnative vegetation and removal of litter and duff. Treatments were repeated annually for four years, and emerging lupine seedlings were monitored for three years. Prior to treatment, ammonium and nitrate were found to increase along the lupine continuum, but organic matter decreased at the extreme lupine end. Yellow bush lupine was not the most significant variable affecting variation in soil nutrients. After four years, nonnative grasses, including *Vulpia bromoides, Holcus lanatus* (velvet grass), *Bromus* spp. (brome), and *Aira* spp. (European hairgrass), were significantly reduced in those restoration plots from which litter and duff was removed. Native species increased significantly in vegetation types that were less influenced by lupine. By the third year, soil variables differed among vegetation types but not by treatment. Bush lupine seedling emergence was higher, however, in plots receiving the litter and duff removal treatment. Based on these results, we conclude that bush lupine invasion results in both direct soil enrichment and indirect enrichment as a result of the associated encroachment of other nonnative species, particularly grasses. Although treatment did not affect soil nutrients during the period of this study, it did reduce establishment of nonnative grasses and recruitment of new bush lupine seedlings. Restoration should therefore include litter and duff removal. In areas that are heavily influenced by lupine and contain few native propagules, revegetation is also required.

Piehler, M. F., V. Winkelmann, L. J. Twomey, N. S. Hall, C. A. Currin and H. W. Paerl. 2003. Impacts of diesel fuel exposure on the microphytobenthic community of an intertidal sand flat. *Journal of Experimental Marine Biology and Ecology* 297:219-237.

Author Abstract. This study employed simulated spills of weathered diesel fuel and measured the initial effects on the intertidal sand flat microphytobenthic (MPB) communities. The goals were to examine the impacts of short-term (hours) and longer-term (days) exposure to petroleum on the native sand flat MPB in coastal North Carolina and to assess recovery of the community following the exposure. We assessed changes in biomass (chlorophyll a), primary productivity ^{14}C bicarbonate incorporation),

photophysiology (P vs. I curves) and species composition (microscopy) and compared diesel exposed samples to unamended controls. We found that short-term impacts of diesel fuel pollution were confined to primary productivity and photophysiology of sand flat MPB. Short-term effects were only detected at relatively high concentrations that are not common outside of a major spill event. In the longer term, diesel fuel was again found to have effects on primary productivity, but at higher concentrations than would be likely to occur in industrialized coastal areas. However, negative impacts on photophysiology were detected at diesel fuel concentrations slightly above typical ambient conditions in coastal waters in industrialized areas. Biomass as measured by chlorophyll a was not affected by any concentration in the longer-term exposure to diesel fuel. Cell counts in the longer-term experiments found cyanobacteria had larger negative impacts from diesel fuel exposure than did diatoms. The recovery portion of this study showed the sand flat MPB communities were fairly resilient following both additions of diesel fuel. However, photophysiology and cell counts did not return to conditions equivalent to the control. Data from this study indicate that the effects of petroleum pollution on the MPB community of tidal sand flats should be considered alongside effects on other coastal microalgae in ecological and damage assessments.

Prandle, D., R. A. F. Flather, M. Regener, K. Duwe, W. Rosenthal, H. Gerritsen, G. Chapelain, J. Monbaliu, J. Ozer, J. Carratero, E. Alvarez, A. Jenkins and H. Wensik. 1999. Coastal Evolution Extending Short Term Simulations, pp. 307-308. In Barthel, K. G., H. Barth, M. Bohle-Carbonell, C. Fragakis, E. Lipiatou, P. Martin, G. Ollier, and M. Weydert (eds.), Third European Marine Science and Technology Conference (MAST conference), Lisbon, 23-27 May 1998: Conference Proceedings. European Commission DG 12 Science, Research and Development, Luxembourg.

Author Abstract. The objectives of this study were to (1) to identify how modeling and monitoring capabilities need to be developed and combined to provide estimates of coastal-nearshore sediment exchanges; and (2) to consider limits to long term predictability. Traditionally shoreline evolution has focused on coastal engineering aspects of the response of beaches to waves. This focus has recently been extended to include coastal-nearshore sediment exchange, reflecting concerns arising from acceleration in: climate change (sea level and storminess), offshore aggregate extraction, steepening of cross-shore slopes, adoption of soft-defense strategies (inc. beach nourishment) and recognition of large-scale interdependencies. Such large-scale sediment exchanges cannot be measured directly and the longer term impact on bathymetry may only be evident in shallow water. Thus models are required, linking dynamical simulations of tide, surge, wave and turbulence to 'dispersion' modules representing the erosion, transport, and deposition of a range of sediment types. The associated dynamical coupling of model components and subsequent evaluation against observations emphasizes the need for a Pre-Operational modeling approach. Monitoring is required to verify the sediment algorithms locally and the integrated depth changes in areas of rapid accretion/ erosion. In the MAST 111 program PROMISE, the North Sea was adopted as a focus because of the existence of forecasting systems for tides, surges and waves. Wave models were adapted for fine-scale application in near-shore shallow regions. Likewise the turbulence models were developed to incorporate wave-tide-surge interactions. Extensive data sets were then assembled to assess these various modules independently and overall. Parallel applications of the above models in the MAST 3 program SCAWVEX have indicated that existing models accurately simulate both currents and waves in

the near-shore zone. Likewise the interaction between these parameters can be reproduced together with their impact on turbulence intensity and locally re-suspended sediments. Thus the dynamics and associated erosion, deposition and suspension of sediments can be accurately simulated (at least at such low sediment concentrations). Longer term (and thereby larger scale) simulations of sediment transport are bedeviled by the chronology of sediment availability and the resultant evolution of bed form etc. Likewise there are inaccuracies in specifying meteorological forcing and 'initial' bathymetry.

Rakocinski, C. F., R. W. Heard, S. E. LeCroy, J. A. McLelland and T. Simons. 1996. Responses by macrobenthic assemblages to extensive beach restoration at Perdido Key, Florida, USA. *Journal of Coastal Research* 12:326-353.

Author Abstract. In this study, we examine and monitored complex responses by macrobenthic assemblages to extensive beach restoration affecting 7 km of open shoreline at Perdido Key, Florida. Beach restoration consisted of two phases, beach nourishment and profile nourishment, each phase lasting roughly one year. Macrobenthic responses using an optimal impact study design incorporating ten macrobenthic surveys completed over a three-year period were examined. This study is important because of its geographical region, its relatively large spatial scale, its long duration, and its consideration of both nearshore assemblages from high energy sandy beaches and diverse assemblages from stable offshore habitats. The physical environment was altered by beach restoration through changes in depth profiles and sediment composition as well as through sediment dynamics. Various macrobenthic responses attributable to beach restoration included: decreased species richness and total density, enhanced fluctuations in those indices, variation in abundances of key indicator taxa, and shifts in macrobenthic assemblage structure. One long-term impact of beach nourishment at nearshore stations included the development of macrobenthic assemblages characteristic of steep depth profiles. Two long-term negative impacts of beach restoration at offshore stations included one from beach nourishment and another from profile nourishment. After beach nourishment, the macrobenthic assemblage structure changed markedly across a considerable offshore area in concert with increased silt/clay loading. Macrobenthic impacts from silt/clay loading were still evident at the end of the study, more than two years after beach nourishment. Macrobenthic populations fluctuated widely at the farthest seaward stations from apparent sediment disturbance, both during and after profile nourishment. These fluctuations involved total densities, species richness, and densities of key indicator taxa. Macrobenthic fluctuations continued through the end of the study, although profile nourishment was completed for more than one year prior to that time. Considerable macrobenthic recovery was apparent during the study, although macrobenthic recovery remained indeterminate in some places. Long-term macrobenthic impacts at several offshore stations supported the hypothesis that diverse offshore assemblages may be less resilient than contiguous nearshore sandy-beach assemblages.

Ray, G. L. 2000. Infaunal assemblages on constructed intertidal mudflats at Jonesport, Maine, USA. *Marine Pollution Bulletin* 40: 1186-1200.

Author Abstract. Dredged materials have been used to construct two mudflats near Jonesport, Maine (USA). A flat at Sheep Island was constructed in 1989 and along with an adjacent reference area (REF) has been monitored for infaunal assemblage development and sediment texture since 1990. The second site, Beals Island, an example of a much older constructed flat (CF), has been monitored since 1991. Infaunal taxa richness, total numerical abundance, species composition, and diversity values were similar between the Sheep Island natural and constructed sites within two years of construction. At Beals Island, taxa richness and other diversity measures were similar between sites, however, abundance and total biomass values were lower at the constructed site. Although total biomass was also lower at the Sheep Island CF than its REF, biomass values at both constructed sites (Sheep Island and Beals Island) were within the range of values previously reported for natural flats.

Rooney, J. J. B. and C. H. Fletcher. 2001. Climate variability and shoreline change along the Kihei Coast of Maui, Hawaii. Coastal Geotools '01. In Proceedings of the 2nd Biennial Coastal Geotools Conference. United States National Oceanic and Atmospheric Administration, NOAA Coastal Services Center, Charleston SC.

Author Abstract. It is difficult to overemphasize the importance of sandy beaches as a resource in the Hawaiian Islands. Despite their importance, beaches on all the main Hawaiian Islands have been degraded. On the island of Maui it has been estimated that one third of the original sandy beach has been lost or narrowed. Given the need for improved management of beach and coastal resources, this project is an effort to improve our understanding of these changes. It has examined movement of the shoreline over the last century at an erosion "hotspot" on the Kihei coast. The techniques and methods developed at this site are now being applied to all significant sandy shoreline areas on the island. To elucidate historical patterns of shoreline change we use soft-copy photogrammetric techniques to rectify available NOS T-sheets and aerial shoreline photographs. Years of coverage include T-sheets from 1900 and 1912 and photographs from 1949, 1960, 1963, 1975, 1987, 1988, and 1997. The landward boundary of the beach (vegetation line) and shoreline (beach step crest) are digitized on orthorectified photomosaics for each year of coverage. Historical movement of these features is measured along shore-normal transects spaced 20 m apart. Average annual erosion hazard rates (AEHRs) are determined for each transect with a reweighted least-squares regression applied to the most recent trend in shoreline position. AEHRs are used to calculate and plot the position of the 30-year erosion hazard line. A model was developed using seasonal beach profile data to estimate volumetric change for each transect, and area-wide rates of net longshore sediment transport (LST). Our data show that between 1900 and 1997 there was severe erosion at the southern end of the site but roughly three times more accretion to the north. Production and delivery of sand to the beach from the fringing reef fronting the site is estimated to account for 6% of the net gain. These changes began prior to 1912 and a major portion of the total change had occurred by 1949, prior to significant western perturbation of the coastline. This suggests that natural rather than anthropogenic forcing is primarily responsible. However, impoundment of sediment behind coastal armoring along one third of the site has contributed to littoral sediment deficiencies since about 1975. Kona storms are large, low-pressure systems approaching the islands from the southwest or west and accompanied by rain-bearing winds. Occasional large kona storms have been shown to cause significant erosion and northward LST along the Kihei coast. Genesis of kona storms changes in response to variations in ENSO activity, which in turn is modulated by the Pacific Decadal Oscillation (PDO). We find that patterns of the PDO cycle, kona storm activity, and LST are similar at multi-decadal time scales. We hypothesize that the general agreement in these records suggests a cause-and-effect relationship between the PDO and LST along the Kihei coast. If further research confirms this hypothesis, PDO-driven shoreline dynamics will be an important consideration in the successful management of Hawaii's south and west facing shorelines.

Samuelson, G. M. 2001. Polychaetes as indicators of environmental disturbance on subarctic tidal flats, Iqaluit, Baffin Island, Nunavut Territory. *Marine Pollution Bulletin* 42:733-741.

Author Abstract. The polychaetes of the tidal flats near the town of Iqaluit, Baffin Island were analyzed along gradients of environmental disturbance resulting from human activity. Sources of environmental disturbance include a sewage lagoon, garbage sites; and an area of the tidal flat that is cleared by bulldozer. Sampling of the tidal flats included 300 biological sediment cores taken from 75 sites along seven transects. Environmental disturbance has resulted in four zones of polychaete communities with increasing distance. The heavily disturbed zone is closest to the disturbances and is devoid of polychaetes. The disturbed zone follows and is characterized by low diversity the result of increased densities of a few opportunistic species such as, *Capitella capitata* sp. The moderately disturbed zone is characterized by increased species diversity due to organic enrichment from the disturbances. The undisturbed zone, located the furthest from the sources of disturbance, is characterized by moderate levels of diversity compared to the other three zones. Methods used in this study can contribute to monitoring whether disturbances have occurred during restoration and how disturbances impact species that are present.

Schoeman, D. S., A. Mclachlan and J. E. Dugan. 2000. Lessons from a disturbance experiment in the intertidal zone of an exposed sandy beach. *Estuarine, Coastal and Shelf Science* 50:869-884.

Author Abstract. Exposed sandy beaches are important, sensitive, and widespread coastal habitats. Although they have been studied for more than 50 years, investigators have been reluctant to attempt manipulative experiments due to the dynamic nature of these environments. Consequently, the ecology of exposed sandy beaches remains relatively poorly understood. We conducted a community-level, manipulative experiment involving a simulated anthropogenic disturbance on an exposed microtidal sandy beach in the Eastern Cape, South Africa; the first of its kind and scale. This study comprised pre- and post-impact sampling at an experimental site and two control sites. The impact involved excavating and removing a 200 m^2 quadrat of sand from the mid-intertidal of the experimental site to a depth of 0.3 m. The intention was to address the prediction that anthropogenic disturbances would be detectable if appropriate spatial and temporal scales were investigated. The following variables were monitored: transect gradient; species richness; macrofaunal abundance; and both the abundance and biomass of the dominant infaunal species, the beach clam *Donax serra* Roeding. Analyses revealed significant differences in temporal patterns of all response variables amongst sites. Some evidence linked these changes to the experimental disturbance, although impacts appear temporary, being ameliorated within, at most, one semi-lunar cycle. This confirms that it is possible to successfully conduct manipulative experiments on exposed sandy beaches. However, the uncontrollable, natural dynamics of the beach face, as expressed by intertidal gradient, contributed significantly to the description of spatio-temporal variation in biotic response variables. It is concluded that to isolate treatment effects from those of natural variation, two advances are necessary on the current research approach. First, experimental designs must take cognizance of the fact that exposed, microtidal sandy beaches have little in common with other intertidal habitats; and second, large-scale treatments must be replicated in space.

Tanner, C. D., J. R. Cordell, J. Rubey and L. M. Tear. 2002. Restoration of freshwater intertidal habitat functions at Spencer Island, Everett, Washington. *Restoration Ecology* 10:564–570.

Author Abstract. In November 1994 dikes were breached around Spencer Island, restoring tidal inundation and connections to the Snohomish River estuary, Washington. Approximately 23.7 ha (58.5 ac) of palustrine wetlands previously dominated by *Phalaris arundinacea* (reed canary grass) now experience diurnal tides and are in the process of transition to a freshwater tidal system. It was expected that brackish water would accompany the return of tidal influence to the site, but post-project monitoring has revealed little evidence of salinity. Pre- and post-project monitoring of changes in habitat function included aerial photography, vegetation and fish sampling, and benthic prey studies. To date site changes include (1) die back of pre-project vegetation, development of tidal mudflat, and emergent wetland habitats, with recruitment of vegetation typical of freshwater tidal wetlands; (2) presence of juvenile coho, chum, and chinook salmon that feed on invertebrate prey typical of the site; (3) presence of three distinct benthic invertebrate assemblages in the project area; and (4) some invasion by *Lythrum salicaria* (purple loosestrife). The unexpected freshwater conditions, the lack of published information about tidal oligohaline marshes in the Pacific Northwest, the use of the site by endangered salmonid species, and the invasion by an undesired plant species underscore the importance of long-term monitoring at the site.

APPENDIX II: SOFT SHORELINE HABITATS
REVIEW OF TECHNICAL METHODS MANUALS

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 Bibliographies, these entries are not, however, a complete list. Entries are arranged alphabetically by author. Wherever possible, web addresses or other contact information is included in the reference to assist readers in 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.

Cook Inlet Keeper. 1998. Volunteer training manual. Contact information: Cook Inlet Keeper, P. O. Box 3269, Homer, AK 99603, Phone # (907) 235-4068 and Fax # (907) 235-4069. http://www.inletkeeper.org/training.htm.

This Manual provides Cook Inlet Keeper volunteers with information needed to monitor water quality in the Cook Inlet watershed. It also provides guidelines for monitoring procedures that are currently included in the Keeper's Citizens' Environmental Monitoring Program (CEMP). Outlined in this document are safety and access issues; a monitoring overview which discusses areas such as water quality test methods, test parameters and sampling schedule; monitoring procedures which include: field procedure checklist, field observations, collecting the samples, testing procedures, sample custody and completing data sheets; equipment care and waste disposal; data management and reporting; and quality control. Additional information for methods and procedures used can be obtained from this manual.

Davies, J., J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull and M. Vincent. 2001. Marine Monitoring Handbook. UK Marine Science Project, and Scottish Association of Marine Science. Joint Nature conservation Committee, English Nature, Scottish Natural Heritage, Environment and Heritage Services. http://www.jncc.gov.uk/marine/mmh/Introduction.pdf.

The UK Marine Science Project developed this hand book to provide guidelines for recording, monitoring, and reporting characteristics and conditions of marine habitats. However, based on location and other environmental conditions methodologies will have to be modified to suit the structural characteristics of the habitat. This manual addresses the fundamentals and procedures for monitoring different parameters in marine habitats, management tools, and benefits and costs for developing a monitoring project. Topics presented in this document include establishing marine monitoring programs highlighting what needs to be measured and methods to use; provides guidance when developing a monitoring program; selecting proper monitoring techniques to attain precision and accuracy; and procedural guidelines for monitoring a specific marine habitat. Detailed information on the tools needed for monitoring marine habitats are described within the marine monitoring handbook.

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.

McCobb, T. D. and P. K. Wieskel. 2003. Long-Term Hydrologic Monitoring Protocol for Coastal Ecosystems. United States Geological Survey Open-File Report 02-497. 94 pp. http://water.usgs.gov/pubs/of/2002/ofr02497/

The United States Geological Survey (USGS) and the National Park Service have designed and tested monitoring protocols implemented at Cape Cod National Seashore. The monitoring protocols are divided into two parts. Part one of the protocol discusses the objectives of the monitoring protocol and presents rationale for the recommended sampling program. The second part describes the field, data-analysis, and data-management, and variables that are to be taken into consideration when monitoring (e.g., sea level rise, climate change and urbanization). This protocol provides consistency when monitoring changes in ground-water levels, pond levels, and stream discharge. The monitoring protocol not only establishes a hydrologic sampling network but provides reasoning for measurement methods selected and spatial and temporal sampling frequency. Data collected during the first year of monitoring and hydrologic analyses for selected sites are presented. Long-term hydrologic monitoring procedures performed at the Cape Cod National Seashore may also assist set a template for deciphering findings of other monitoring programs.

Morton, R. A., M. P. Leach, J. G. Paine and M. A. Cardoza. 1993. Monitoring beach changes using GPS surveying techniques. *Journal of Coastal Research* 9: 702-720.

Author Abstract. A need exists for frequent and prompt updating of shoreline positions, rates of shoreline movement, and volumetric nearshore changes. To effectively monitor and predict these beach changes, accurate measurements of beach morphology incorporating both shore-parallel and shore-normal transects are required. Although it is possible to monitor beach dynamics using land-based surveying methods, it is generally not practical to collect data of sufficient density and resolution to satisfy a three-dimensional beach-change model of long segments of the coast. The challenge to coastal scientists is to devise new beach monitoring methods that address these needs and are rapid, reliable, relatively inexpensive, and maintain or improve measurement accuracy. The adaptation of Global Positioning System (GPS) surveying techniques to beach monitoring activities is a promising response to this challenge. An experiment that employed both GPS and conventional beach surveying was conducted, and a new beach monitoring method employing kinematic GPS surveys was devised. This new method involves the collection of precise shore-parallel and shore-normal GPS positions from a moving vehicle so that an accurate two-dimensional beach surface can be generated. Results show that the GPS measurements agree with conventional shore-normal surveys at the 1 cm level, and repeated GPS measurements employing the moving vehicle demonstrate a precision of better than 1 cm. In addition, the nearly continuous sampling and increased resolution provided by the GPS surveying technique reveals alongshore changes in beach morphology that are undetected by conventional shore-normal profiles. The application of GPS surveying techniques combined with the refinement of appropriate methods for data collection and analysis provides a better understanding of beach changes, sediment transport, and storm impacts.

Oregon Watershed Enhancement Board. 1999. Oregon Aquatic Habitat: Restoration and Enhancement Guide. Salem Oregon, 97301, Phone # (503) 986-0178. http://www.oweb.state.or.us/publications/habguide99.shtml

This guide was developed to provide guidance on restoration and enhancement measures that would assist in aquatic ecosystem recovery. The guide is divided into five sections: An overview of restoration activities, activity guidelines, overview of agency regulatory functions and sources of assistance, grants and assistance, and monitoring and reporting. The purpose of this document is to provide information that will assist in developing effective restoration projects; to define standards and priorities that will be approve by state and receive funding or authorized restoration projects; to identify state and federal regulatory requirements and receive assistance in restoration projects. Additional information on monitoring techniques for salmonid restoration and guidelines and considerations for reporting restoration progress over time are described within the document.

Pohle, G. W. and M. L. H. Thomas. 2001. Monitoring Protocol for Marine Benthos: Intertidal and Subtidal Macrofauna. A Report by the Marine Biodiversity Monitoring Committee (Atlantic Maritime Ecological Science Cooperative, Huntsman Marine Science Centre) to the Ecological Monitoring and Assessment Network of Environment Canada. Contact information: Gerhard Pole, arc@sta.dfo.ca. http://www.eman-rese.ca/eman/ecotools/protocols/marine/benthics/intro.html.

This document provides methods used for sampling and monitoring intertidal and subtidal macrofauna. The information presented here is for monitoring and sampling in hard bottoms and soft bottoms habitats. The tools for monitoring these habitats allow changes in fauna abundance and diversity to be detected with regard to natural variability, and what elements are responsible for altering the habitat conditions. Depth and sediment grain size significantly affects species composition of benthic macrofauna therefore should be sampled at comparable depths and measured within a narrow scope size of grain size. Methods that are recommended for sampling intertidal and subtidal soft bottom areas and described in this document include subtidal grab sampler or corer methods for quantitative sampling and dredge and trawls for qualitative sampling in subtidal areas. Methods of analysis for data collected include: univariate (measures species richness), multivariate, graphical, indicator species and taxonomic reductions. Additional information on methods used for sampling is described in this document.

Raposa, K. B. and C. T. Roman. 2001. Monitoring Nekton in Shallow Estuarine Habitats. A Protocol for the Long Term Monitoring Program at Cape Cod National Seashore. 39 pp. Narragansett Bay National Estuarine Research Reserve, Prudence Island, RI 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 (<1m) 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 $1m^2$) 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.

Shelton, L. R. 1994. Field guide for collecting and processing stream-water samples for the National Water Quality Assessment Program. U.S. Geological Survey Report 94-455, Sacramento, CA. http://ca.water.usgs.gov/pnsp/pest.rep/sw-t.html

Author Abstract. The U.S. Geological Survey's National Water-Quality Assessment program includes extensive data-collection efforts to assess the quality of the Nation's streams. These studies require analyses of stream samples for major ions, nutrients, sediments, and organic contaminants. For the information to be comparable among studies in different parts of the Nation, consistent procedures specifically designed to produce uncontaminated samples for trace analysis in the laboratory are critical. This field guide describes the standard procedures for collecting and processing samples for major ions, nutrients, organic contaminants, sediment, and field analyses of conductivity, pH, alkalinity, and dissolved oxygen. Samples are collected and processed using modified and newly designed equipment made of Teflon to avoid contamination, including nonmetallic samplers (D-77 and DH-81) and a Teflon sample splitter. Field solid-phase extraction procedures developed to process samples for organic constituent analyses produce an extracted sample with stabilized compounds for more accurate results. Improvements to standard operational procedures include the use of processing chambers and capsule filtering systems. A modified collecting and processing procedure for organic carbon is designed to avoid contamination from equipment cleaned with methanol. Quality assurance is maintained by strict collecting and processing procedures, replicate sampling, equipment blank samples, and a rigid cleaning procedure using detergent, hydrochloric acid, and methanol.

Trippel, E. A. 2001. Marine Biodiversity Monitoring: Protocol for Monitoring of Fish Communities. A Report by the Marine Biodiversity Monitoring Committee (Atlantic Maritime Ecological Science Cooperative, Huntsman Marine Science Centre) to the Ecological Monitoring and Assessment Network of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/fishes/intro.html#Rationale

This document presents a monitoring protocol for estimating species diversity of bottom dwelling or demersal fish species inhabiting the Canadian continental shelf regions. Monitoring protocols presented in this document can be used to monitor and evaluate fish communities in regions other than the Canadian continental shelf. Methods used to estimate the abundance of different demersal fish species include random stratified sampling and fixed station sampling. Using these standardized procedures helps to maintain precision. Some factors taken into consideration when monitoring fish communities include depth, temperature, salinity, seasonal shifts and diurnal behavior patterns. Additional information found in this document includes size of area and sampling intensity, sampling gear, sampling procedures, and treatment of data.

United States Environmental Protection Agency (USEPA). 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.

United States Environmental Protection Agency (USEPA). 1997. Volunteer Stream Monitoring: A Methods Manual. United States Environmental Protection Agency, Office of Water 4503F, Office of Wetlands, Washington D.C. EPA Report 841-B-97-003. http://www.epa.gov/volunteer/stream/stream.pdf.

This document has been developed to provide guidance for project managers when developing monitoring programs and describes the importance of volunteer monitoring. Described in the document are parameters that are monitored in stream habitats but will vary depending on project goals as well as methods used for sampling and conducting surveys.

Some methods described in this document include a watershed survey which is a visual assessment that describes the geography, land and water use, and potential and current pollution sources, history of the stream and its watershed; biological monitoring of macroinvertebrates which involves collecting, processing and analyzing aquatic organisms which can help determine health of the habitat. Surveys may be performed by using the rock rubbing method which involves randomly picking a rock from the bed and removing organisms from the rock surface or the stick picking method which collects several sticks from the stream, place in water and then remove it to examine organisms present on the stick over a pan; and water quality examination by measuring stream flow, temperature, turbidity, dissolved oxygen, pH, fecal bacteria, nutrients, total solids, conductivity and alkalinity. Additional information on methods and parameters used for monitoring stream habitats are described in detail in this document.

United States Environmental Protection Agency. 2002. National Beach Guidance and Required Performance Criteria for Grants. United States Environmental Protection Agency, Office of Water, Washington D.C. http://www.epa.gov/waterscience/beaches/grants/guidance/all.pdf

In order to be funded under the Beaches Environmental Assessment and Coastal Health Act (BEACH Act) coastal and Great Lakes state, local, and tribal governments must meet the performance criteria provided in the Act for implementing coastal recreation water monitoring and public notification programs. Performance criteria provides guidelines for monitoring and assessing coastal recreation waters adjacent to beaches so that water quality standards for pathogen indicators are achieved; and warning the public of increasing or likelihood of increasing water quality standards for pathogens indicators for coastal recreation. The document also outlines procedures that are used for sample handling, water sample collection, laboratory analysis, and predictive models to estimate indicator levels. Performance criteria requirements described in this document include: developing a risk-based beach evaluation and classification plan; developing a monitoring plan; providing reports on data collected; describing methods and assessments to be used; designing a public warning and risk communication plan; present measures that will be followed to alert EPA, local governments and the public; and public evaluation of the program. Additional information on performance criteria guidelines for beaches as well as methods and procedures used are described in this document.

United States Environmental Protection Agency (USEPA). 2002. Assessing and Monitoring Floatable Debris. EPA-842-B-02-002, Oceans and Coastal Protection Division, U.S. Environmental Protection Agency, Washington, D.C.

Assessing and Monitoring Floatable Debris document is devised to assist states, tribes, and local governments in producing assessment and monitoring programs that suit their needs for floatable debris in coastal waters. Floatable debris can negatively impact both wildlife and humans. For example, birds, fish, crustaceans negatively affected mainly by entanglement and ingestion whereas debris can endanger human health and safety through disease transmission or sharp objects which can result in injury. This document provides information on monitoring and assessment programs in the United States that address the impact of floatable debris, as well as some mitigation activities with reference to floatable debris. Also provided are: the types of floatable debris and their origins such as street litter, medical items, debris from industrial activities, sewage-related items, and a few others; a variety of plans and programs that have been created and implemented to evaluate and monitor floatable debris; recommendations for creating assessment and monitoring programs that can be found in the Marine Debris Survey Manual, created by the National Oceanic and Atmospheric Administration, and Chapter 16 of EPA's Volunteer Estuary Monitoring: A Methods Manual (USEPA, 1993) and; provides various examples of future prevention and mitigation activities affiliated with floatable debris. This document should provide the basis for monitoring debris that can affect the soft shoreline ecologically, economically, and recreationally.

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 SOFT SHORELINE HABITAT 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.

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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

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