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 2: RESTORATION MONITORING OF THE WATER COLUMN

David Merkey, NOAA Great Lakes Environmental Research Laboratory[1]

INTRODUCTION

The water column, defined as a volume of water that extends from the water surface down to (but not including) the substrate, is a very dynamic habitat subject to waves, currents, tides, and river flow. It is also the only habitat in this guidance document that is associated with all the other habitat types described in the rest of Volume Two. The water column is responsible for transporting materials, nutrients, sediments, and toxins from upland sources into estuarine environments and from one aquatic habitat to another. As such, the water column has direct effects on all other associated habitats (e.g. SAV, coral reefs, riverine forests etc.), and, therefore, must be taken into consideration for any restoration monitoring program.

The hydrodynamics[2] and chemistry within water column habitats are tremendously diverse across different marine, tidally-influenced riverine, and freshwater lacustrine systems. In marine environments, hydrologic patterns are determined by the ebb and flow of ocean tides, the movement of nearshore currents, and freshwater inputs from upland sources. Salinity in estuarine water column habitats in coastal marine areas ranges from seawater (approximately 35 ppt[3]) to fresh water (approximately 0.5 ppt or less). Water level fluctuations in these systems are controlled by both ocean tides and wind events, the relative importance of each varies with location. The hydrodynamics of riverine water columns are dominated by freshwater flows from upland sources. In tidally influenced areas, the surface of the river rises and falls with the tide, allowing for the development of tidal freshwater marshes. In coastal waters of the Great Lakes, hydrodynamics are dominated by seasonal and annual water level fluctuations of the lakes and shorter-term (daily) fluctuations caused by seiches. Seiches (Figure 1) are oscillations of the water's surface and occur in enclosed or semi-enclosed basins. They can be caused by local changes in atmospheric pressure, wind, tidal currents, and earthquakes. Seiches may last from a few minutes to several hours and range in size from a few centimeters to several feet depending on the severity and duration of storms or wind creating them. Seiches are not unique to the Great Lakes and can happen in any body of water with a long enough fetch[4].

In all open water areas (from marine to freshwater) food webs are supported largely by phytoplankton with additional inputs of detritus carried in from upland sources (Day et al. 1989). The relative importance of each food source depends on several factors including: time of year, freshwater inputs, nutrient concentrations, salinity, and oxygen concentration. The presence, absence, and composition of plants and animals in the water column is a result of physical factors related to basin morphology, water quality and chemistry (primarily salinity in marine settings), and to the mixing of communities from adjacent areas.

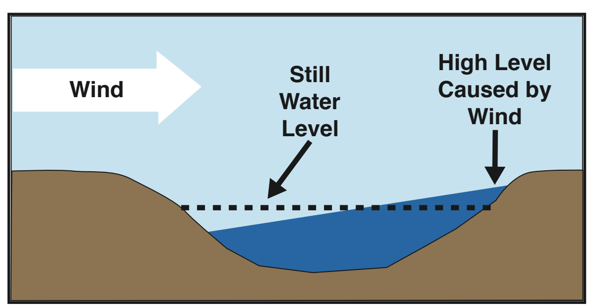

Figure 1. Once the wind driving the seiche stops, the water that has piled up on the right will slosh back toward the left. The effect is similar to water sloshing back and forth in a large bathtub. Graphic by David Merkey, NOAA Great Lakes Enviornmental Research Laboratory (GLERL).

[1] 2205 Commonwealth Boulevard, Ann Arbor, MI 48105.
[2] Water level fluctuations and water movement.
[3] Parts per thousand.
[4] The distance wind can travel over open water. Longer fetches allow for the development of larger waves and seiches.

HUMAN IMPACTS TO THE WATER COLUMN HABITAT

Impacts to estuarine and near shore water quality include but are not limited to: pollutant loading from urban and agricultural runoff, waste discharge, dam construction, dredging, withdraw of water for agriculture and human consumption, logging, and urban development in coastal areas (NOAA 1993). The effects of these impacts varies from one estuary to another but often include increases in nutrient concentrations and associated eutrophication, loss of native plant and animal habitat and diversity, and decreases in commercial and recreational finfish and shellfish stocks (NOAA 1993; Bricker et al. 1999).

This chapter is meant to cover all of the open water coastal habitats of the United States and its protectorates. However, considering the diversity of plants and animals that utilize open water in many different habitat types, we can only provide very general descriptions of water column habitat and associated impacts. Restoration practitioners are strongly encouraged to seek out local and regional experts (Appendix III of this chapter) for assistance in identifying plant and animal species and understanding the complex interrelationships of water chemistry, biology, and physical processes within a particular restoration area. Analysis of restoration monitoring parameters such as salinity, oxygen, and nutrient concentrations requires a "big picture" understanding of systems and processes outside the scope and control of most local restoration efforts. Accurate interpretation of monitoring data is not possible without an understanding of the larger processes at work within an estuary. This is not meant to discourage monitoring water column habitats in estuaries but rather to inform practitioners of the potential complexity involved with such monitoring efforts.

Pollutant Load[5]

There are two sources of pollution that need to be accounted for when calculating pollutant load:

- Point sources, and
- Non-point sources

Point source

Point source pollution is that which is directly discharged from an identifiable pipe or location (Figure 2). While many of these sources have been controlled since the Clean Water Act was passed, some point sources still remain. Sewage treatment plants that are forced to discharge partially treated wastewater into rivers during storm events are one example. Sewage overflows release bacteria and nutrients into rivers and streams that ultimately flow into estuaries. Excess amounts of fecal bacteria and other waste-born pathogens can trigger beach closures and affect human health. Discharged organic matter can lower the dissolved oxygen content of the water column as it is broken down. Certain industrial operations are still permitted to discharge their wastewater into streams and

Figure 2. Point source pollution, such as discharges from this agricultural operation, is one of the major impacts to surface water quality. Photo from the NOAA Photo Library.

[5] The EPA's "Nutrient criteria technical guidance manual: estuarine and coastal marine waters" of 2001 has been extensively used in the writing of this section. It is cited here instead of repeatedly through text. U.S. EPA. 2001a. Nutrient criteria technical guidance manual: estuarine and coastal marine waters. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/waterscience/standards/nutrients/marine/index.html

rivers. This often results in increased turbidity, altered water chemistry, and potential increases in toxic contaminants entering connected estuaries.

Non-point source

One of the largest threats to water quality currently comes from non-point sources such as farms, urban storm water systems, industrial sites, lawns, and golf courses (Figure 3). Non-point source pollution can originate from a variety of activities and take on many forms. Runoff from agricultural land can carry sediments, nutrients, and pollutants such as herbicides and pesticides into streams that eventually flow into estuaries. Logging operations can cause increases in turbidity and water temperature. Runoff from construction sites can also lead to increases in turbidity, water temperature, and toxics, and lead to decreases in dissolved oxygen. Urban runoff can be particularly harmful, causing increases in turbidity, nutrient concentration, water temperature, heavy metals, bacteria, as well as gasoline, oil and other auto-related fluids from parking lot runoff.

Four resources (listed below) have been heavily drawn upon in preparation of this document. In sections where one of these resources has been used extensively, a citation referring the reader to the pertinent reference will appear in the section heading instead of being repeated throughout the text.

American Public Health Association (APHA). 1999. Standard Methods for the Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, D.C.

Environmental Protection Agency Publication (EPA). 2001. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water, Washington, D.C. EPA 842-B-93-004. http://www.epa.gov/owow/estuaries/monitor/

Environmental Protection Agency (EPA). 2001. Nutrient criteria technical guidance manual: estuarine and coastal marine waters. United States Environmental Protection Agency, Office of Water, Washington, D.C. http://www.epa.gov/waterscience/standards/nutrients/marine/index.html

Gibson, G. R., M. L. Bowman, J. Gerritsen and B. D. Snyder. 2000. Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance. EPA 822-B-00-024. U.S. Environmental Protection Agency, Office of Water, Washington, D.C. http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html

Figure 3. Non-point source runoff from an industrial site in Green Bay, Wisconsin. Photo courtesy of Michigan Sea Grant. http://www.epa.gov/glnpo/image/viz_iss2.html

STRUCTURAL CHARACTERISTICS OF THE WATER COLUMN

As discussed above, monitoring of the water column can be extremely complex. This is due to the interrelationships among the many variables that could be measured. While it is straightforward enough to obtain a water sample for nutrient analysis, if one has not taken into consideration the tidal period, circulation of water through the estuary, loading from upland sources, recent weather patterns, and spatial and temporal changes in characteristics, then the data obtained from a single sample will not provide useful information. The structural characteristics of the water column have been broken into three categories:

Physical

- Turbidity
- Temperature

Hydrological

- Tides/hydroperiod
- Water source
- Gravitational circulation, and
- Wind and wave energy

Chemical

- Nutrient concentration, and
- pH, salinity, redox, and DO

Each of these characteristics is described below. Some of these characteristics, such as nutrient concentration, may be measured directly as part of a restoration monitoring plan. Others such as upland water sources may be outside of the control of restoration efforts but have direct or indirect effects on functional and other structural characteristics suggested for monitoring and therefore need to be considered as well.

PHYSICAL

Turbidity

Turbidity is a measure of how clear the water is. The type and amount of material suspended in the water decreases the depth to which light can penetrate. It also influences the color of light reaching different depths. The color and depth of light penetration determine what species of vascular plants and algae can live there. Suspended materials commonly include: sediment (fine sand, silt, and clay), and zooplankton and phytoplankton. The amount and size of particles depends on how much energy a particular body of water has. Some areas prone to strong tides, large river flows, frequent or strong storms or wave action have more energy and are able to keep more particles in suspension. Areas protected from wave action, with low river flow, and weaker tides and storms tend to have lower amounts of material suspended in the water column. Runoff from agriculture, urban areas, construction sites, and logging operations are all common causes of increased turbidity (Figure 4). Turbidity is often worst shortly after a storm event that washes accumulated dust, dirt, and other material into streams and storm sewers, causes overflows of waste treatment facilities, and increased erosion of stream banks. Estuaries typically have greater amounts of suspended sediment than do other

Figure 4. Turbidity is often worst shortly after storm events that wash accumulated dust, dirt, and other material into streams and storm sewer. Photo from the NOAA Photo Library.

coastal systems. Suspended sediments and other particles are carried in river water and may be re-suspended through tidal currents and wave action. Other coastal features in comparison may have relatively low concentrations of suspended materials and have clearer water due to lower amounts of materials being delivered to and resuspended in them.

Turbidity can also be used as an inexpensive surrogate measure for nutrient concentrations. Krieger (1984, cited in Heath 1992) found that turbidity correlated well with nutrient concentrations entering estuaries with storm water runoff. Nutrients such as ammonia and phosphorus were carried into estuaries on sediments eroded during storm events. Potassium and ammonia were also dissolved in runoff from agricultural fields. Nitrite showed a delayed reaction to storm water loading, implying that it first needed to be mobilized out of the soil and entered the stream as interflow (shallow groundwater inputs to a stream following storm events (Baker 1984, cited in Heath 1992). Other ions such as calcium and magnesium were negatively correlated with turbidity, meaning that they entered the estuary at a constant rate and were diluted by rainwater.

Sampling

The amount of light available for photosynthesis can be directly measured as PAR (photosynthetically available radiation) or indirectly by measuring turbidity[6]. PAR is the portion of visible light between 400 and 700 nm[7] (Kirk 1994). It can be measured using a device called a quantum sensor at the water surface and throughout the water column to determine how much light has been absorbed by the water column. Quantum sensors can be connected to a dataloggers[8] and left in place allowing for the continuous measurement of PAR over time and include random events such as storms or large river flows. These events can temporarily increase turbidity and might be missed with less-frequent, manual sampling.

PAR at various depths can also be measured indirectly using the following equation from Carr et al. (1997):

$$\text{PAR} = I_o * e^{(-kz)}$$

Where I_o equals PAR at the surface, k is the light extinction coefficient of the water and dissolved material, and z is the depth. If PAR is to be inferred in this manner, depth (z) can be estimated by using the mean water level or if more precise measurements are required, continuous monitoring of water level fluctuation in tidal and Great Lakes areas subject to seiches may be needed. These hydrodynamic processes change a key input to the equation (z) and may also affect k by changing the amount and type of dissolved material in the water.

A simpler, less expensive (although not as precise) way to gauge light availability is to measure turbidity using a secchi disc (Figure 5). A secchi disc is a weighted black and white circle, typically made of plastic that can be

Figure 5. A secchi disc can be lowered from the shady side of a boat or dock as a measure of turbidity. Photo courtesy of Aaron Podey, Louisiana State University.

[6] The following information is also presented in Chapter 9: Restoration Monitoring for Submerged Aquatic Vegetation (SAV).

[7] Nanometers, there are 1 million nm in a millimeter.

[8] An electronic device that continually records data over time.

lowered from the shady side of a boat or dock to avoid glare off the water's surface. As light travels through the water column, some of it is absorbed or scattered by phytoplankton and other suspended or dissolved material. The left over light reflects off the secchi disc and travels back through the water column where more is absorbed. The light that remains is what we see as the disc[9]. As the disc is put lower and lower in the water, it gets harder and harder to see as more and more of the light is absorbed. The depth at which the disc disappears from sight, is the depth at which all the light is being absorbed as it passes down and back up through the water column. This is recorded as the secchi disc depth. The frequency of using a secchi disk to sample turbidity should account for tidal regime and hydroperiod and include post-storm measurements whenever possible as these will affect water depth and the amount of suspended and dissolved material carried in the water column. Samples should be taken at a variety of locations in the estuary or water body and at least weekly or biweekly throughout the year for several years to more accurately account for natural variability in the system.

Temperature[10]

Temperature has direct impacts on several variables important to plants and animals and is one of the easiest water characteristics to measure. Every living organism has a range of temperatures to which it is adapted. Water temperatures outside of those ranges can stress organisms and make them more susceptible to parasites and diseases. At higher water temperatures the rate of photosynthesis increases producing more food and oxygen. However, respiration rates are also greater in warmer water resulting in higher consumption of food and oxygen resources. In addition, less oxygen is able to dissolve in warmer water. Low oxygen levels and warm temperatures can harm aquatic plants and animals.

Sampling

The temperature of water in an estuary is a function of water depth, season, amount of mixing from wind and storms, the degree of stratification in the water column, the temperature of water flowing into the estuary, and human influences such as urban runoff from warm parking lots or thermal discharges from factories and power plants. Therefore, water temperatures should be taken at a variety of locations throughout a restoration site, throughout the year, and at different depths in the water column. Since so many factors influence water temperature and water temperature has such a direct impact on the plants and animals of a system, it is recommended that this characteristic be measured at frequent intervals. The availability of inexpensive automated data loggers makes this possible. Data loggers can be set up to record temperatures at any desired interval and store data until it can be retrieved.

HYDROLOGICAL

The hydrologic conditions of open water habitats are produced by the circulation and mixing of freshwater from upland sources with marine or Great Lakes water. Circulation and mixing are affected by the relative amounts and chemical content of upland and receiving waters, the geomorphology of the estuary, water temperature, and wave and tidal action. These factors control much of the variability observed in most restoration monitoring parameters such as nutrient concentrations, dissolved oxygen content, phytoplankton and zooplankton concentrations, turbidity, and fish community dynamics (Day et al. 1989). Three main forces work to circulate and mix freshwater throughout an estuary: tides, water sources (and associated gravitational circulation caused by differences in water densities), and wind and wave energy (Day et al. 1989). Water sources and gravitational circulation will not be

[9] Sunglasses should NOT be worn while taking a secchi disc measurement.

[10] Section developed using material from EPA, U.S. 2001b. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

characteristics that are commonly measured as part of a restoration monitoring program. They are, however, important ecological phenomena that need to be understood when interpreting other hydrologic data.

Tides and Hydroperiod

Understanding the tidal regime or hydroperiod of a particular estuary is important for planning the timing of sampling (i.e., will the sampling location be an exposed mudflat or under several feet of water), and has important implications for the circulation, stratification, and mixing of freshwater and saltwater. In shallow estuaries with a large tidal range (>2 m), tidal circulation can be particularly strong and interact with the geomorphic[11] shape of the estuary to disperse freshwater throughout the estuary (Day et al. 1989). As tides slosh back and forth the two waters get mixed together. In areas of low energy, lack of mixing can lead to vertical stratification of the water column that may require monitoring samples to be taken at several depths, especially for measurements of dissolved oxygen, nutrient concentration, plankton, and salinity (U.S. EPA 2001b) (see Figure 2).

Tidal circulation and mixing are not uniform over time. Neap tides[12] have smaller tidal ranges and less energy and thus produce less mixing. Water columns during neap tides tend to be more stratified than during spring tides that have larger tidal ranges and more energy for mixing (Day et al. 1989). Lunar tides characteristic of marine estuaries are insignificant on the Great Lakes (Day et al. 1989; Schwab and Bedford 1995) with a maximum range of only 3.3 cm (Herdendorf 1990). Seiches, however, can be quite large (e.g., 5.5 m, Herdendorf 1990) and provide many of the same circulation and mixing functions on Great Lakes coastal habitats as lunar tides do in marine areas. Wind/storm driven seiches do not exhibit the same level of predictability as lunar tides. Seasonal seiches also occur in the Gulf of Mexico and are a regular part of the annual water level fluctuations of coastal estuaries there (Gosselink 1984).

Sampling

Tide tables for most of the United States and its protectorates are available from the National Oceanic and Atmospheric Administration (NOAA) at http://tidesonline.nos.noaa.gov/. If the restoration site is reasonably close to the tidal table site, monitoring of the tidal period as part of the restoration monitoring may not be required (U.S. EPA 2001b). The United States Geological Survey also operates a series of gauging stations on rivers throughout the country. Historical and real-time data on hydroperiod and characteristics of the watershed are available for many areas at http://water.usgs.gov/waterwatch/. Smaller coastal rivers may not have a gauging station, however, requiring that restoration practitioners implement other methods to collect this information. A variety of manual gauges are commercially available in different lengths and measurement intervals. These can be attached to metal poles driven into the substrate. Electronic gauges are also available that can be set up and left in place to continually record water level fluctuation. Thus recording data that might otherwise be missed by manual sampling alone.

Water Sources

Inflow from upland sources (i.e., river discharge) is the quantity of freshwater available to dilute seawater. Freshwater discharge influences the relative location of freshwater, brackish and marine habitats within an estuary (Day et al. 1989). The amount of inflow from upland sources affects the chemistry and biology of the water column and is therefore an important component to monitor. When river discharge is high, (e.g. in the spring), more freshwater is delivered to the estuary and freshwater habitats may extend out toward the ocean. During droughts or other seasons with normally low

[11] The form or shape of features on the earth's surface.
[12] A tide of minimum range occurring at the first and the third quarters of the moon.

precipitation, riverine discharge is low and freshwater habitats may be pushed inland by the relatively greater amounts of seawater in the estuary (Day et al. 1989; Mitsch and Gosselink 2000).

Gravitational Circulation

Gravitational circulation is another factor that influences the structure of the water column. Gravitational circulation results from differences in the density of river water and that of the receiving body. Density differences can be caused by difference in salinity or temperature. In marine habitats, gravitational circulation is controlled primarily by the density difference between riverine freshwater and marine salt water, though there are usually differences in temperature as well. In estuaries of the Great Lakes, where riverine freshwater mixes with freshwater of the lakes, seasonal temperature differences are responsible for gravitational circulation.

Freshwater is less dense than salt water and floats on the top of the water column when rivers discharge into marine estuaries and freshwater spreads out over the estuary. This often results in a highly stratified water column (Figure 6). Wind, waves, and tides reduce stratification by mixing the freshwater with the saltwater. The amount of wind and wave action, strength of the tide, and quantity of freshwater discharged combined determine whether or not the estuarine water column remains highly stratified, becomes moderately stratified, or is vertically well mixed. Stratification and degree of mixing are critical to almost all other characteristics that can be measured in the water column including dissolved oxygen, nutrient concentrations, and diversity and abundance of plankton and fish communities. Stratification of the water column requires that sampling be conducted frequently and at a variety of depths.

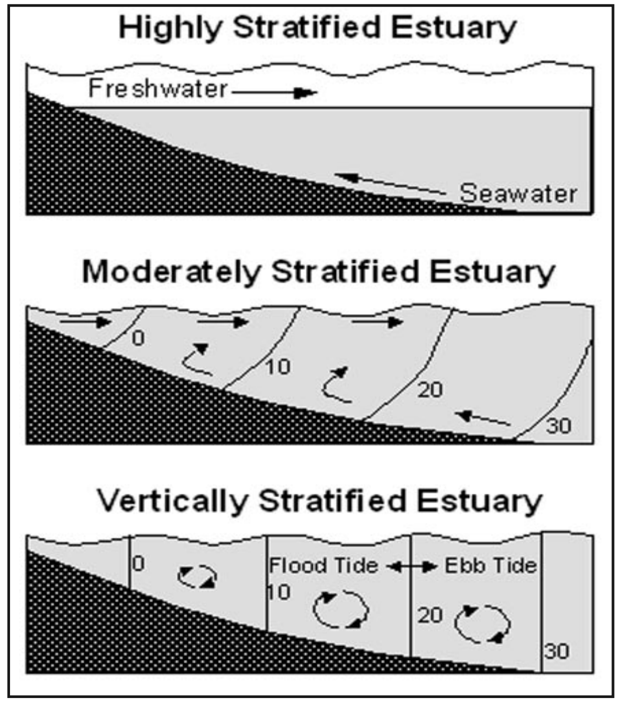

Figure 6. Density gradients caused by differences in salinity. Numbers refer to salinity in parts per thousand. Modified from U.S. EPA 2001b.

Gravitational circulation in freshwater systems of the Great Lakes is caused by seasonal temperature differences between river and lake water. This makes gravitational circulation in freshwater estuaries more complex and ephemeral than in marine estuaries. Although not a lot of research has been conducted on temperature gradients across seasons, in theory, they should works as follows (Bedford 1992). Runoff from upland sources responds to changes in air temperature faster than deeper lake water, making it colder in winter and warmer in summer relative to lake water. In the early spring, when the surface of the lakes is still frozen, water from upland sources is slightly warmer and denser[13] and slips under lake water. As rivers continue to warm faster than lakes in the spring they eventually reach temperatures above 4 degrees. At this point river water is less dense than lake water and is stratified on top of the lake water. As heating of the two water

[13]Freshwater reaches maximum density at 4° C, water between 0 and 4° C is less dense and rises to the surface of the water column.

bodies reaches equilibrium in the summer, this effect is minimized. In the fall, the reverse happens. River water is cooled faster than lake water and reaches maximum density sooner. Again riverine flow slips under lake water. As the lake continues to cool to 4 degrees C, river water is by then colder and floats on top. These effects have been measured, but are completely dependent on climate and, as such, vary from place to place and year to year (Bedford 1992).

Gravitational circulation based on salinity gradients does not exhibit seasonal variability and is of greater importance in understanding the chemistry and biology of marine estuary water columns. Large freshwater inputs during storm events may also deliver large quantities of nutrients to estuaries that may lead to algal blooms and eutrophic conditions. If density gradients are strong, hypoxic[14] conditions at lower depths may occur. This can happen even in estuaries without significant human inputs of nutrients (Day et al. 1989).

Wind and Wave Energy

Wind and waves are important forces for mixing riverine and receiving waters (Figure 7). Wind generates surface waves, internal waves[15], seiches, and Langmuir wind rows/cells[16], all of which significantly enhance the mixing of estuary water columns (Day et al. 1989). In the absence of strong tides or wind and waves to mix estuarine waters, water columns tend to remain stratified. In addition to mixing of freshwater and saltwater and breaking up density gradients, wind and wave action is also responsible for the resuspension of sediments. This increases turbidity and brings once deposited nutrients back into the water column. Water samples taken after a storm event will differ significantly (in a variety of characteristics) from samples obtained during a relatively calm period. Therefore, recent weather patterns (as an indication of wind and wave effect) need to be recorded as part of the routine sampling protocol for coastal restoration monitoring.

Figure 7. Winds from a winter storm make large waves that mix the water column. Photo courtesy of Peter Dyrynda.

Sampling

The Army Corps of Engineer's Shore Protection Manual (U.S. Army Coastal Engineering Research Center 1984) is an extensive document that explains many wave characteristics and mathematical formulae for predicting them. Using equations from that document, it is possible to calculate the depth at which waves reach the sediment surface (i.e., touch the bottom). Simplified equations that may be of use in some coastal areas are provided in Appendix IV of this chapter. Electronic devices to measure wave energy (such as pressure sensors) are also commercially available.

CHEMICAL

Nutrient Concentration[17]

In general, estuaries tend to be relatively nutrient rich environments compared to other

[14]Low oxygen levels (DO ~ 0.5 ppt).

[15]Waves within the water column, between layers of water of different densities. Often seen in areas where fresh- and saltwater meet.

[16]Three-dimensional circulation of water within the water column, created by constant, unidirectional winds.

[17]Section developed using material from U.S. EPA 2001a. Nutrient criteria technical guidance manual: estuarine and coastal marine waters. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/waterscience/standards/nutrients/marine/index.html

types of coastal systems. High nutrient levels lead to high primary productivity. High nutrient levels and high productivity are due, in part, to the constant inflow of materials such as sediments, nutrients, and organic matter from upland sources. Although they are generally rich in nutrients, the maximum productivity of any coastal habitat is determined by one or more key limiting nutrients. In marine ecosystems nitrogen is typically the limiting nutrient, while in freshwater systems phosphorus tends to be the limiting nutrient. At certain times of the year other nutrients, such as silica, may also become limiting in either freshwater or marine settings (Conley et al. 1993). The ratio of these three nutrients (nitrogen, phosphorus, and silica) to one another dictates what species of algae dominate the plankton community. If a nutrient that is limiting is added to the water column, phytoplankton productivity can increase and the entire community composition may be altered. Since phytoplankton are the base of the food web in estuarine water columns, this can have serious and possibly detrimental consequences such as altering the species composition of higher levels in the food chain (Burkholder 1998).

Monitoring nutrient levels is an important part of a restoration monitoring plan because of the effect high nutrient levels have on phytoplankton productivity. Nutrient concentrations tend to be high in estuaries (both freshwater and marine) in the spring and after rain events. High levels of nutrients can lead to increases in algae productivity and can lead to excessive production, called blooms. When algae dies it sinks to the bottom of the estuary where bacteria break it down. In the process, bacteria use up the oxygen in the water column, sometimes faster than it can be replenished by diffusion or physical mixing induced by waves. Hypoxic or anoxic conditions (low to no oxygen) can result, killing fish and other wildlife and altering the biochemical cycling of nutrients and other compounds.

Estuaries are highly dynamic environments, and nutrient concentrations can vary widely on an annual, weekly, or even daily basis. For example, after a rainstorm large amounts of nutrients are delivered to an estuary. These excess nutrients are quickly absorbed by the phytoplankton. Depending on the frequency and spatial location of sampling that pulse of nutrients to the estuary may be missed. Nutrients also have complex interactions with hydrology (freshwater vs. saltwater) and dissolved oxygen concentrations both of which can also be affected by seasonal weather patterns and isolated storm events. Therefore, it is recommended that nutrient sampling be conducted on at least a weekly or biweekly schedule over several years and at enough points throughout the restoration area to be effective.

Fecal coliforms[18]

Increased nutrient loading and resulting eutrophication is not just an aesthetic issue or a problem for bottom dwelling organisms,

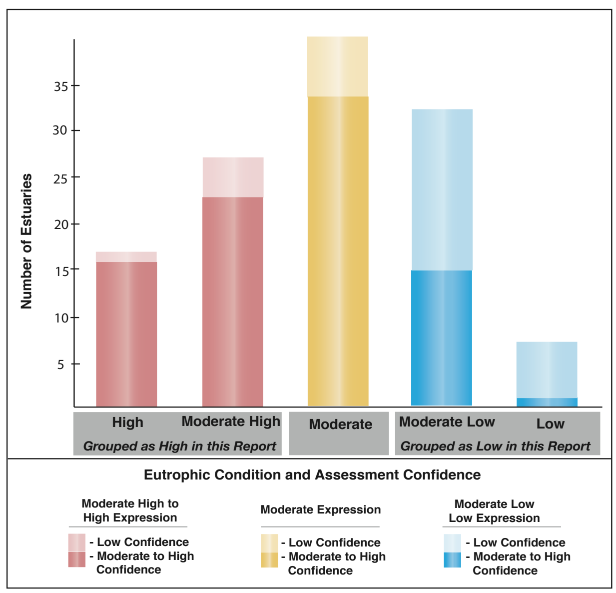

Figure 8. Approximately 65% of estuaries sampled as part of a nation-wide NOAA study were found to be moderately to highly impaired from high levels of nutrient inputs. Figure courtesy of Suzanne Bricker, NOAA National Centers for Coastal and Ocean Science.

[18] Section developed using material from U.S. EPA. 2001b. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/.

it has human health implications as well. A variety of human diseases have been associated with nutrient enrichment in coastal waters. Increases in *Escherichia coli* (*E. coli*) and other disease causing organisms, concentration of trihalomethanes[19], frequency of hazardous algal blooms, and cholera outbreaks in relationship to algal blooms in coastal waters have all been linked to increased nutrient concentrations in coastal waters. Approximately 65% of the estuaries of the United States (out of 138 surveyed) have moderate to serious nutrient enrichment problems (Figure 8 - Bricker et al. 1999).

Pathogenic microorganisms (bacteria, viruses, and protozoans) that cause illnesses such as typhoid, cholera, giardiasis, and hepatitis are often associated with fecal waste. These microorganisms are particularly important to monitor in recreational and water supply areas. Since the pathogens that cause such illnesses are rare and difficult to sample, indicator organisms are often used to determine if contamination with fecal material has occurred. Four indicators are commonly used: total coliforms, fecal coliforms, *E. coli*, and enterococci. Total coliforms include organisms naturally occurring in plant material and soil and therefore are not the best indicator of contamination from sewage treatment plants, leaky septic tanks, industrial discharges, or livestock feed lots. Measurement of enterococci requires an expensive growth media that is toxic to humans. Fecal coliforms (and *E. coli* specifically) make better indicators of sewage contamination in terms of getting the best information for the time and money invested. Natural populations can, however, be found in areas with large wildlife populations or where waters tend to be warm and have high organic content. If biological contamination is suspected, it is important to sample in a variety of locations, frequently (i.e., weekly or bi-weekly), and near suspected contamination sites. It is also important to sample for these bacteria during and after storm events, as this is when discharges from sewage treatment plants and stockyards are most likely to occur. When sampling is conducted to monitor the restoration of a recreational area, sampling can be limited to warmer months when people are likely to use the area for swimming and boating. If sampling is being conducted to monitor oyster or clam beds, it must be continued throughout the year.

Sampling

Sampling, handling, and processing nutrient and bacterial samples of any sort requires special instrumentation and reagents. Detailed information on equipment requirements and laboratory procedures is found in the American Public Health Association's (1999) *Standard Methods for the Examination of Water and Wastewater*. The U.S. Environmental Protection Agency (U.S. EPA 2001a) has also published a useful document on monitoring nutrient concentrations in estuarine habitats. More information on this document is available at: www.epa.gov/owow/estuaries/monitor/.

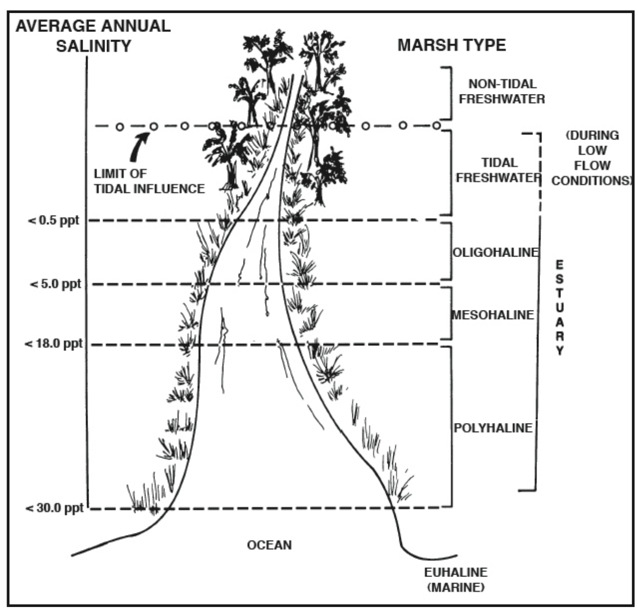

Figure 9. The Venice classification of estuarine salinity. Taken from Odum et al. 1984.

[19]A carcinogenic byproduct of chlorine based waste water treatment.

Salinity (tidal systems only)

Salinity is the key determinant in the distribution and abundance of estuarine flora and fauna (Gibson et al. 2000). Some species may be restricted to the freshwater portion of the estuary (< 0.5 ppt), while others are restricted to more saline environments, yet others are able to tolerate a range of conditions. Classification of salinity levels is often broken down according to the Venice system, illustrated in Figure 9. A salinity level below 0.5 ppt is considered freshwater, a level between 0.5 and 5.0 ppt is called oligohaline (also referred to as brackish), between 5.0 and 18.0 ppt is mesohaline, between 18.0 and 30.0 ppt polyhaline, and anything over 30.0 ppt euhaline or marine (Gibson et al. 2000).

Salinity also has direct effects on other chemical and physical parameters of the water column. For example, the total concentration of oxygen able to dissolve in saltwater is less than that for freshwater. This places a lower natural limit on the supply of oxygen in the estuary water column compared to freshwater systems, particularly at lower depths. The impact of lower oxygen levels near the sediment surface can be compounded during calm weather when mixing of the upper water column is reduced or if eutrophic conditions are present in the estuary. In order to be properly calibrated, most oxygen meters also require a measurement of salinity (U.S. EPA 2001b). Salinity also affects turbidity, which, in turn, affects primary production by limiting the depth at which photosynthesis by phytoplankton and submerged aquatic vegetation can occur. Material that is dissolved in freshwater can clump together in saltwater. These clumps increase turbidity thereby decreasing the depth to which light can penetrate in the water column (EPA 2001).

The segregation of estuarine fish species based on salinity gradients is illustrated in Figure 10. Restricted to freshwater areas are such species as:

Bluegill (*Lepomis macrochirus*)
Largemouth bass (*Micropterus salmoides*)
Sunfish (*Lepomis gibbosus*)

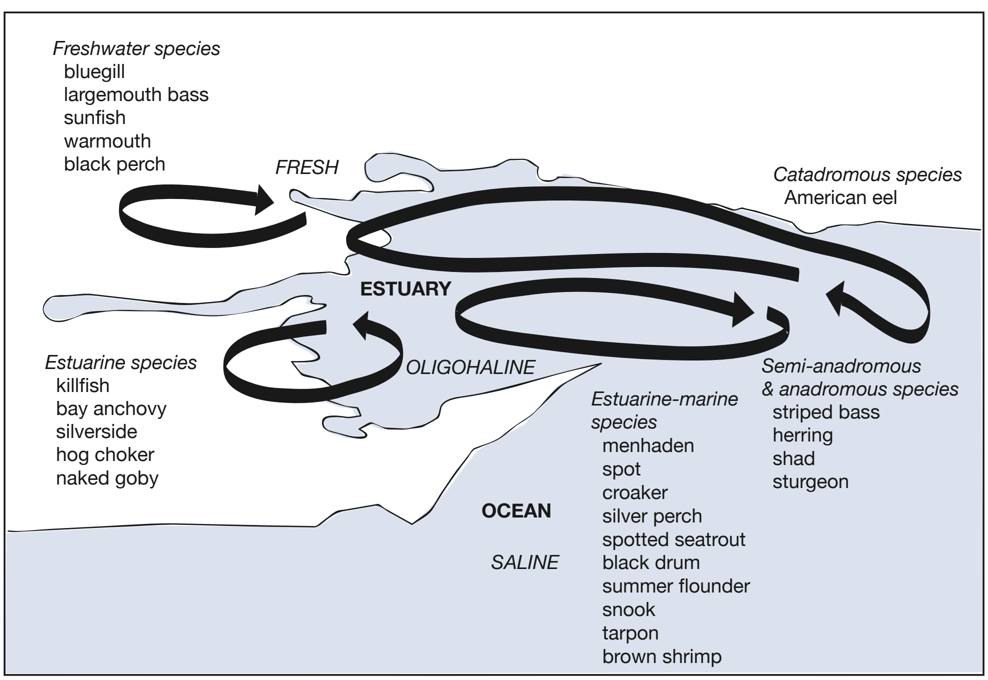

Figure 10. Fish species distribution in an estuary is dependent upon salinity. Modified from Mitsch and Gosselink 2000.

Species adapted to oligohaline conditions include:

Killifish (*Fundulus confluentus*)
Bay anchovy (*Engraulis mordax*
Naked goby (*Gobiosoma bosc*)

Other species are able to tolerate a variety of conditions. As salinity concentrations shift back and forth across the estuary due to freshwater inflow from upland sources, plant and animal communities adapt to those ever-changing conditions (Mitsch and Gosselink 2000).

Sampling

A variety of electronic meters are commercially available for measuring salinity and range in price from tens to several hundreds of dollars. Most meters are designed for use within a given range of salinity. Use outside of this range will result in the collection of incorrect data if salinity levels are below that which the meter is designed for or permanent damage to the meter if salinity levels are too high.

Dissolved Oxygen (concentration, spatial coverage, frequency of low oxygen events)[20]

Nearly all aquatic life requires dissolved oxygen (DO) to survive. Lack of oxygen can become a significant problem. In addition to its use in respiration by higher organisms such as fish, DO is used by bacteria in the process of breaking down organic matter. In nutrient-rich waters, where algal production is high, bacteria can use up practically all of the oxygen dissolved in the water to decompose the algae once it dies. Normally, aquatic organisms require at least 5 mg/L DO to survive and reproduce. If the DO concentration falls below 3 mg/L (referred to as hypoxia), organisms become stressed. Below 2 mg/L most fish species die. If DO levels go below 0.5 mg/L (anoxia), all but anaerobic organisms will be killed (U.S. EPA 2001b). Anoxia resulting from eutrophication and excess oxygen consumption has resulted in massive fish die-offs in Lake Erie (Czapla et al. 1995) and is currently causing the large 'dead zone' in the Gulf of Mexico (Mitsch et al. 2001).

DO also affects the concentration and availability of nutrients and some toxic chemicals. In the presence of oxygen, phosphorus is bound to sediments. Under anoxic conditions, phosphorus becomes soluble and is available for uptake by plants, furthering the process of eutrophication (Mortimer 1941; Mortimer 1942). During periods of low oxygen concentration, nitrogen is transformed from nitrate and nitrite (NO_3 and NO_2) to ammonia (NH_4) which, like soluble phosphorus, is readily taken up by plants. At low oxygen concentrations, hydrogen sulfide and some metals also become soluble. Both are toxic to plants and animals (U.S. EPA 2001a).

Dissolved oxygen enters the water column through gas exchange with the atmosphere and by photosynthesis of aquatic plants. Concentrations vary with time of day, season, temperature, and salinity. DO measures, therefore, need to be taken at regular intervals, as a single measure will not provide meaningful information. On bright, sunny days adequate nutrients lead to high rates of photosynthesis. Under these conditions it is possible to achieve supersaturated DO concentrations. By early morning, DO levels can reach critical lows as plants and animals use up dissolved oxygen over night. DO concentrations tend to be highest during the winter since more oxygen can dissolve in cold water than in warm water and biological activity (i.e., respiration) is lower. As mentioned above, salinity level also affects DO concentrations (i.e., freshwater has higher concentrations than salt water). Warm, seawater then, can have low oxygen concentrations even in absence of any adverse human impacts.

[20]Section developed using material from EPA, U.S. 2001. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

Sampling

DO measurements should be taken at least weekly and twice during the same day, in the early morning and mid-afternoon (always at the same times). This frequency should provide useful maximum and minimum DO values for monitoring purposes. Measurements should also be taken at varying depths in the water column in relation to changes in salinity and temperature. Measurements should be taken year-round where- and whenever possible. At a minimum they should be taken throughout the growing season, as this is when plant communities will have their greatest affect on oxygen concentrations.

The American Public Health Association (APHA) *Standard Methods for the Examination of Water and Wastewater* describes, in detail, a number of chemical and electronic methods for measuring dissolved oxygen concentration in fresh- and salt waters. A variety of electronic oxygen sensors are also commercially available. These have the benefit of allowing measurements to be taken in the field, thus decreasing the chance that handling and transporting the sample will change oxygen concentration before it can be processed in the laboratory.

FUNCTIONAL CHARACTERISTICS OF THE WATER COLUMN

The water column performs a variety of biological and physical functions. As water is the common link between all of the habitats in Volume Two, these functions are often performed within and between other habitats. These functions include:

Biological
- Contributes to primary production
- Supports biomass production
- Provides breeding grounds
- Provides feeding grounds

Physical
- Affects transport of suspended/dissolved material

Chemical
- Affects nutrient and chemical concentrations

Much of the information on the physical and chemical functions of the water column (transporting suspended and dissolved material) has been covered in the associated structural characteristics above. The biological functions listed, along with specific parameters that may be monitored to assess them during restoration projects, are described below.

BIOLOGICAL

Contributes to Primary Production

Primary production is the amount of plant tissue created as a result of photosynthesis over time. As previously discussed, many coastal ecosystems are nutrient rich and thus have high rates of primary production. The primary productivity of the water column in coastal water columns is predominantly measured using two different indicators: the diversity and abundance of phytoplankton and the amount of chlorophyll *a*. The presence and frequency of harmful algal blooms can also be a measure of productivity and is also an indicator of eutrophic conditions as well.

Plankton diversity and abundance[21]

The term plankton refers to plants and animals suspended in the water column that are unable to prevent being moved around by currents. There are three types of plankton:

- bacterioplankton[22]
- phytoplankton[23]
- zooplankton[24]

The most commonly measured types of plankton are phyto- and zooplankton. Phytoplankton and the associated measurement of chlorophyll *a* content of the water are discussed here. The importance of zooplankton (which are animals) is discussed under the section on biomass production below.

Phytoplankton
Phytoplankton are the primary food producers in freshwater, marine, and estuarine water columns. As plants, they produce food through photosynthesis then are eaten by zooplankton that are in turn eaten by larger zooplankton and small fish that are then eaten by larger fish and so on up the food chain. If toxic compounds are present in the water they can be absorbed by phytoplankton, and these chemicals can accumulate in the food chain until harmful concentrations are reached at higher levels (bioaccumulation).

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[21] Section developed using material from APHA. 1999. American Public Health Association, Standard Methods for the Examination of Water & Wastewater. 20 ed. American Public Health Association, Washington, D.C.
[22] Bacteria.
[23] Unicellular, colonial, or filamentous algae.
[24] Animals, both those that live full time as plankton and the larval stages of organisms such as fish and crustaceans.

Phytoplankton make excellent indicators of nutrient loads because they respond very quickly to changes in nutrient concentrations. This aspect also makes them useful for picking up isolated, nutrient-loading events that may be missed by chemical sampling alone. For example, a storm event may deliver a surge of nutrients to a water body. Phytoplankton communities respond to the presence of the excess nutrients by growing and reproducing rapidly. When practitioners return for chemical sampling, nutrient concentrations dissolved in the water column may have become more dilute but the algae will still be visible, indicating that excess nutrients had been available.

High nutrient concentrations can also affect algal species composition. Algal blooms, following high nutrient inputs have lower species diversity than under lower nutrient conditions (Sanders and Kuenzler 1979). Nutrient rich conditions also favor a shift from diatom dominated phytoplankton communities to communities dominated by non-siliceous[25] algae, altering the base of estuarine food webs (Béthoux et al. 2002). Thus the change in phytoplankton community as it pertains to nutrient enrichment can be measured through overall production, loss in phytoplankton diversity (Rabalais et al. 1996), or by a change in community structure.

The complexity of the relationship between nutrients, phytoplankton and the rest of the estuarine food web is illustrated in Figure 11. As the diagram indicates, phytoplankton, zooplankton, microbes, and nutrient concentrations are all closely inter-related. One could also include varying concentrations

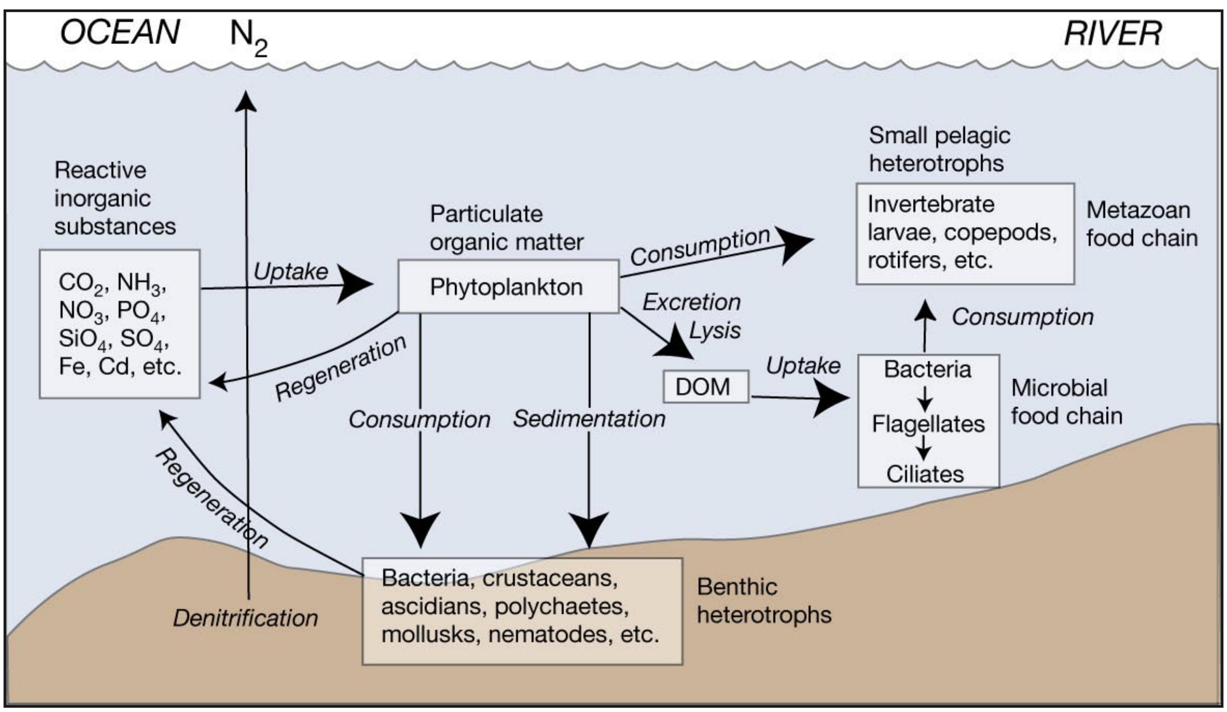

Figure 11. The central role phytoplankton play as agents of nutrient transformation in shallow open water systems. Phytoplankton take up nutrients (reactive inorganic substances) and convert these into particulate (POM) and dissolved organic matter (DOM). Each of these supports the production of pelagic and benthic zooplankton and fish. The arrows indicate material exchanges between these different ecosystem components. Denitrification has also been added to the figure. Modified from Cloern 1996.

[25]Diatoms are unicellular algae that make hard shells out of silica (SiO_2). Algae with shells (also called tests) made of something other than silica or those that lack shells entirely are 'non-siliceous'.

of salt and oxygen to add further detail (and complexity) to this diagram. Monitoring just one component of the system provides only a small piece of the overall picture and may not provide all of the information needed to properly assess the success or failure of a restoration effort. Many qualitative and quantitative methods exist for monitoring plankton communities. Practitioners interested in using plankton as part of a restoration monitoring effort are referred to the American Public Health Association (1999) "Standard Methods for the Examination of Water and Wastewater" for a thorough explanation of sampling methods and analysis techniques.

Figure 12.1 Microcystis, toxic to zooplankton and thus harmful to fish, is one type of algae responsible for harmful algal blooms. This concentrated sample was taken in Lake Erie off the northwest Ohio coast. Photo courtesy of Tom Bridgeman, University of Toledo.

Chlorophyll a[26]

All green plants, including phytoplankton, produce chlorophyll *a*[27]. Chlorophyll *a* concentration is often used to determine how much phytoplankton is in the water column. There are two main methods for measuring chlorophyll *a*, depending on the type of system you are monitoring. In freshwater systems, chlorophyll *a* is measured using the spectrophotometric method. In marine systems, the fluorometric method produces better information. As with phytoplankton, readers are again referred to American Public Health Association (1999) *Standard Methods for the Examination of Water and Wastewater* for a thorough explanation of sampling methods and analysis techniques.

Figure 12. A harmful algal bloom in a Lake Erie estuary in northwest Ohio. Photo courtesy of OhioLink. http://www.biosci.ohio-state.edu/~eeob/limnologylab/photoslesatellite.htm

Harmful algal blooms (concentration, frequency, duration)[28]

Some phytoplankton produces toxins that can cause illness or death in fish, shellfish, and marine mammals. Humans can be affected as well if infected shellfish are eaten. In recent years, there has been an increase in the number and frequency of harmful algal blooms (HABs)

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[26]Section developed using material from APHA. 1999. American Public Health Association, Standard Methods for the Examination of Water & Wastewater. 20 ed. American Public Health Association, Washington, D.C..

[27]A green pigment that gives most plants their color and enables them to perform photosynthesis.

[28]Section developed using material from EPA, U.S. 2001. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

in the United States and globally. Some HABs are naturally occurring (i.e., red tides) while others are caused by humans and linked to nutrient enrichment of estuaries and coastal waters (Figures 12 and 12.1). Increased monitoring efforts are being conducted for improved forecasting and early detection of harmful blooms that may save human suffering and lives. If reduction of nuisance and toxic algal blooms is a goal of a restoration project, monitoring can help discern whether or not nutrient abatement projects are achieving the desired results. Representatives from several federal agencies[29] have teamed together with various state agencies to coordinate a national HAB research and monitoring strategy[30]. Additional information on these and other research and monitoring activity can be found at http://www.cop.noaa.gov/Fact_Sheets/MERHAB.html. The U.S. Environmental Protection Agency has formed a network of volunteers to monitor the occurrence of harmful algal blooms in the nation's estuaries. Information on sampling techniques and particular species of concern can be found in *The Volunteer Monitor* (volume 10, number 2 fall 1998). This issue is available on-line at http://www.epa.gov/owow/estuaries/monitor/.

Manual monitoring of algal toxins in specific areas can, however, be expensive and time consuming. This has led to the use of remote sensing techniques such as aerial and satellite imagery to detect potentially harmful algal blooms over larger areas (Boesch et al. 1997).

Supports biomass production and provides breeding and feeding grounds

Biomass production is different than primary production. Biomass is the total weight of all living material (plant and animal) produced in a particular area. Methods for sampling primary plant productivity were discussed above. Parameters for monitoring animal production are presented here. There are two main groups of organisms can be useful in monitoring the functions of biomass production, breeding, and feeding grounds in water column habitats: fish and zooplankton. The community composition, diversity, and abundance of fish and zooplankton as well as the health (body condition) of fish may all be useful parameters to monitor depending on the goals of a restoration project.

Figure 13. Striped bass (shown here) and other predators feed on smaller fish that feed on zooplankton. Photo courtesy of the US Environmental Protection Agency. http://www.epa.gov/gmpo/education/photo/birds-animals.html

Fish community composition, diversity, and body condition

Fish can be useful indicators of estuarine health and are important for restoration monitoring. Since they are near the top of the aquatic food web, fish community composition and health incorporate a variety of information related to overall water quality and conditions at lower trophic levels (APHA 1999). Fish represent an important link in the food web between invertebrates and piscivorous birds and mammals, including humans. Smaller feeder fish, such as menhaden, mummichog, and bay anchovies (*Anchoa mitchilli*) feed on phyto- and zooplankton, the first organisms in the food web to absorb toxins. These small fish are then eaten by larger fish such as striped bass (Figure 13 - *Morone saxatilis*) that are eventually eaten

[29]U.S. Department of the Interior, Centers for Disease Control, U.S. Food and Drug Administration, U.S. Department of Agriculture, U.S. Environmental Protection Agency, National Oceanic and Atmospheric Administration, and the National Institute for Environmental Health Services.

[30]www.redtide.whoi.edu/hab/announcements/pfiesteria/pfiesteriastrategy.html

by larger fish or people. Thus fish at all levels bioaccumulate toxins that may eventually impact human populations (U.S. EPA 1998; Gibson et al. 2000).

Although tremendous diversity in environmental preference, tolerance to disturbance, and pollution exists, most fish species are sensitive to increased turbidity, low oxygen levels, contaminants, and loss of habitat. Certain species are very intolerant of these conditions and are thus useful indicators of disturbance. Atlantic menhaden (*Brevoortia tyrannus*), an important estuarine feeder fish, is one example of a pollution intolerant fish. The presence of trout (family Salmonidae) or sculpin (family Cottidae) also often indicates good water quality in freshwater systems. On the other hand, some fish are quite tolerant of a variety of conditions. Mummichogs (*Fundulus heteroclitus)*, channel catfish (*Ictalurus punctatus*), and the common carp (*Cyprinus carpio*) are examples of more tolerant estuarine and freshwater fishes. Fish are also generally long-lived and useful in indicating long-term factors that may be missed by short-term periodic sampling of other parts of the ecosystem. There are, however, no universal indicators that can be used to measure the same thing in all locations, as species sensitivities often vary by the specific type and location of disturbance (U.S. EPA 1998; APHA 1999; Gibson et al. 2000).

Other characteristics of fish communities and health may also be useful in monitoring restoration projects. Fish are mobile and are therefore able to move away from stressful environments. Thus presence/absence alone can be a useful measure of whether or not a restoration activity is having the desired effect (U.S. EPA 1998; Gibson et al. 2000). Fish also exhibit a variety of physiological, morphological, and behavioral responses to stress. Deformities such as tumors, lesions, parasites, fin rot, skin ulcers, abnormal growths, and skeletal deformities can be used to determine the presence of contamination (Blazer et al. 1994) before costly chemical sampling needs to be conducted (U.S. EPA 1999). Where commercially or recreationally valuable species are involved, long-term data sets may be available from state and federal agencies for comparison to data collected for restoration purposes or may even be substituted for additional data collected as part of a restoration monitoring effort (U.S. EPA 1998; Gibson et al. 2000).

Despite these advantages, there are limitations to using fish to monitor restoration progress. Because some fish are higher in the food chain, other organisms lower on the food web may respond to environmental stressors and restoration activities faster. The mobility of fish can also add complications to monitoring programs. While some species of fish may spend their entire life cycle within one estuary, others such as bluefish (*Potatomus saltatrix*) migrate along the Atlantic coast of the U.S. and move in and out of estuaries with the availability of food resources. The use of some migratory species for restoration monitoring can be further complicated because the location of their normal occurrence varies by season. In addition, the presence of fish deformities may not necessarily indicate adverse conditions

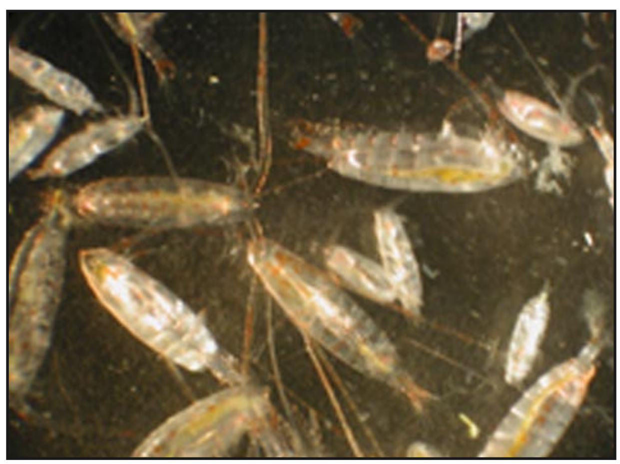

Figure 14. Calanoids, one of the three main types of copepods, are a zooplankton commonly eaten by fish. Photo courtesy of the NOAA Photo Library. http://www.photolib.noaa.gov/fish/images/big/fish3251.jpg

within the restoration area since the fish may have migrated in from elsewhere.

Sampling

A tremendous diversity of sampling approaches and techniques are available to sample fish. The optimum method depends upon the goal of a particular restoration effort and the specific location to be sampled. Restoration practitioners interested in sampling fish populations as part of a monitoring program are referred to two resources: 1) APHA (1999) "Standard Methods for the Examination of Water & Wastewater" and 2) American Fisheries Society "Fisheries Techniques" (Murphy and Willis 1996).

Zooplankton community composition, diversity, and abundance

Zooplankton are small (< 2 mm) invertebrates that float in the water column of all estuaries, freshwater and saltwater (Figure 14). Some are able to weakly swim up and down through the water column to feed on suspended phytoplankton or detritus and escape predation from larger invertebrates or fish (Day et al. 1989). Zooplankton are generally short lived, have high reproductive rates and are very responsive to a number of environmental factors (Deibel 2001) such as water temperature, light, chemistry (pH, oxygen, salinity, and toxic chemicals), food availability, and predation (Paterson 2001). Therefore, zooplankton diversity and abundance may be useful to monitor during a restoration-monitoring program because they are sensitive to so many important environmental factors.

Zooplankton communities can also be very robust and rebound relatively quickly after disturbance. Osbourne and Kovacic (1993) studied the zooplankton community of a freshwater lake in Polk County, Florida. They found that the zooplankton community underwent significant changes in composition, diversity, and abundance during hydraulic dredging of the lake. Though initially wiped out by dredging activities, the zooplankton community had begun to return within one year after dredging was completed.

Zooplankton communities can be very diverse and upwards of 20 species in any one body of water is not uncommon (Paterson 2001). While this diversity may allow for the use of particular species as indicators in certain areas, it also adds considerable complexity to designing a sampling protocol to accurately reflect the entire zooplankton community. Since zooplankton come in a variety of sizes (from microscopic up to 2 mm), the mesh size of the net used to sample them will directly affect which types of animals are caught (Deibel 2001; Paterson 2001).

Sampling

Zooplankton diversity and abundance vary spatially and temporally (i.e., daily, seasonally) within an estuary. In the presence of planktivorous fish, many plankton will swim to lower depths during the day to evade predators and then move up in the water column at night to take advantage of richer food sources in the top of the water column. Due to seasonal population fluctuations sampling at only one spot at one time may underestimate actual community size and structure by as much as 67% (Paterson 2001). Restoration practitioners interested in using zooplankton for monitoring are encouraged to consult with local experts, look for previous studies of the area (if available), and conduct pilot studies to determine what types of animals are found in their system. This will lead to more efficient restoration sampling. Quantitative and qualitative methods to monitor plankton are presented in the American Public Health Association's (1999) *Standard Methods for the Examination of Water and Wastewater*.

PHYSICAL

The importance and monitoring of the physical functions of the water column have been discussed within the Structural Characterics above, under the section titled "Hydrological."

CHEMICAL

The importance and monitoring of the chemical functions of the water column have been discussed within the structural characteristics above under sections titled "Water Sources", "Nutrient Concentration", and "Dissolved Oxygen".

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The matrices of structural and functional parameters for restoration monitoring provided below were developed through extensive review of the restoration and ecological monitoring-related literature. Additional input was received from recognized experts in the field of water column ecology. This listing of parameters is not exhaustive, it is merely intended as a starting point to help restoration practitioners develop monitoring plans for this habitat. Parameters with a closed circle (●) are those that, at a minimum, should be considered in monitoring restoration progress. Parameters with an open circle (❍) may also be monitored depending on specific restoration goals. Information on why these parameters are important for monitoring and how they relate to structural and functional characteristics as well as to one another is found throughout the preceeding text. Literature directing readers toward additional information on the ecology of the water column, restoration case studies, and sampling strategies and techniques can be found in the Annotated Bibliography of the Water Column and the associated Review of Technical Methods Manuals.

Parameters to Monitor the Structural Characteristics of the Water Column

Parameters to Monitor	**Physical**	Turbidity	**Hydrological**	Tides / Hydroperiod	Water sources	Current velocity	Wave energy	**Chemical**	Nutrient concentration	pH, salinity, toxics, redox, DO[31]
Geographical										
Acreage of habitat types				●						
Biological										
Plants										
Phytoplankton diversity and abundance		❍								
Hydrological										
Physical										
Chlorophyll concentration		●								
PAR[32]		❍								
Seiche disc depth		❍								
Shear force at sediment surface						❍	❍			
Temperature				❍	❍					
Upstream land use					●					
Water column current velocity						❍				
Water level fluctuation over time				●	●					
Chemical										
Dissolved oxygen										●
Groundwater indicator chemicals[33]					●					
Nitrogen and phosphorus									❍	
pH										❍
Salinity (in tidal areas)				●	●					●
Silicon									❍	
Toxics										❍

[31] Dissolved oxygen.
[32] Photosynthetically active radiation, measured at canopy height and substrate surface.
[33] Calcium and magnesium.

Parameters to Monitor the Functional Characteristics of the Water Column

Parameters to Monitor	**Biological**	Contributes primary production	Supports biomass production	Provides breeding grounds	Provides feeding grounds	**Physical**	Affects transport of suspended/dissolved material
Geographical							
Acreage of habitat types		●	●	●	●		●
Biological							
Plants							
Interspersion of habitat types			❍	❍	❍		❍
Nutrient levels in algal tissues (N and P)		❍	❍				
Phytoplankton diversity and abundance		❍	❍		❍		
Biological							
Animals							
Species, composition, and abundance of:							
Fish			❍	❍	❍		
Invasives			❍		❍		
Invertebrates			❍	❍	❍		
Fecal coliforms							❍
Hydrological							
Physical							
Secchi disc depth		❍	❍				❍
Trash							❍
Upstream land use							●
Water column current velocity							❍
Water level fluctuation over time				●	●		●
Chemical							
Chlorophyll concentration		●	●		●		●
Dissolved oxygen				●			
Groundwater indicator chemicals							❍
Nitrogen and phosphorus		❍	❍				
pH				❍	❍		❍
Salinity (in tidal areas)				●	●		●
Silicon		❍	❍				
Toxics				❍	❍		

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U.S. EPA. 2001b. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

APPENDIX I: WATER COLUMN 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 author of the associated chapter.

Bedford, K. W. 1992. The physical effects of the Great Lakes on tributaries and wetlands. *Journal of Great Lakes Research* 18:571-589.

Author Abstract. Wetlands and tributary confluences are susceptible to physical influences imposed by the Great Lakes, particularly through the effects of short and long-term water level fluctuations and accompanying transport disruptions including flow and transport reversals. With there being few, if any, direct observations of these disruptions based upon velocity measurements, the objective of this paper is to review the possible physical effects on these regions by first, reviewing the relevant contributing physics known about the Great Lakes; second, contrasting possible marine estuary transport mechanisms with was little is published about the Great Lakes circumstances; and third, summarizing modeled results exemplifying these behaviors from a study of Sandusky Bay, Lake Erie. Because it exhibits the strongest response to storms and the clearest measurable signals resulting from them, attention is centered on Lake Erie. In contrast to a typical research paper, the objective herein is to provide a summary of what is known and commonly accepted about these physics which can serve as a backdrop for the other papers in this special issue.

Davies, J., J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull and M. Vincent. 2001. Marine Monitoring Handbook. 405 pp. 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/contents.htm

The United Kingdom Marine Science Project developed this handbook to provide guidelines for recording, monitoring, and reporting characteristics and conditions of marine habitats. Methodologies will need to be modified to suit the structural characteristics of habitats in the United States. 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 this handbook.

Day, J. W., Jr., C. A. S. Hall, W. M. Kemp and A. Y.-A. (eds.). 1989. Estuarine Ecology. John Wiley and Sons, NewYork.

Editors Comments. Estuaries are critical to the life cycles of fish and other aquatic animals. This book is a comprehensive synthesis of the field of estuarine ecology, incorporating much new research not covered by other books. The authors provide up-to-date information on the structure and function of estuaries, integrating the various components and processes of these key ecosystems. They also present a classification of estuaries bases on ecological principles. *Estuarine Ecology* is suitable as a text, for it presents all relevant background material – and it is complete and well-referenced enough to serve as a standard reference. Specific environmental impacts are addressed and classified.

Initial chapters describe the physical and chemical aspects of estuaries, with emphasis on nutrient cycling, and show how these fundamental factors provide a setting for the study of estuarine ecology. Middle chapters address estuarine plants, microbial ecology, estuarine consumers, and fish life-history patterns. Considerable information is provided on rates, patterns, and factors controlling primary production; the role of detritus in coastal systems (a topic that has been important in estuarine ecology for thirty years); and estuarine consumers (zooplankton, benthos, nekton, and wildlife). Of special note is the importance of estuaries in supporting fisheries.

Estuarine Ecology also deals with the effects of civilization on estuaries, including commercial fishing, and the side effects of industry and development. The authors examine traditional approaches to fisheries management, then present a modern ecological viewpoint. In the final chapter they present a general classification of the effects of human activities on estuarine ecology and give examples of each.

Estuarine Ecology is a thorough introduction to the subject – it presents an acceptable synthesis of modern estuarine science for those new to the field and develops sophisticated analysis for the professional.

Johnson, G. E., B. D. Ebberts, R. M. Thom, N. M. Ricci, A. H. Whiting, J. A. Southard, G. B. Sutherland, J. D. Wilcox and T. Berquam. 2003. An ecosystem-based approach to habitat restoration projects with emphasis on salmonids in the Columbia River Estuary, 154 pp., Pacific Northwest National Laboratory, Richland, WA.

Author Overview. The intent of this document is to provide a scientific basis and implementation guidelines for a habitat restoration program designed to improve ecosystem functions and enhance juvenile salmonid survival in the Columbia River estuary (CRE). The document does not address economic, social, or political aspects of habitat restoration in the CRE. The focus here is on habitat for listed salmon, although the ecosystem-based approach necessarily affects other species as well. Salmon habitat restoration is best undertaken within the context of other biota and physical processes using an ecosystem perspective. The anticipated audience includes entities responsible for, interested in, or affected by habitat restoration in the CRE. Timeframes to apply this document extend from the immediate (2003-2004) to the near-term (2005-2006) to the long-term (2007 and beyond). We anticipate and encourage that the document be revised as new knowledge and experience are attained.

Lewis, R. R., III, P. A. Clark, W. K. Fehring, H. S. Greening, R. O. Johansson and R. T. Paul. 1998. The rehabilitation of the Tampa Bay estuary, Florida, USA, as an example of

successful integrated coastal management. *Marine Pollution Bulletin* 37:468-473.

Author Abstract. The Tampa Bay Ecosystem is located in the state of Florida, USA. The 6739 km^2 ecosystem has undergone major changes due to coastal development, including dredging for maintenance and expansion of the 10th largest port in the USA. Approximately 44% of the historic emergent coastal wetlands and 81% of the historic submergent seagrass meadows had been lost through 1981. Declines in commercial and recreational fisheries harvests and coastal wildlife populations followed similar trends in declines. Beginning three decades ago, an informal Integrated Coastal Management (ICM) program initiated by citizen groups has progressed to a formal ICM program that has initiated restoration of the ecosystem and management through a unique multi-county umbrella organization, the Tampa Bay Estuary Program.

Osborne, J. A. and M. R. Egan. 1997. The impact of lake restoration on the zooplankton community in Banana Lake, Polk County, Florida. *Florida Scientist* 60(2):104–111.

Author Abstract: Zooplankton were monitored in Banana Lake between January, 1990 and March, 1992 to evaluate the impact of lake restoration by hydraulic dredging. Zooplankters were collected on a monthly basis at eight stations using an 8.1 L Kemmerer water sampler. The samples were concentrated by straining the samples through a #20 nylon bolting cloth zooplankton net. Microscopic enumeration was employed to determine abundance of rotifers and microcrustaceans. Dredging was conducted within Banana Lake between August, 1990 and August, 1991. During and after dredging, all species of zooplankters had decreasing trends except for *Asplanchna* sp., a predatory rotifer. Most species started to decline in January, 1991 and by October, 1991 all of the cladocerans and copepods had disappeared. Recovery had begun by March, 1992.

Poulakis, G. R., J. M. Shenker and D. S. Taylor. 2002. Habitat use by fishes after tidal reconnection of an impounded estuarine wetland in the Indian River Lagoon, Florida (USA). *Wetlands Ecology and Management* 10:51-69.

Author Abstract. Most of the wetlands located along the Indian River Lagoon (IRL) in east-central Florida (USA) have been impounded since the 1950's and 1960's to reduce mosquito reproduction. Impounded marsh (i.e., impoundment) dikes physically separate the wetlands from the estuary to allow artificial flooding of the impoundments during the mosquito breeding period (May to October). Presently, Rotational Impoundment Management (RIM) is the preferred impoundment management technique in the IRL. Impoundments maintained under RIM have culverts installed through the dikes which are kept closed during the mosquito breeding season (to control mosquitos) and are allowed to remain open for the remainder of the year (to allow tidal flow). A 24.3 ha impoundment 8 km north of Sebastian Inlet that had been isolated from the IRL for over 39 years was studied for 12 months to determine habitat use by fishes after tidal reconnection and the implementation of RIM. Fish sampling was conducted with a seine in the perimeter ditch and with clover and minnow traps in the upper marsh and tidal creek areas of the impoundment. Water level, impoundment bottom topography, and the seasonal nursery function of the impoundment were factors that contributed to observed patterns of fish habitat use during the study. Within the first 15 weeks of perimeter ditch sampling, an increase from 9 to 40 species was observed. Transient species used the perimeter ditch almost exclusively and entered the impoundment primarily during the spring open period. Juvenile

Pogonias cromis (Linnaeus), *Elops saurus* Linnaeus, *Centropomus undecimalis* (Bloch), and *Megalops atlanticus* Valenciennes were the most abundant recreationally important species, respectively. Habitat use by the most abundant resident species (*Gambusia holbrooki* Girard, *Poecilia latipinna* (Lesueur), *Cyprinodon variegatus* Lacepède, and *Fundulus confluentus* Goode & Bean) was influenced primarily by water level fluctuations. Resident species used the upper marsh and tidal creek habitats during summer flooded periods and the cyprinodontids left the interior surface of the impoundment last as water levels decreased. This study is the first to document the recovery of fish populations in a reconnected impoundment north of Sebastian Inlet using both active and passive sampling techniques.

Smakhtin, V. U. 2004. Simulating the hydrology and mouth conditions of small, temporarily closed/open estuaries. *Wetlands* 24:123-132.

Author Abstract. Many small estuaries and coastal lagoons in different parts of the world may be classified as temporarily closed/open ecosystems. They are blocked off from the sea for varying lengths of time by a sand bar, which forms at the estuarine mouth. The lengths of the closed and open phases, which are determined primarily by the interaction of river inflow and the sea in the mouth region, affect the structure and functioning of the estuarine biotic community. Freshwater inflow to such estuaries is normally not measured, and observations on the duration of estuarine mouth openings / closures are very scarce. As a result, relevant management decisions are often made on the basis of general experience and intuitive judgment. This paper describes an innovative approach for linking hydrologic data to mouth state in ungauged estuaries. A key characteristic in the method is the stream/river flow duration curve. It is first established for a daily index, which reflects the upstream catchment wetness and is calculated using rainfall information from the nearest rain gauge(s). This duration curve is then used to convert the current precipitation index time series into a continuous daily inflow time series at the ungauged estuarine mouth location. The conversion is based on the assumption that precipitation index values in a small catchment, and daily inflows to the estuarine mouth correspond to similar probabilities on their respective duration curves. The paper further illustrates how the generated inflow data could be used for the simulation of a continuous time series of estuary mouth openings/closures. Inflows are routed through a reservoir model, and the estuary mouth is considered open on days when the spillage from an estuarine "reservoir" occurs. The approach is illustrated using limited observed data on estuary mouth conditions from the South African coastline.

Weinstein, M. P., J. M. Teal, J. H. Balletto and K. A. Strait. 2001. Restoration principles emerging from one of the world's largest tidal marsh restoration projects. *Wetlands Ecology and Management* 9:387-407.

One of the world's largest tidal wetland restoration projects was conceived to offset the loss of nekton to once through cooling at a power plant on Delaware Bay, USA. An aggregated food chain model was employed to estimate the area of tidal salt marsh required to replace these losses. The 5040 ha was comprised of two degraded marsh types - *Phragmites*-dominated marshes and diked salt hay farms - at eleven locations in oligo-mesohaline and polyhaline reaches of the estuary. At a series of 'summits' convened with noted experts in the field, it was decided to apply an ecological engineering approach (i.e., 'self design', and minimal intrusion) in a landscape ecology framework to the restoration designs while at the same time monitoring long-term success of the project in the context of a 'bound of expectation'. The latter encompassed a range of reference marsh planforms and acceptable end-points established interactively with two advisory committees, numerous resource agencies, the permitting agency and multiple-stakeholder groups. In addition to the technical recommendations provided by the project's advisors, public health and safety, property protection and public access to the restored sites were a constant part of the dialogue between the utility, its consulting scientists and the resource/permitting agencies. Adaptive management was used to maintain the restoration trajectories, ensure that success criteria were met in a timely fashion, and to protect the public against potential effects of salt intrusion into wells and septic systems, and against upland flooding. Herbicide spray, followed by prescribed burns and altered microtopography were used at *Phragmites*-dominated sites, and excavation of higher order channels and dike breaching were the methods used to initiate the restorations at the diked salt hay farms. Monitoring consisted of evaluating the rate of re-vegetation and redevelopment of natural drainage networks, nekton response to the restorations, and focused research on nutrient flux, nekton movements, condition factors, trophic linkages, and other specific topics. Because of its size and uniqueness, the Estuary Enhancement Program as this project is known, has become an important case study for scientists engaged in restoration ecology and the application of ecological engineering principles. The history of this project, and ultimately the Restoration Principles that emerged from it, are the subjects of this paper. By documenting the pathways to success, it is hoped that other restoration ecologists and practitioners will benefit from the experiences we have gained.

West, T. L., L. M. Clough and W. G. Ambrose, Jr. 2000. Assessment of function in an oligohaline environment: Lessons learned by comparing created and natural habitats. *Ecological Engineering* 15:303-321.

Author Abstract. Assessments of nursery area function were carried out over a 10-year period in a 3-ha oligohaline marsh and creek system (`Project Area 2') and four natural `control' creeks (Drinkwater, Jacks, Jacobs, and Tooley) located in the Pamlico River estuary, North Carolina. Habitat function was assessed by comparing (1) growth and survival of fish; (2) long-term monitoring of water quality, sediment organic carbon, and the benthic infaunal community; and (3) measurement of benthic food availability. Growth (weight gain) and survival of the fish *Leiostomus xanthurus* held within enclosures were similar in both created and natural habitats. Species composition, total fauna density, and species richness of the infaunal community of the Project Area and the natural creeks were comparable within 3 years after construction of the Project Area. However, the sediments of the Project Area lacked the woody detrital cover, high peat content, and predominance of silt and clay characteristic of the natural creek sediments. There was no evidence of significant accretion of total organic carbon in the Project Area during the course of the study. This study has heuristically inspired four recommendations concerning assessment criteria of mitigation success. (1) Direct experimentation is needed to assess habitat function for motile species such as fish. (2) Studies of community structure need to be carried out long enough to permit testing of community stability, especially when working in areas exposed to stochastic abiotic and biotic stressors. (3) Measurements of nutritional content of the sediments should include estimates of overall organic quantity and nutritional quality. (4) Site design or restoration techniques should be included in the experimental design of each mitigation effort. Specifically, the lack of replication in these aspects of the mitigation process limits the inferential potential of the study, constrains the ability to make accurate predictions about the probability of success of future mitigation endeavors, and impedes our understanding of the critical mechanisms governing successful habitat creation, restoration, and enhancement.

APPENDIX II: WATER COLUMN
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.

Alliance for the Chesapeake Bay. 2002. Chesapeake Bay citizen monitoring program manual, 25 pp. Methods Manual, Alliance for the Chesapeak Bay, Richmond, VA. http://www.acb-online.org/pubs/projects/deliverables-206-1-2003.PDF

Author Abstract. This manual was prepared to assist volunteers performing chemical water quality monitoring and is a revision of the original manual prepared by Kathleen K. Ellett. This manual contains background material and instructions for measuring air and water temperature, dissolved oxygen, water clarity and pH. A sample data sheet is also included.

American Public Health Association. 1999. Standard Methods for Examination of Water & Wastewater. 20 ed. American Public Health Association, Washington, D.C.

Standard Methods for Examination of Water and Wastewater is an essential resource for any laboratory performing every imaginable analysis on water samples whether they be for chemical or biological components. Procedures for the sampling of zooplankton, phytoplankton, periphyton, macrophytes, benthic macroinvertebrates, and fish are also included as well as general identification keys to these organisms. Each procedure is explained in step-by-step detail with information on the strengths and weaknesses of various measurement methods. To a general practitioner, this resource would be useful to explain the chemical and biological components they are sampling, what the analysis entails, and the meaning of the final value obtained from each analysis. Various editions should be available at most any laboratory, or scientific or university library.

Anderson, D. M., P. Andersen, V. M. Bricelj, J. J. Cullen and J. E. Rensel. 2001. Monitoring and Management Strategies for Harmful Algal Blooms in Coastal Waters, APEC #201-MR-01.1, 235 pp. Technical Series 59, Asia Pacific Economic Program, Singapore, and Intergovernmental Oceanographic Commission, Paris. www.whoi.edu/redtide/Monitoring_Mgt_Report.html

In response to a red tide event in Hong Kong in 1998 that devastated the local fishing industry, the government of Hong Kong launched a program to study the effects of Harmful Algal Blooms (HABs) and develop methods to monitor their occurrence. The report by Anderson et al. is an edited version of the information supplied to the Hong Kong government and is a thorough inventory and assessment of HAB monitoring and management practices from around the world as of 1999. Research into HABs is a very dynamic field and much has been learned in the last few years, particularly with advancements in technology for detecting HABs remotely using satellite imagery. The scope of this report, however, would make it a valuable resource to anyone interested in the effects of HAB, efforts to monitor them, and strategies to minimize there impact on human and coastal fisheries.

Campbell, G. and S. Wildberger. 1992. The Monitor's Handbook. Lamotte Company ENC-016429, Chestertown MD. Contact information: Phone # (410) 778-3100, (800) 344-3100 or Fax # (410) 778-6394. Reference No.1507.

Author Abstract. This handbook provides the background and testing procedures for individuals who want to learn more about their local waterways or are involved in a water monitoring program. Aquatic ecosystems, such as streams, rivers, and lakes, are explained and a pre-monitoring sequence of activities is discussed. The handbook outlines sampling techniques and the equipment involved. Information for each of the water quality factors covered in the book (such as hardness, pH, and coliform bacteria levels) include: how to measure the factors, what the significant levels are, and what the measured levels indicate. Tips are provided for assuring the test results' accuracy for each test method. Quality assurance practices that contain calibration procedures and audits are suggested. Readers can find discussions of data analysis and presentation methods. A glossary, bibliography, and conversion table is included in the document. Appendices provide an overview of management concerns for a volunteer water monitoring program and lists of additional resources. Black and white photographs and drawings are found throughout the book.

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.

Deibel, D. 2001. Marine biodiversity monitoring: monitoring protocol for zooplankton, 14 pp. 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, Environment Canada, St. John's, Newfoundland, Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/zooplankton/zooplankton_marine_e.pdf

Diebel explains many of the reasons why zooplankton are an important component of aquatic systems to monitor, many stemming from the relationship zooplankton play in the food web linking phytoplankton to fish communities. He also highlights many of the problems associated with zooplankton sampling calling for a more standardized approach. Sampling zooplankton with nylon nets is highly selective and biased. Biases are caused by the size of mesh in relation to the varying size of animals (i.e. smaller animals get extruded through larger mesh nets), larger animals being able to avoid the net by swimming away, and the physical destruction of soft-bodied animals. Diebel points out that different types of sampling gear (i.e. different mesh sizes, different materials, different size openings) will all have different biases making comparison of data from one sample type to the next impossible.

Diebel also points out that the distribution and abundance of zooplankton species is greatly influenced by light, water depth, temperature, salinity, tides, and time of year and that these measurements too should be taken along with the zooplankton sample. He suggested that a stratified random sample design would be an appropriate sampling technique to account for the spatial variability of zooplankton communities. The strata should be subdivided on the abiotic characteristics listed above, which are also correlated to three general vertical layers in the water column: the upper mixed layer, the thermocline/pycnocline, and the bottom mixed layer. It has also been shown that zooplankton communities segregate out in vertical bands within these larger zones, indicating that a vertical tow may be useful in deeper waters. Since zooplankton communities vary depth, an onshore-offshore gradient could also be added as an addition stratum if a large area is to be sampled. Diebel also states that any zooplankton sampling scheme is a trade off between the length of tow and clogging. Ideally, the longest tow possible before the net is clogged more accurately samples the zooplankton community. Calculations for finding the ideal tow length are provided.

Zooplankton populations also vary according to different time scales. Sampling may thus need to be stratified on a daily time scale (day vs. night), a medium time scale (i.e. before and after storms), seasonal time scales, and decadal scales related to climate change. The choice of the appropriate time scale for measure depends on the question being answered by the practitioner. It is generally suggested that the frequency of samples should be greater while the zooplankton abundance is changing most rapidly and is thus most variable. Fewer samples can be taken when populations are more stable.

Eddy, S. and J. C. Underhill. 1978. How to Know the Freshwater Fishes. Third ed. Wm. C. Brown Company Publishers, Debuque, IA.

The Pictured Key Nature Series has a variety of identification keys available for a host of freshwater and terrestrial plants and animals. This particular volume is geared toward the identification of freshwater fishes found throughout the United States. Some marine fishes that occasionally found in estuarine environments are also included. The key provides accurate and detailed, yet easily understood drawings of representatives from each family as well as specific features that can be used to identify individuals to species. Brief summaries of preferred habitat and extent of range are also provided for most individual species to aid in identification.

Environment and Natural Resources Institute. 2002. Quality assurance project plan, 59 pp. Alaska Biological Monitoring and Assessment Program, Anchorage, AK. http://www.uaa.alaska.edu/enri/bmap/pdfs/ENRI_QAPP_2-02.pdf

This quality assurance project plan (QAPP) is designed for use in collecting data to assess wadable streams in Alaska focusing on the collection of benthic invertebrates and chemical water quality parameters. It can be used by practitioners restoring and monitoring other coastal habitats as a template of the types of information and level of detail required for a QAPP. QAPPs are important documents for any monitoring effort to have readily available. They are used by to ensure that data are collected in a comparable and consistent fashion regardless of who is obtaining the sampling. Some of the topics included in this QAPP include the identification of responsible parties; procedures for properly selecting sample locations and reference conditions; the collection, handling, and preservation of biological and chemical samples; methods to analyze samples and record data; data management; contingency plans for foreseeable mistakes and accidents; and methods to verify and validate the accuracy of data. Example data sheets and procedures for using specific types of equipment are also included.

Findlay, D. L. and H. J. Kling. 2002. Protocols for measuring biodiversity: phytoplankton in freshwater. Ecological Monitoring and Assessment Network Coordinating Office, Knowledge Integration Directorate of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/freshwater/phytoplankton/intro.html

This manual briefly describes the importance and use of phytoplankton in water quality monitoring. Abiotic factors that effect phytoplankton populations are also briefly described. Procedures for selecting sample sites and frequency of measurement, use of qualitative and quantitative sampling methods, and sample handling are also provided. Examples are used to illustrate laboratory procedures and data analysis techniques. As with the other volumes in this series, a list of persons to contact (in Canada) for additional information and assistance is also included.

Garrison, G. 2002. Monitoring water quality, 31 pp. Protocol, Florida Caribbean Science Center, St. John, US Virgin Islands. http://science.nature.nps.gov/im/monitor/protocols/WQPR0719.doc

This manual was designed specifically for monitoring the low-nutrient waters around the United State's Virgin Islands of St. John, Buck Island, and Dry Tortugas. They may also be applicable to other coastal areas with low nutrient concentrations. These areas had historically of low nutrient concentrations that benefited the coral reefs, seagrass beds, and other marine organisms found there. Recent development in the area has, however, led to decreases in water quality. Field and laboratory protocols for the monitoring of temperature, dissolved oxygen, salinity, conductivity, pH, light transmission, visibility, turbidity, suspended solids, photosynthetically reactive radiation (PAR), and nutrients are discussed.

Gibson, G. R., M. L. Bowman, J. Gerritsen and B. D. Snyder. 2000. Estuarine and coastal marine waters: bioassessment and biocriteria technical guidance, 300 pp. EPA 822-B-00-024, U.S. Environmental Protection Agency, Office of Water, Washington, D.C. http://www.epa.gov/ost/biocriteria/States/estuaries/estuaries1.html

Biological assessment can be a cost-effective tool for evaluating water quality, determining water resource status and trends, and following the progress of restoration projects. This technical guidance document is designed to assist managers and biologists in developing methods and approaches for implementing biological assessment and criteria projects. The guidance offered in this manual provides descriptions of the physical and chemical measures needed to properly classify sites for assessment as well as detailed descriptions of the biological measurements themselves. The document describes four levels of monitoring intensity that may be used depending on the particular project in question, and availability of monitoring funds available, and the investigative intensity required.

- Tier 0 is a preliminary review of existing literature and data on the site in question.
- Tier I is a one-time site visit to gather additional data and refine information collected in Tier 0.
- Tier II repeats and expands Tier I measurements. These measurements will be used to establish the reference condition against which comparisons can be made.
- Tier III requires the most intensive sampling to help determine why certain sites are not meeting biological criteria goals.

When using biological criteria to monitor a habitat, it is critical that physical and chemical measurements are also obtained and documented so that adequate comparisons of biological communities can occur. Salinity, depth, sediment grain size, and water quality (i.e. pH, temperature, DO, nutrients, and toxicants) can all affect biological communities and therefore must be taken into consideration when comparing one site to another for assessment of general system health or monitoring the progress of restoration efforts. In addition to discussion of the physical and chemical parameters listed above, use of and techniques to measure benthos, fish, submersed aquatic vegetation, phytoplankton, zooplankton, and epibenthos are described. The classification and characterization of reference conditions is also detailed and several case studies are provided as examples.

Griffith, L. M., R. C. Ward, G. B. McBride and J. C. Loftis. 2001. Data analysis considerations in producing 'comparable' information for water quality management purposes, 44 pp. Technical Report 01-01, U.S. Geological Survey, National Water Quality Monitoring Council. http://water.usgs.gov/wicp/acwi/monitoring/pubs/tr/nwqmc0101.pdf

Water quality monitoring is being used in local, regional, and national scales to measure how water quality variables behave in the natural environment. A common problem, which arises from monitoring, is how to relate information contained in data to the information needed by water resource management for decision-making. This is generally attempted through statistical analysis of the monitoring data. However, how the selection of methods with which to routinely analyze the data affects the quality and comparability of information produced is not as well understood as may first appear.

To help understand the connectivity between the selection of methods for routine data analysis and the information produced to support management, the following three tasks were performed.

- An examination of the methods that are currently being used to analyze water quality monitoring data, including published criticisms of them.
- An exploration of how the selection of methods to analyze water quality data can impact the comparability of information used for water quality management purposes.
- Development of options by which data analysis methods employed in water quality management can be made more transparent and auditable.

These tasks were accomplished through a literature review of texts, guidance and journals related to water quality. Then, the common analysis methods found were applied to portions of a river water quality dataset from New Zealand. The purpose of this was to establish how information changes as analysis methods change, and to determine if the information produced from different analysis methods is comparable.

The results of the literature review and data analysis are then discussed and recommendations are made addressing problems with current data analysis procedures. Options are listed through which to begin solving these problems and produce better information for water quality management.

It was found that null hypothesis testing is the most popular method through which to produce information, yet assumptions and hypotheses are loosely explained and alternatives rarely explored to determine the validity and comparability of the results. Other data analysis methods (using graphical, non-null hypotheses or Bayesian methods) that might be more appropriate for producing more comparable information are discussed, along with recommendations for further research and cooperative efforts to establish water quality data analysis protocols for producing information for

Hubbs, C. H. and K. F. Lagler. 1983. Fishes of the Great Lakes Region. The University of Michigan Press, Ann Arbor, MI.

Fishes of the Great Lakes Region offers detailed descriptions and identification tips for all 172 species of fish found throughout the Great Lakes Basin. Brief introductions to the general characteristics of each family are also provided. Very detailed descriptions of characteristic traits and accompanying pictures facilitate accurate identification of individuals to species. The geographic extent of each species is also presented as an additional aid to proper identification.

Lindbo, D. T. and S. L. Renfro. 2003. Riparian and Aquatic Ecosystem Monitoring: A Manual of Field and Lab Procedures. 4th ed. Saturday Academy's Student Watershed Research Project, Beaverton, OR.

The Student Research Watershed Project has developed a set of field and lab data collection procedures that has successfully translated scientific methodologies for use by non-scientists. The procedures were designed for use by students (grades 8 – 12) and can easily be adapted for volunteer efforts to collect baseline and restoration monitoring data for streamside and aquatic (in-stream) habitats. Methods for the collection of physical, chemical, and biological criteria are included. The manual covers the steps necessary to design a monitoring plan as well as a quality assurance project plan. Rationale behind and the steps involved in monitoring the following parameters are also included: stream flow, temperature, dissolved oxygen, pH, alkalinity, solids and turbidity, conductivity, phosphorus, nitrogen, chlorine, microbes, and macroinvertebrates. Information on the collection of information on in-stream habitat, riparian vegetation, stream reach mapping, photo monitoring, and soils is also included. Example data sheets are provided to assist in the systematic and complete recording of monitoring results by different parties.

Marcogliese, D. J. 2002. Protocols for measuring diversity: parasites of fishes in freshwater. Ecological Monitoring and Assessment Network Coordinating Office, Knowledge Integration Directorate of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/freshwater/parasites/intro.html

Parasites typically have complex life cycles and can often be used to indicate different aspects of host biology including diet, migration, recruitment, health, and phylogeny. They can also be used as indicators of stress and environmental contaminants. Parasites can be microscopic such as bacteria, fungi, protozoans, and myxozoans or macroscopic such as flukes, tapeworms, nematoads, and copepods. The lamprey eel is a large, famous parasite that had a devastating effect on large sportfishes of the Great Lakes. The protocols listed in this on-line resource include methods for sampling parasite host populations (i.e., fish). Information includes procedures for collecting, handling, and storing samples, identification keys, quality assessment/quality control (QA/QC) documentation, recommendations for using volunteers, and methods to analyze data. There is also a list of experts (in Canada) for those who require additional information and assistance.

Martin, J. L. 2001. Marine biodiversity monitoring: protocol for monitoring phytoplankton, 13 pp. 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, Environment Canada, St. Andrews, New Brunswick, Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/phytoplankton/phyto_marine_e.pdf

Martin's report covers a variety of aspects concerning phytoplankton sampling in marine waters. She covers the some of the general ecology of marine phytoplankton including the abiotic factors that dictate species presence, absence, and abundance. These include water exchange throughout the area to be sampled, depth, water column stability, proximity to aquaculture sites, or other agriculture and industry. She also gives suggestions on certain places where sampling should be avoided as well as sampling frequency. Martin also covers several methods for obtaining quantitative and qualitative samples including some strengths and limitations of each sampling type. There is also a section on sample treatment and processing and several methods for preserving samples. Also of use to practitioners interested in using phytoplankton for monitoring, a variety of methods and equipment needed in the identification process are also introduced including references to identification manuals for different types of these microscopic algae.

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. 97 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.

Merritt, R. W. and K. W. Cummins, (eds.). 1996. An Introduction to the Aquatic Insects of North America. Third edition ed. Kendall/Hunt Publishing Company, Dubuque, IA, USA.

While the bulk of Merritt and Cummins is on identification of aquatic insects of North America, they include several chapters useful in project planning as well. Various experts in the field of aquatic insect collection and identification have submitted chapters on: the general morphology of aquatic insects, designing studies, collection techniques, aquatic insect respiration, habitat and life history, and the ecology and distribution of aquatic insects. The rest of the manual is devoted to identification keys for each family of aquatic insect found in North America with many detailed and useful pictures of identifying characteristics.

Since this book is continental in scope, it is suggested that practitioners first look for identification keys prepared for their local or regional waterways. This will reduce much confusion in the identification process by eliminating species that are not found locally. Any local aquatics expert or science librarian should be able to locate these materials. If local materials are not available, then Merritt and Cummins will be useful, however, be sure to check the distribution of species identified whenever possible.

Mueller, D. K., J. D. Martin and T. J. Lopes. 1997. Quality-control design for surface-water sampling in the national water-quality assessment program, 8 pp plus appendices. Open-File Report 97-223, U.S. Geological Survey, Denver, CO. http://water.usgs.gov/nawqa/protocols/OFR97-223/ofr97-223.pdf

This brief report summarizes the quality control methods employed for sampling under the national water-quality assessment program. Although this document is not a complete quality assurance program plan (QAPP), the information included may be useful for monitoring programs developing sampling protocols for contaminated areas. The use of field blanks, trip blanks, field-matrix spikes, and analysis replicates are discussed.

Murphy, B. R. and D. W. Willis, (eds.). 1996. Fisheries Techniques: Second edition. American Fisheries Society, Bethesda, MD, USA.

Murphy and Willis have edited the industry standard for fisheries sampling techniques. A variety of experts in the field have written chapters that cover all aspects of how to sample and measure fish. Topics include: planning for sampling, data management and statistical techniques, safety, habitat measurements, care and handling of samples, passive and active capture techniques, collection and identification of eggs and larvae, sampling with toxics, invertebrates, tagging and marking, acoustic assessment, field examination and measurements, age and growth rate determination, diet, underwater observation, creel sampling, commercial surveys, and socioeconomic measurements.

Ossinger, M. 1999. Success standards for wetland mitigation projects - a guideline, 31 pp. Washington State Department of Transportation, Environmental Affairs Office. http://pnw.sws.org/forum/success.PDF

This report offers guidance and examples on how to write specific success criteria for mitigation and restoration projects. Though it was designed to address mitigation projects in the Pacific Northwest, its information and approach make it useful throughout the United States. It outlines the steps necessary for planning the monitoring and management of a mitigation/restoration project. Guidance in writing the following program elements is provided: how to set project goals, how to select specific project objectives (i.e. what functions or values will the mitigation/restoration provide), how to select performance objectives (i.e. what structural characteristics need to be in place to provide desired functions), selection of success standards (measurable benchmarks used to determine success of performance objectives), monitoring method (how will the success standard be measured), contingency measure (what to do if the success standards are not met). Several examples are provided of each of these steps. These examples, while not all-inclusive, facilitate the application of this method to diverse areas and project types.

Paterson, M. 2001. Protocols for measuring biodiversity: zooplankton in freshwaters. Ecological Monitoring and Assessment Network Coordinating Office, Knowledge Integration Directorate of Environment Canada. http://www.eman-rese.ca/eman/ecotools/protocols/freshwater/zooplankton/intro.html

Patterson has compiled an extensive literature review on the topic of zooplankton sampling in freshwater environments. This review covers the topics of selecting sample sites within a water body, preparing a site description, sampling frequency, and includes a list of other environmental factors that need to be measured that affect zooplankton and should be measured in conjunction with it. There is also a brief review of field sampling protocols for various sizes of zooplankton and methods for sample preservation as well as a list of literature reviewing sampling methods in greater detail. Patterson also lists laboratory techniques for identification and biomass estimation directing readers to additional literature as needed. Data analysis techniques for comparing abundance, community measures, and multivariate methods for community analysis are also described. One of the most useful sections of this document for restoration practitioners developing monitoring programs will be the extensive literature review Patterson has conducted as well as the thorough list of references available for freshwater zooplankton identification.

Ribic, C. A., T. R. Dixon and I. Vining. 1992. Marine debris survey manual, 92 pp. NOAA Technical Report NMFS 108, NOAA National Marine Fisheries Service, Seattle, Washington.

Author Introduction. Over the last several years, concern has increased about the amount of man-made materials lost or discarded at sea and the potential impacts to the environment. The scope of the problem depends on the amounts and types of debris. Once problem in making a regional comparison is the lack of a standard methodology. The objective of this manual is to discuss designs and methodologies for assessment studies of marine debris.

This manual has been written for managers, researchers, and others who are just entering this area of study who seek guidance in designing marine debris surveys. Active researchers will be able to use this manual along with applicable references herein as a source for design improvement. To this end, the authors have synthesized their work and reviewed survey techniques that have been used in the past for assessing marine debris, such as sighting surveys, beach surveys, and trawl surveys, and have considered new methods (e.g., aerial photography). All techniques have been put into a general survey planning framework to assist in developing different marine debris surveys.

Steyer, G. D., R. C. Raynie, D. L. Steller, D. Fuller and E. Swenson. 1995. Quality management plan for Coastal Wetlands Planning, Protection, and Restoration Act **monitoring** program, 8 pp. Open-File Report 95-01, Louisiana Department of Natural Resources, Coastal Restoration Division, Baton Rouge, LA. http://www.lacoast.gov/cwppra/reports/MonitoringPlan/index.htm

This document is a Quality Assurance Project Plan (QAPP) used for all restoration projects conducted under the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) and similar legislation for coastal Louisiana. Though it does not explain how to develop a QAPP for new wetland restoration monitoring projects, it can be used as a template by which monitoring plans can be developed. Detailed explanations of how to data is to be collected, acceptable error rates, and methods to ensure high quality data is collected, recorded, and analyzed are included. Quality assurance guidelines are provided for field data collection, remote sensing and airphoto interpretation, computer systems to be used, data entry procedures, data review, laboratory procedures, and documentation and reporting. Any restoration practitioner attempting to develop a monitoring plan or preparing a QAPP for their project may find this document a valuable example to follow.

Trippel, E. A. 2001. Marine biodiversity monitoring: protocol for monitoring of fish communities, 10 pp. 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, Environment Canada, St. Andrews, New Brunswick, Canada. http://www.eman-rese.ca/eman/ecotools/protocols/marine/fishes/intro.html

Trippel reviews the standard protocols used in sampling fish communities in marine environments for biodiversity and abundance studies performed by Environment Canada. Trippel cites a preference for stratified random sampling as it increases the homogeneity of catches within each stratum sampled compared to a purely random or fixed station sampling strategy. The need for a stratified approach is re-enforced through the measurement of depth, temperature, salinity and other abiotic factors that affect fish species presence and abundance. Trippel also addresses the issue of sampling frequency, as some migratory species may only be present in a certain area for a short period of time. Knowledge of the life cycle and migratory patterns of target species must be taken into consideration when designed any sampling effort. Additionally, frequent sampling in early years may allow for the determination of patterns in the timing of target species presence so that sampling may be cost effectively scaled back in later years. The Canadian sampling efforts also prefer the use of bottom trawls as opposed to gill nets or baited hooks as the trawls capture a greater diversity of species and body sizes as well as allowing for the calculation of abundance since the area of the trawl is known. However, topographically diverse areas may exclude the use of bottom trawls. Additionally, bottom trawls can be expensive, as they require the use of a large vessel with numerous scientific and technical crewmembers.

In addition to fish-related measurements such as number of individuals, length, weight, sex, and species, abiotic factors must also be measured for each trawl to ensure the proper comparison of strata. These include: cruise, set, vessel, stratum, sample (or station) number, date, positions, time, distance, speed, depth (minimum, maximum), auxiliary equipment, warp, wind force, current, and water temperature and salinity at specific depths.

U.S. EPA. 1996. The volunteer monitor's guide to quality assurance project plans, 59 pp. EPA 841-B-96-003, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/volunteer/qapp/vol_qapp.pdf

Author Abstract. The Quality Assurance Project Plan, or QAPP, is a written document that outlines the procedures a monitoring project will use to ensure that the samples participants collect and analyze, the data they store and manage, and the reports they write are of high enough quality to meet project needs.

U.S. Environmental Protection Agency-funded monitoring programs must have an EPA-approved QAPP before sample collection begins. However, even programs that do not receive EPA money should consider developing a QAPP, especially if data might be used by state, federal, or local resource managers. A QAPP helps the data user and monitoring project leaders ensure that the collected data meet their needs and that the quality control steps needed to verify this are built into the project from the beginning.

Volunteer monitoring programs have long recognized the importance of well-designed monitoring projects; written field, lab, and data management protocols; trained volunteers; and effective presentation of results. Relatively few programs, however, have tackled the task of preparing a comprehensive QAPP that documents these important elements. This document is designed to help volunteer program coordinators develop such a QAPP.

U.S. EPA. 2002. Assessing and monitoring floatable debris, 49 pp. EPA-842-B-02-002, Oceans and Coastal Protection Division, U.S. Environmental Protection Agency, Washington, D.C.

This manual is designed to help states, tribes, and local units of government develop assessment and monitoring programs for floating debris (trash) in coastal waterways. The manual is broken into five parts with appendices. Part 1 introduces the impacts of floating debris on the aquatic environment and describes current legislation to address the issue. Part 2 discusses the types and origins of trash in coastal waters. Part 3 describes a variety of plans and programs that have been developed and implemented in various coastal areas to assess and monitor trash. Part 4 provides recommendations for developing assessment and monitoring programs that were originally presented in NOAA's *Marine Debris Survey Manual* and the EPA's *Volunteer Estuary Monitoring: A Methods Manual*. Part 5 provides methods to prevent and mitigate the problems associated with floating debris. The Appendices include information on international coastal cleanup efforts, a National Marine Debris Monitoring Program data card, storm drain stenciling cards, and surveys from the *Marine Debris Survey Manual*.

U.S. EPA. 2002. Guidance for quality assurance project plans, 57 pp. EPA QA/G-5, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/swerust1/cat/epaqag5.pdf

This document is designed to guide those involved with Quality Assurance Project Plan (QAPP) development for environmental monitoring and data analysis. It describes various issues to be addressed when preparing a QAPP, with an emphasis on systematic planning. The report is divided into three chapters. An introduction that describes the target audience and the importance of systematic sampling. A second chapter describes all of the pieces of a QAPP, focusing on environmental data collection and analysis. The third chapter describes methods for developing QAPPs for projects that use previously collected data.

The importance of having high quality, reliable data cannot be over estimated. Use of this document or the EPA's *Volunteer Monitor's Guide to Quality Assurance Project Plans*, will help restoration practitioners develop monitoring plans that will provide the high quality, reliable data necessary to monitor and manage restoration projects. The step-by-step approach of this document takes restoration practitioners through the entire planning, data collection, data analysis, and reporting process from start to finish. Ensuring that all aspects of the monitoring project are well thought out ahead of time and that contingency plans are in place.

U.S. EPA. 2001. National coastal assessment: field operations manual, 72 pp. EPA 620/R-01/003, U.S. Environmental Protection Agency, Office of Research and Development, National Health and Environmental Effects Research Laboratory, Gulf Ecology Division, Gulf Breeze, Florida. http://www.epa.gov/emap/nca/html/docs/c2kfm.pdf

This manual presents a standard set of field data and sample collection techniques for the EPA's National Coastal Assessment, the current state of the EPA's Environmental Assessment Program (EMAP). Though the methods collected here are geared specifically toward this program, some restoration practitioners may find them useful particularly in areas where restoration projects overlap existing monitoring activities, as this will facilitate the comparison of current data with historic trends. The measurement protocols described in this manual include:

- sediment contaminant concentrations
- sediment toxicity
- benthic species composition
- sediment characteristics
- water column dissolved nutrients
- chlorophyll *a* concentrations
- total suspended solids
- surface and bottom dissolved oxygen, salinity, temperature, and pH
- water clarity
- contaminant levels in fish and shellfish
- external pathological condition of fish
- fish community structure

A suggested monitoring routine is presented for data collection at each site to maximize sampling efficiency while in the field. Of particular use to the beginning restoration-monitoring practitioner, a list of necessary field and laboratory equipment is also provided in an appendix.

U.S. EPA. 2001. Nutrient criteria technical guidance manual: estuarine and coastal marine waters. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/waterscience/standards/nutrients/marine/index.html

This manual provides and introduction and definition to estuaries and coastal systems of the United States, focusing primarily on marine-estuarine systems and the problem and scope of nutrient over-enrichment in America's estuaries. Techniques for classifying estuaries for comparison of one system to another are outlined. Variables and measurement methods to assess and monitor estuarine and marine conditions are provided and divided into two groups: causal and response. This allows practitioners to choose which types of measurements are best suited toward their needs and abilities. Measurements discussed include: nutrients (nitrogen and phosphorus), water clarity, dissolved oxygen, benthic macrofauna, phytoplankton, sediments, primary productivity, macroalgae, seagrasses and SAV. An overview of existing databases from across the US is given along with guidance on the development of sampling designs, quality assurance and control, and statistical analyses. Methods to determine reference condition, nutrient and algal monitoring criteria, and methods for using this information to help protect water quality are also discussed in detail. Several case studies are included as examples of how these criteria have been implemented in estuaries in California, New York, Florida, Washington state, and areas around the Chesapeake Bay.

U.S. EPA. 2001. Volunteer Estuary Monitoring: a Methods Manual. United States Environmental Protection Agency, Office of Water. http://www.epa.gov/owow/estuaries/monitor/

Partial Author Abstract. This document presents information and methodologies specific to estuarine water quality. The first eight chapters of the manual deal with typical issues that a new or established volunteer estuary monitoring program might face:

- Understanding estuaries, what makes them unique, the problems they face, and the role of humans in solving the problems
- Establishing and maintaining a volunteer monitoring program
- Working with volunteers and making certain that they are well-positioned to collect water quality data safely and effectively
- Ensuring that the program consistently produces data of high quality, and
- Managing the data and making it available to data users

The remaining chapters focus on several water quality parameters that are important in determining the health of an estuary. These chapters are divided into three units, which characterize the parameters as measures of the chemical, physical, or biological environment of the estuary.

The significance of each parameter and specific methods to monitor it are detailed in a step-by-step fashion. The manual stresses proper quality assurance and quality control techniques to ensure that the data are useful to state agencies and any other data users.
References are listed at the end of each chapter. Appendices containing additional resources are also supplied. These references should prove a valuable source of detailed information to anyone interested in establishing a new volunteer program or a background resource to those with already established programs.

U.S. Geological Survey. variously dated. National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations. Book 9, chapts. A1-A9. http://pubs.water.usgs.gov/twri9A

The U.S.G.S. National Field Manual was designed to promote the consistency of scientific methods and procedures used to collect water quality data. Individual chapters from this electronically available document can be downloaded from the government website listed above. The manual includes information on methods to plan and prepare for water sampling, selection and cleaning of equipment, collection and processing of water samples, and appropriate field methods for collection of temperature, dissolved oxygen, conductivity, pH, redox potential, alkalinity, and turbidity. Methods for collecting and analyzing biological indicators of water quality such as bacterial and viral indicators of fecal contamination are also included as are guidelines for analysis of bottom materials and field safety practices.

Virginia Citizen Water Quality Monitoring Program. 2003. Virginia citizen water quality monitoring program methods manual, 81 pp plus appendices. Methods Manual, Virginia Department of Environmental Quality, Richmond, VA. http://www.deq.state.va.us/cmonitor/pdf/cmonman.pdf

This document provides guidance on the selection and use of available water quality monitoring methods commonly used by citizen volunteer groups in the state of Virginia. It is not a comprehensive list of every available method, it is intended as an introduction to sampling for the uninitiated. The manual opens with information on planning a monitoring program and developing a quality assurance project plan (QAPP). The following sections explain the pros and cons of various methods to monitor chemical, biological, and physical parameters of the water column and associated habitats such as submerged aquatic vegetation and riverine forests. A variety of appendices also provide lists of contacts, equipment suppliers, and other resources useful to citizen monitoring efforts. Although this manual is designed for use in Virginia, monitoring volunteers in other areas may also find it useful.

Walk, M. F. 2003. Lake volunteer water quality monitoring manual, 91 pp. Massachusetts Water Watch Partnership, University of Massachusetts, Amherst, MA. http://www.umass.edu/tei/mwwp/acrobat/lake%20manual.pdf

The Massachusetts Water Watch Partnership (MassWWP) has developed this guidebook to introduce individuals and/or lake associations to water quality monitoring. It contains instructions on how to start a successful monitoring program including information on proper study design, building community support for the monitoring program, field and lab techniques, and quality control. Detailed sampling and measuring protocols are provided for water temperature and transparency, dissolved oxygen, pH, alkalinity, total phosphorus, and chlorophyll. These protocols reflect MassWWP's suggested data quality requirements and may not be appropriate for every monitoring effort. The manual is divided into two main parts with appendices. Part One provides background information on watershed ecology and how to design a monitoring program. Part Two describes each of the water quality indicators covered and procedures for analysis in the field and laboratory. The appendices include references for further reading, a copy of the 2000 Massachusetts Surface Water Quality Standards, a list of agencies and organizations that can provide monitoring assistance, a list of recommended equipment and supplies, and examples of typical lake surveys. Protocols for chemical and physical parameters as well as suggested biological parameters (including some for rivers) can be accessed directly at: http://www.umass.edu/tei/mwwp/protocols.html.

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 WATER COLUMN 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

References

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