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 12: RESTORATION MONITORING OF DEEPWATER SWAMPS

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INTRODUCTION

Deepwater swamps are forested wetlands that develop along edges of lakes, on alluvial river floodplains, in slow-flowing strands, and in large, coastal-wetland complexes. Deepwater swamps are commonly referred to as cypress swamps and in Cowardin et al. (1979) these forests are referred to as 'estuarine forested wetlands'. They can be found along the coasts of the Atlantic Ocean and Gulf of Mexico and throughout the Mississippi River valley from southern Illinois to Louisiana. Dominant species commonly include:

- Baldcypress (*Taxodium distichum)*
- Water tupelo (*Nyssa aquatica)*, and
- Swamp tupelo (*N. sylvatica* var. *biflora*) (Wharton et al. 1982).

The dominant vegetation in deepwater swamps is distinguished from other forested swamps in that it is significantly more tolerant of flooding than other tree species (Figure 1 - Conner and Day 1992b; Allen et al. 1996). Adult baldcypress and tupelo can survive permanent inundation although seedlings require exposed sediments to germinate and become successfully established (Schneider and Sharitz 1988; Keeland et al. 1997; Middleton 2000). The soils of cypress swamps range from mineral to accumulated peat depending on the hydrodynamics and topography of the specific system (Giese et al. 2000; Mitsch and Gosselink 2000).

Essential to the health and functioning of downstream water bodies, deepwater swamps in alluvial forests allow floodwaters to spread out and deposit suspended sediment loads. Deepwater swamps, in these and other settings, filter flood- and surface water, absorb and transform nutrients, thus helping to prevent the eutrophication of downstream areas. Recent studies also indicate that some deepwater swamps may be useful in storing carbon, helping to offset the impact of global climate change (Bondavalli et al. 2000).

Figure 1. Adult baldcypress trees, shown here, can tolerate constantly flooded conditions. Photo from NOAA photo library.

Figure 2. Crayfish. Photo by Mary Hollinger, NOAA/ National Oceanographic Data Center, NOAA photo library. http://www.photolib.noaa.gov/coastline/line2281.htm

[1]2205 Commonwealth Blvd., Ann Arbor, MI 48105.

Figure 3. More light reaches the forest floor in areas with open canopies, this coupled with exposed soils, allows understory herbs and shrubs to grow. Photo from NOAA photo library.

DEEPWATER SWAMP INHABITANTS

Deepwater swamps support a diversity of wildlife. Macroinvertebrates such as crayfish (Figure 2) shrimp, insects, clams, snails, and worms are commonly found in deepwater swamps (Sklar 1985; Thorp et al. 1985). Fish can be temporary or permanent residents of deepwater swamps. While flooded, deepwater swamps provide spawning, nursery, and foraging areas for fish. Fish are able to survive periods of low water by concentrating in river channels, backwater areas, and deep holes (Hoover and Killgore 1998). Reptiles and amphibians are also common residents of deepwater swamps (Mitsch and Gosselink 2000). Due to the near-constant flooding, only a few mammal species are common to deepwater swamps. Of these, nutria, an exotic rodent, is a major obstacle to successful reforestation efforts. Nutria and white-tailed deer graze heavily on the roots and shoots of newly planted and germinating trees. In areas where these animals are particularly abundant, special management practices need to be implemented to ensure the success of restoration/reforestation efforts (Llewellyn and Shaffer 1993; Myers et al. 1995).

The presence and abundance of understory vegetation depends upon the amount of light that penetrates the canopy and the local flooding regime (Figure 3). Some areas with open canopies and moderate flooding may have a diverse shrub and herbaceous ground flora including such species as:

Buttonbush (*Cephalanthus occidentalis*)
Fetterbush (*Lyonia lucida*), and
Wax myrtle (*Myrica cerifera*)

Other swamps, with closed canopies or longer flooding times, may be devoid of any ground layer vegetation. In some swamps, floating logs and tree stumps provide the only substrate for understory vegetation and regeneration of overstory species. In these cases, it is possible to develop entire floating mat communities[2]. Deepwater swamps that are continually flooded and have high nutrient concentrations may also develop thick mats of floating aquatics such as duckweed (*Lemna* spp. and *Spirodela* spp.)

[2] Floating mat communities are wetlands whose substrate is composed of a thick layer of organic material held together with roots from living vegetation. The entire mat rises and falls with the ambient water level. Thus the vegetation community is freed from any hydrologic fluctuation, sediment deposition, or surface water inflows. It is also somewhat immune from saltwater intrusion and supports a relatively stable plant community (Mitsch and Gosselink 2000).

and mosquito fern (*Azolla* spp. - Mitsch and Gosselink 2000).

HUMAN IMPACTS TO DEEPWATER SWAMPS

Although once common throughout the southeastern United States, only a small portion of the original deepwater swamps exists today. Historically, losses were due to extensive logging and conversion to agriculture. Current impacts to deepwater swamps include altered hydrology, herbivory from exotic nutria, saltwater intrusion, and sea level rise (Sklar 1985; Conner and Toliver 1990; Myers et al. 1995; Allen et al. 1996). Logging of cypress swamps began in the mid 1700s when the southeastern United States was first settled by Europeans in large numbers (Conner and Toliver 1990; Conner and Buford 1998). Baldcypress was the main cash crop for colonists of Louisiana until about 1790 and remained a staple of the lumber industry until the early 1900's because of its tremendous durability and ease of workability. These early logging efforts were limited to periods of high water when the logs could be floated out.

In the 1890's, however, the use of the pull boat[3], overhead skidder, and the expansion of the rail system industrialized logging operations. Logging could now be conducted year round and throughout a greater extent of swampland than before. As early as 1915, people noted that cutover swamps were not regenerating on their own but there was no interest in reforestation efforts at that time. By the 1930's, baldcypress logging operations were already past their peak. The last major baldcypress logging operation closed in 1956 although some smaller operations still continue to harvest baldcypress (Conner and Toliver 1990).

Because of its long history of logging, there are no good estimates of precisely how much deepwater swamp habitat has been lost since European settlement began. Estimates of loss are further complicated by the various methods used to classify forests over time[4]. A general trend indicates that between 1934 and 1985 the area of oak/gum/baldcypress swamp decreased from 3 million ha to 1.6 million ha. A 50% decrease in 50 years.

Two early restoration projects were attempted in 1949-1950, one by the Rathborne Lumber Company, another by a private landowner (Bull 1949, Rathborne 1951, and Peters and Holcombe 1951 cited in Conner and Toliver 1990). In each case, initial monitoring a few months after seedlings were planted, indicated a high survival rate (~90%). It was later found, however, that many of the trees planted by Rathborne had eventually been killed by animals and the project had been abandoned (Brown and Montz 1986, cited in Conner and Toliver 1990). There was no additional monitoring of the other project so long-term results are unknown.

[3] Pull boats and skidders also contributed greatly to the degradation of deepwater habitats. By dragging large logs through the marsh, deep, wide ditches were created. In some cases, these ditches altered local hydrology by draining some swamps, further reducing the ability of cypress forests to regenerate (Conner and Buford 1998, Conner and Toliver 1990).

[4] See Conner and Toliver (1990) for a complete listing of various methods to measure area of deepwater (cypress) habitats over time.

STRUCTURAL CHARACTERISTICS OF DEEPWATER SWAMPS

When planning a restoration and monitoring project, practitioners should be mindful that it may take several decades before a deepwater swamp is able to fully perform all ecological functions. Therefore, it is important to state early on in the restoration planning process what the particular goals of the restoration project are and how the project will be monitored over time to determine if those goals are being achieved. For example, if the goal of a restoration project is to restore a natural flood regime to a floodplain allowing fish to access the area for feeding or breeding purposes, these results might be seen within a year or two. If the goal of the project is to restore a diversity of plant species to an area that is similar to a reference condition[5], that might be achieved in a relatively short time period such as five to ten years. If planting of sapling trees is undertaken with the goal of restoring native bird species that require standing deadwood for nesting, monitoring may take a human life-time or more as this function requires large trees that take a long time to grow. Understanding project goals and how they will be tracked through monitoring also helps determine what management actions may be required later to ensure that goals are achieved.

As with many of the other habitats described in Volume Two, the monitoring of restoration efforts in deepwater swamps should focus first on the primary structural characteristics of the habitat and then shift toward functional characteristics over time. The primary structural characteristics of deepwater swamps have been broken down into four categories:

Biological
- Habitat created by plants

Physical
- Sediment/Soil
  - Grain size
  - Organic matter
- Topography/Bathymetry

Hydrological
- Hydroperiod
- Water source
- Current velocity

Chemical
- Salinity

These structural characteristics were identified as being fundamental to the development of a healthy deepwater swamp habitat. Each of these dictates whether or not a forest can develop in an area, which particular tree species will become established, and the degree to which the habitat can perform characteristic biological and physical functions.

BIOLOGICAL

Habitat Created by Plants

Deepwater swamps are dominated by mixed or pure stands of baldcypress, water tupelo, and swamp tupelo, as these are the only species truly adapted to almost permanently flooded conditions. A variety of other species, however, are commonly associated with deepwater habitats at higher (i.e., dryer) elevations. These may include:

Red maple (*Acer rubrum*)
Black willow (*Salix nigra* a common successor to bald cypress after clear cutting)
Swamp cottonwood (*Populus heterophylla*)
Green and pumpkin ash (*Fraxinus pennsylvanica* and *F. profunda)*
Pond pine (*Pinus serotina*)
Waterlocust (*Gledistia aquatica*)
Water-elm (*Planera aquatica*)
Overcup oak (*Q. lyrata*)
Water oak (*Q. nigra*)
Water hickory (*Carya aquatica*)

[5] See Chapter 15 for a discussion of methods to select proper reference conditions for restoration monitoring.

Redbay (*Persea borbonia*), and
Loblolly pine (*Pinus taeda*) (Conner and Buford 1998)

Devall (1998) accumulated lists of understory species commonly associated with deepwater swamps. In areas where light gaps occur or where canopies have not closed to prevent understory growth, a variety of trees, shrubs, and herbaceous vegetation may be found (Conner and Buford 1998). These include:

Swamp-privet (*Forestiera acuminata*)
Carolina ash (*F. caroliniana*)
Poison sumac (*Toxicodendron vernix*)
Dahoon (*Ilex cassine*)
Buttonbush (*Cephalanthus occidentalis*)
Poison ivy (*T. radicans*)
Muscadine grape (*Vitis rotundifolia*)
Spanish moss (*Tillandsia usneioides*)
Cattail (*Typha latifolia*)
Lizardtail (*Saururus cernuus*)
Holly (*Ilex* spp.)
Viburnums (*Viburnum* spp.)
Lyonias (*Lyonia* spp.)
Sedges (family Cyperaceae)
Grasses (family Poaceae), and
Ferns (Johnson 1990; Wilhite and Toliver 1990)

Due to the flooding regime and low light conditions below a dense forest canopy, understory vegetation is typically sparse, if present at all in mature deepwater swamps. Recently, invasive exotic species such as Chinese tallow (*Sapium sebiferum*) and Brazilian pepper (*Schinus terebinthifolia*) have invaded deepwater swamps and are changing species composition in these forests (Devall 1998).

Sampling

The types of measurements used to monitor the restoration of a forested site change as the site matures. If plantings are part of the restoration project, the first few years are typically spent monitoring damage from herbivores, seedling survival, density, and growth rate as measured by plant height (Conner 1989; Kolka et al. 1998; Conner et al. 2000). As sites mature (e.g., starting around 10 years after planting), the monitoring of canopy closure becomes important as this factor is strongly related to light availability and understory vegetation (Fletcher et al. 2000). Growth rate can still be measured but the method changes from using seedling height to diameter at breast height (DBH).

Numerous field guides for the identification of plant species are available for different areas of the country. Practitioners should select a book (or books) from as close a region as possible to their study area. Most field guides, however, are not comprehensive and only cover the most common species one is likely to find. When knowing the exact species is absolutely necessary, such as when study results are to be published, then more detailed and comprehensive identification guides should be consulted. A few examples of these sorts of texts include:

- Godfrey and Wooten's *Aquatic and Wetland Plants of Southeastern United States: Dicotyledons* or their second volume *Aquatic and Wetland Plants of Northeastern North America: Angiosperms: Monocotyledons (Volume II)*
- Crow, Hellquist's, and Fassett's *Aquatic and Wetland Plants of Northeastern North America: Pteridophytes, Gymnosperms and Angiosperms: Dicotyledons and Aquatic and Wetland Plants of Northeastern North America: Angiosperms: Monocotyledons (Volume II)*, and
- Voss' three-volume *Michigan Flora*

PHYSICAL

Sediment/Soil

Grain size

The soils of deepwater swamps range from mineral to accumulated peat, depending on the hydrodynamics and topography of the specific system (Conner and Buford 1998; Giese et al. 2000). Deepwater swamp soils are typically nutrient rich and have high percentages of both clay and organic matter resulting in high concentrations of phosphorus and nitrogen (Conner and Buford 1998). These conditions lead to extremely high primary productivities (see *Primary Production* below). The soils of these habitats also tend to be moderately to strongly acidic and have an impervious subsoil (Conner and Buford 1998).

Organic matter

Soil organic matter is an important component of forest soils. It is composed of leaf litter, woody debris, plant roots, and microbes (Barton et al. 2000). Wigginton et al. (2000) measured forest floor organic matter, soil carbon content, and soil structure at restoration sites of different ages at the Savannah River Site in South Carolina. They found that forest floor organic matter increased in the first few years after restoration (657 g/m^2 maximum) but then dropped off as the system continued to mature (338 g/m^2). This was accompanied by a change in the type of forest floor litter as well. Originally organic matter of herbaceous origin dominated the forest floor litter. As the restoration sites aged and developed, organic matter from woody species (predominately leaves) became more abundant. Carbon content of the soil continually increased as restoration sites aged. It was, however, estimated that it would take over 50 years for soil carbon levels to reach 75% of those in reference sites. Additionally, soil structure had been severely altered by the original disturbance at the site. Soil structure too was changing in the restoration sites at a slow but measurable pace (Wigginton et al. 2000).

Giese et al. (2000) also measured soil carbon content, biomass production, and intra-site variability at the same restored locations. They found that soil carbon accumulation, soil carbon content in wetter areas increased faster than in dryer settings. Differing concentrations of carbon in the soil did not seem to have any measurable affects on above ground biomass productivity, however. Giese et al. (2000) reached a similar conclusion as Wigginton et al. (2000), that restored sites were slowly developing soil characteristics similar to mature reference forests.

Sampling and Monitoring Methods

The Soil Science Society of America publishes a 4-volume *Methods of Soil Analysis*. These volumes, revised in Appendix II, cover a variety of standard methods to sample the physical, mineralogical, microbiological, biochemical, and chemical properties of soils. This would be a valuable resource to anyone seriously considering soil sampling over the long-term. Most university libraries should also carry these as well.

Topography/Bathymetry

Deepwater swamps are found in a variety of settings such as along the edges of lakes, on alluvial river floodplains, in slow-flowing strands[6], and in large, coastal wetland complexes. Well-known examples of some of these systems include the Maurepas Swamp in Louisiana, the Big Cypress Swamp in Florida, the Okefenokee Swamp in Georgia, and the Great Dismal Swamp in Virginia. Areas where deepwater swamps occur typically have low topographic relief with subtle changes in elevation (a few cm) leading to a variety of hydrologic conditions, soil types, and vegetative communities (Conner and Buford 1998). Common geomorphic features of deepwater swamps include meandering river channels that help form backwater swamps, oxbow lakes, sloughs, and meander scrolls[7] (Figure 4 - Conner and Buford 1998).

Sampling

Topographic maps available from the United States Geologic Survey can provide a rough estimate of elevations in the study area. In most

[6] Shallow elongated depressions, often the remnants of old river channels.
[7] Ridges and swales created as the river channel moves back and forth across the floodplain.

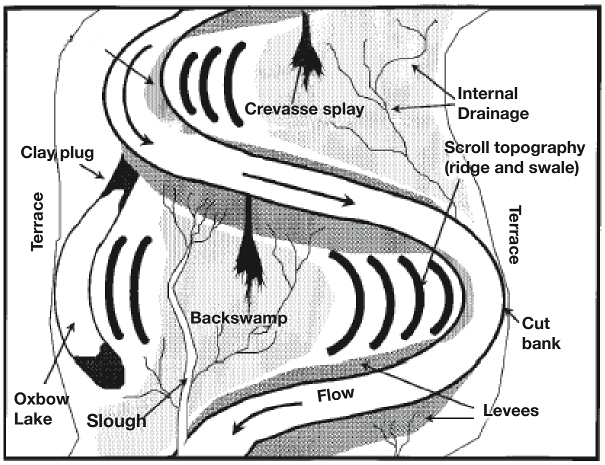

Figure 4. Some of the common geomorphic features of alluvial floodplains where deepwater swamps can often be found. Taken from Hupp 2000.

cases, however, a detailed survey or the area to be restored will need to be conducted. The surface elevations and topographic diversity of the area must be measured in relation to existing or projected water level changes as differences of only a few inches may determine whether or not planted material survives.

HYDROLOGICAL

Hydroperiod, Water Source, and Current Velocity

Regardless of the specific geomorphic setting, all deepwater swamps are freshwater ecosystems and their hydrodynamics are dominated by surface water runoff from adjacent uplands and/or overbank flooding from rivers (Mitsch and Gosselink 2000). Although deepwater swamps are typically flooded most of the year, seasonal water level fluctuations do occur (Figure 5). High water levels occur in winter and spring as a result of increased rainfall and snowmelt in headwater areas. Low levels occur in late summer and early fall, resulting from low precipitation levels and increased evapotranspiration (Conner and Buford 1998). During severe droughts, deepwater swamps may lack surface water completely (Conner and Buford 1998). These water level fluctuations and periodic drydowns are essential for the long-term maintenance of baldcypress, the dominant tree species of

Figure 5. Battle Creek Cypress Swamp in late spring/early summer when water levels are receding. Photo by Max Davis, Edgewater, MD.

deepwater swamps. Of all the trees found in these areas, baldcypress is the most tolerant of prolonged flooding (Conner et al. 1997). Seedlings, however, need to become established under non-flooded conditions in order to survive (Schneider and Sharitz 1988; Allen et al. 1996; Keeland et al. 1997; Middleton 2000). Once established they may be just as flood tolerant as adult trees as long as they are not completely submerged by floodwater (Keeland and Conner 1999).

Factors important to the growth and health of deepwater swamp forest trees include the depth, duration, and timing of inundation (collectively referred to as the 'hydroperiod'). While Young et al. (1995) and Keeland et al. (1997) both noted that growth rate of baldcypress, as measured by changes in diameter at breast height (DBH), initially increased with lengthened periods of flooding, this effect eventually subsided and tree growth diminished with permanent inundation over a period of several years (Young et al. 1995; Allen et al. 1996). Brinson et al. (1981) noted that the amount and frequency of water moving through a wetland was one of the predominant factors in determining wetland primary productivity. If reference sites are used as part of the monitoring program, it is critical that the restored sites and reference sites are subject to similar hydrologic conditions (water source, depth, timing, duration of flooding, and velocity) for accurate comparisons to be made.

Sampling

The United States Geological Survey operates a series of gauging stations throughout the country. Historical and real-time data on hydroperiod and characteristics of the watershed for many of these sites are available at http://water.usgs.gov/waterwatch/. Smaller, coastal rivers or more isolated areas 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.

CHEMICAL

Salinity

Increases in salinity due to rising sea levels or large storm surges can impact the growth rate of baldcypress (Conner 1993; Allen et al. 1996; Conner and Day 1998). As salinity increases, seedling height, diameter, leaf biomass, and survival all decrease (Kraus et al. 1998). Although some local varieties of baldcypress have been shown to be adapted to slightly higher salinities, intrusion of salt water will kill adult trees (Allen et al. 1996; Allen et al. 1997; Kraus et al. 1998). In areas where storm surges are common or where surface elevations are actively subsiding, selection of more salt tolerant genotypes is recommended for restoration success (Allen et al. 1996).

Measuring and Monitoring Methods

A variety of electronic probes are commercially available for measuring salinity in the water column and in the sediment. If salinity levels are unknown, then a probe with a wide measurement range is recommended as use of a probe outside of its operational range may damage the instrument. Data loggers[8] can also be left in place to record data frequently (e.g., hourly or daily) if it is suspected that salinity levels change fairly often. In areas were salinity levels are more stable, a less expensive manual probe can be used to measure salinity during site visits.

[8]Instruments left in place to record data frequently over time.

FUNCTIONAL CHARACTERISTICS OF DEEPWATER SWAMPS

Deepwater swamps provide a variety of biological and hydrological functions. Some of these functions, such as feeding and breeding grounds for fish and nutrient cycling are socially and economically important. The list of functions commonly attributed to deepwater swamps presented below has been broken into three categories Biological, Hydrological, and Chemical.

Biological

- Contributes to primary production
- Supports biomass production
- Produces wood
- Provides breeding grounds
- Provides nursery areas
- Provides feeding grounds
- Supports a complex trophic structure

Physical

- Affects transport of suspended and dissolved material
- Alters turbidity
- Reduces erosion potential
- Modifies water temperature
- Provides temporary floodwater storage

Chemical

- Supports nutrient cycling
- Modifies chemical water quality

BIOLOGICAL FUNCTIONS

Contributes to Primary and Biomass Production and Produces Wood

Deepwater swamps exhibit primary productivities among the highest recorded for forested ecosystems. Aboveground biomass production often exceeds 8,900 lbs/acre (10 t/ha/yr) and can be as high as 17,800 lbs/acre (20 t/ha/yr) in some cases (Conner and Buford 1998)[9]. As stated previously, hydrology has a large impact on primary productivity, too much or too little water can lower forest productivity. Poor drainage or stagnant water contributes to anoxic soil conditions which in turn lead to lower nutrient turnover rates, nitrogen limitations, low pH (Conner and Buford 1998), accumulation of biological waste products, and an increase in the solubility of certain heavy metals in the soil (Sharitz and Mitsch 1993). Swamps, such as the Okefenokee, with permanent standing water have lower decomposition rates, lower rates of nutrient cycling, and low nutrient inputs leading to very low rates of primary production (Devall 1998) compared to other systems with flowing water.

Swamps that have been drained can also exhibit reduced productivity (Conner and Buford 1998). Carter et al. (1973, cited in Conner and Buford 1998) found that drainage of a deepwater swamp in Florida resulted in a thinning of the canopy, and a reduction in productivity as measured by tree growth, litterfall, and herbaceous plants. The productivity of the drained swamp was 3,453 lbs/acre (3.87 t/ha/yr) compared to 7,656 lbs/acre (8.58 t/ha/yr) for an undrained swamp.

Sampling and Monitoring Methods

Some common methods to measure primary productivity include collection of leaf litter and calculation of growth rate from repeated measurements of diameter at breast height (DBH) or height of seedlings (Brown 1981; Conner and Day 1992a; Conner et al. 1997; Keeland et al. 1997). Although not much is known about belowground productivity, some evidence indicates that it is similar in scale to litterfall (Symbula and Day 1988). Methods for measuring belowground biomass production include taking a series of soil cores or placing

[9] Mickler et al (2002) estimated net primary productivity for all forest types in the southern U.S. to average 12,900 lbs/acre in 1992. Mickler, R. A., T. S. Earnhardt and J. A. Moore. 2002. Regional estimation of current and future forest biomass. *Environmental Pollution* 116:S7-S16.

soil-filled nylon bags in the substrate allowing roots to grow into them (Symbula and Day 1988; Powell and Day 1991). The bags are then retrieved after a specified amount of time and the root content analyzed. Neither of these methods is particularly effective at sampling roots greater than 5 cm in diameter, however, and may actually underestimate total underground productivity. Litterfall can account for approximately 39% of the above ground primary production and can be easily collected (Brown 1981; Conner and Buford 1998). Seedling height is also easily obtained although requires repeated (e.g., weekly) site visits if knowledge of seasonal differences in growth rate is desired. Annual measurements may, however, be acceptable for many restoration monitoring projects. Keeland et al. (1997) provide methods and equations for calculating growth rate from repeated measurements of DBH.

Provides Breeding, Nursery, Feeding Grounds, and Supports Trophic Structure

Macroinvertebrates

Macroinvertebrates such as crawfish, shrimp, insects, clams, snails, and worms are commonly found in deepwater swamps (Sklar 1985; Thorp et al. 1985). The types and abundance of invertebrates depend on several factors including water depth, flood duration, velocity, substrate, food source, and oxygen level (Sklar 1985; Thorp et al. 1985; Conner and Buford 1998).

Sklar (1985) compared backwater cypress swamp invertebrate communities on the substrate and in floating vegetation (*Lemna* spp.). He found that floating vegetation had greater numbers of individuals and higher density (individuals/m^2) than benthic areas, but benthic areas had greater biomass production. Overall, backwater swamps had some of the highest recorded invertebrate densities and biomass of any freshwater or estuarine soft bottom habitat. Due to frequent anoxic conditions and desiccation to which few invertebrate species are adapted, however, species diversity of backwater swamps was somewhat low. Sklar (1985) also found that density, biomass, and diversity changed throughout the year, peaked in spring and fall, and were related to seasonal flooding and water temperature. Restoration monitoring programs of deepwater or backwater areas that plan to incorporate invertebrate sampling should take these patterns into account.

As with other habitat functions of deepwater areas, complete restoration of a typical deepwater invertebrate community is dependent on the recovery of the vegetation community and may take several decades or longer. In areas that have had their canopy trees removed, exposing the water to full sunlight, submergent and emergent vegetation may have become established. These vegetation types provide significantly different habitat structure and will therefore have different invertebrate communities than areas with a closed forest canopy. Although Thorp et al. (1985) found that invertebrates will quickly colonize woody debris in the water, it may take decades (or longer) for planted seedlings to grow large enough to contribute such debris in significant quantities to alter aquatic invertebrate communities. Lakly and McArthur (2000) studied the invertebrate communities in the thermally impacted Savannah River of South Carolina. All canopy trees had been killed by thermal pollution from an upstream power plant. Impacted areas were being studied to assess both natural recovery and restoration efforts compared to un-impacted areas. They found that although the general abundance and diversity of organisms had recovered since thermal flows ceased in 1988, invertebrate communities in the once impacted streams with open canopies remained structurally and functionally distinct from reference areas with closed canopies. This may be the case for the early stages of many restoration efforts.

Fish, amphibians, reptiles, and birds

Conner and Buford (1998), Mitsch and Gosselink (2000), and Wharton et al. (1982) provide lists and examples of fish, amphibian, reptile, and bird species commonly associated with deepwater habitats. The presence or abundance of fish, amphibian, reptile, and bird species can be used to monitor the success of restoration efforts, particularly where wildlife were absent prior to the restoration effort. Many of the species listed in these sources, however, are dependent upon extensive tracts of mature deepwater forests and may not be able to utilize habitats provided by forests of seedlings or saplings. Hooded mergansers (*Lophodytes cucullatus*) and prothonotary warblers (*Protonotaria citrea*), both of which nest in tree cavities, are good examples of birds unable to use a restored deepwater forest for decades after initial planting. The re-establishment of species dependent on mature forests may take several decades and is likely dependent on the availability of migration corridors to and from existing populations and the restored area. If no suitable populations for natural migration into the restored area are available, trap and release activities may be required once suitable habitat has become established. This should not deter restoration practitioners from using wildlife to monitor restoration efforts but serves as a reminder to set realistic goals for restoration efforts within the time frame of monitoring activities.

Mammals

Nutria, an exotic rodent introduced to Louisiana in the 1930s from South America (Figure 6 - Conner and Buford 1998), is now a common pest in deepwater swamps of the southern United States and is one of the major obstacles to successful reforestation efforts. Nutria, as well as rabbits and white-tailed deer, can heavily graze the roots and shoots of newly planted or germinating trees.

Figure 6. The invasive, exotic nutria. Photo from the Louisiana Department of Wildlife and Fisheries.

Newly planted trees should be monitored for damage. In areas where nutria and other herbivorous mammals are particularly abundant or troublesome, special management practices need to be implemented to ensure the success of restoration/reforestation efforts. Without extra precautions to safe guard seedlings from herbivory, restoration and reforestation efforts are likely to fail. Methods of controlling herbivory of baldcypress seedlings using a variety of shelter types are described in Myers et al. (1995), Conner et al. (2000), and Conner and Ozalp (2002) .

PHYSICAL

The main physical functions performed by deepwater swamps are the transport of suspended/dissolved material, alteration of turbidity, modification of water temperature, and temporary floodwater storage. These have been described with the associated structural characteristics above.

CHEMICAL

Supports Nutrient cycling and Modifies Water Quality

As noted earlier, deepwater swamps are essential to the long-term health and sustainability of downstream waters. This function is carried out by the deposition of suspended sediments on alluvial floodplains and the absorption and transformation[10] of nutrients such as nitrogen and phosphorus. These processes are closely linked to hydrologic processes. The depth, duration, timing, and flow rate of flooding control the soil and water oxygen content and affect the microbial processes that determine whether a particular swamp acts as a nutrient sink, source, or transformer. Deepwater swamps with seasonal or annual water level fluctuations and/or moving, as opposed to stagnant, water typically have higher oxygen concentrations, faster rates of nutrient cycling, and higher growth rates of trees (Conner and Buford 1998). In addition, the deposition, uptake, and transformation of sediments and nutrients within deepwater swamps prevent these materials from being deposited in downstream water bodies where they may lead to eutrophication.

Soil type and oxygen concentration also have direct affects on the biogeochemistry of deepwater swamps and affect downstream water quality. Soil type and oxygen concentration impact the processes of nutrient cycling and transformation and storage of metals and toxics. Soils with high clay content such as those of deepwater swamps tend to be poorly aerated even when flooding subsides (Conner and Buford 1998). This leads to increases in the solubility of minerals such as phosphorus, nitrogen, magnesium, sulfur, iron, manganese, boron, copper, and zinc making them readily available for uptake by plants (Mitsch and Gosselink 2000). Extremely low oxygen levels over prolonged periods of time may, however, can cause toxic chemicals to accumulate in the soil (Sharitz and Mitsch 1993). These may harm plants and animals, limit the nutrient cycling ability of the swamp, and impact its ability to contribute to downstream water quality.

Sampling

The American Public Health Association's *Standard Methods for the Examination of Water & Wastewater* provides detailed field and laboratory procedures for analyzing any water quality parameter selected for use in restoration monitoring.

[10]Also referred to as biogeochemical cycling.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The matrices of structural and functional parameters for restoration monitoring provided below were developed through extensive review of restoration and ecological monitoring literature. Additional input was received from recognized experts in the field of deepwater swamp 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. Additional parameters not in this list, such as human dimensions parameters, may also be appropriate for restoration monitoring efforts. Parameters with a closed circle (●) are those that, at the 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 text above. Literature directing readers toward additional information on the ecology of deepwater swamps and restoration case studies can be found in the Annotated Bibliography of Deepwater Swamps. Information on sampling strategies and techniques can be found in the associated Review of Technical Methods Manuals.

Parameters to Monitor the Structural Characteristics of Deepwater Swamps

Parameters to Monitor	Biological		Physical		Hydrological			Chemical
	Habitat created by plants	Sediment grain size	Topography/Bathymetry	Tides/Hydroperiod	Water sources	Current velocity	pH, salinity, toxics, redox, DO[11]
Geographical							
Acreage of habitat types	●						
Biological							
Plants							
Species, composition, and % cover of:							
Herbaceous vascular	○						
Woody	●						
Basal area	○						
Canopy aerial extent and structure	○						
Plant height	○						
Seedling survival	●						
Stem density	●						
Woody debris (root masses, stumps, logs, etc.)	○		○				
Hydrological							
Physical							
Sheet flow						●	
Temperature				○	○		
Upstream land use					●		
Water level fluctuation over time				●	●		
Chemical							
Salinity (in tidal areas)				○	○		○
Toxics							○
Soil/Sediment							
Physical							
Basin elevations			○				
Depth of mottling				○			
Geomorphology (slope, basin cross section)			●	●			
Moisture levels and drainage				○			
Organic content		○		○			
Percent sand, silt, and clay		○					
Sedimentation rate and quality		○	○	○		○	
Chemical							
Pore water salinity (in tidal areas)							○
Redox potential							○

[11]Dissolved oxygen.

Parameters to Monitor the Functional Characteristics of Deepwater Swamps

Parameters to Monitor	Biological	Contributes primary production	Supports biomass production	Produces wood	Provides breeding grounds	Provides nursery areas	Provides feeding grounds	Supports a complex trophic structure	Physical	Affects transport of suspended and dissolved material	Alters turbidity	Reduces erosion potential	Modifies water temperature	Provides temporary floodwater storage	Chemical	Supports nutrient cycling	Modifies chemical water quality
Geographical																	
Acreage of habitat types		●	●	●	●	●	●	●		●	●	●	●	●		●	●
Biological																	
Plants																	
Species, composition, and % cover of:																	
Herbaceous vascular		❍	❍		❍	❍	❍	❍		❍	❍	❍	❍			❍	❍
Invasives					❍	❍	❍	❍									
Woody		●	●	●	●	●	●	●		●	●	●	●	●		●	
Basal area		❍	❍	❍													
Canopy aerial extent and structure				❍	❍	❍	❍						❍				
Interspersion of habitat types			❍		❍	❍	❍	❍		❍	❍	❍	❍	❍			
Litter fall		❍	❍				❍	❍			❍					❍	
Plant health (herbivory damage, disease)							❍										
Plant height		❍	❍														
Rate of canopy closure		❍	❍	❍									❍				
Seedling survival[12]				●								●					
Stem density				❍						❍	❍	❍	❍				
Woody debris (root masses, stumps, logs, etc.)				❍	❍	❍	❍	❍				❍	❍				

[12]If the whole community is destroyed by disease or lack of seedling survival, all vegetation-related functions will be impaired

Parameters to Monitor the Functional Characteristics of Deepwater Swamps (cont.)

Parameters to Monitor	**Biological:** Contributes primary production	Supports biomass production	Produces wood	Provides breeding grounds	Provides nursery areas	Provides feeding grounds	Supports a complex trophic structure	**Physical:** Affects transport of suspended and dissolved material	Alters turbidity	Reduces erosion potential	Modifies water temperature	Provides temporary floodwater storage	**Chemical:** Supports nutrient cycling	Modifies chemical water quality
Biological (cont.)														
Animals														
Species, composition, and abundance of:														
Birds		○		○	○	○	○							
Fish		○		○	○	○	○							
Invasives		○						○	○					
Invertebrates		○		○	○	○	○							
Mammals		○		○	○	○	○							
Reptiles		○		○	○	○	○							
Hydrological														
Physical														
Fetch								○	○	○				
PAR[13]	○	○						○	○					
Seiche disc depth	○	○						○	○					
Shear force at sediment surface								○	○	○				
Sheet flow								○	○	○		○	○	○
Temperature				○	○						○			○
Trash								○	○					
Upstream land use								●	●		●			●
Water column current velocity								○	○	○			○	○
Water level fluctuation over time	●	●		●	●	●	●	●	●	●		●	●	●

[13]Photosynthetically active radiation. Methods to calculate PAR underwater can be found in Chapter 2 ‘Restoration Monitoring of the Water Column’ and Chapter 9, ‘Restoration Monitoring of Submerged Aquatic Vegegation’.

Parameters to Monitor the Functional Characteristics of Deepwater Swamps (cont.)

Parameters to Monitor	Biological: Contributes primary production	Biological: Supports biomass production	Biological: Produces wood	Biological: Provides breeding grounds	Biological: Provides nursery areas	Biological: Provides feeding grounds	Biological: Supports a complex trophic structure	Physical: Affects transport of suspended and dissolved material	Physical: Alters turbidity	Physical: Reduces erosion potential	Physical: Modifies water temperature	Physical: Provides temporary floodwater storage	Chemical: Supports nutrient cycling	Chemical: Modifies chemical water quality
Hydrological (cont.)														
Chemical														
Nitrogen and phosphorus	○	○							○				○	○
Salinity (in tidal areas)														○
Toxics				○	○	○								○
Soil/Sediment														
Physical														
Basin elevations				○	○	○		○	○		○	○		
Bulk density										○			○	
Geomorphology (slope, basin cross section)				●	●	●		●	●	●	●	●	●	●
Moisture levels and drainage												○	○	○
Sediment grain size (OM[14]/sand/silt/clay/gravel/ cobble)		○						○	○	○			○	○
Sedimentation rate and quality								○	○	○				○
Chemical														
Organic content in sediment		○				○	○	○	○				○	○
Pore water nitrogen and phosphorus		○											○	○
Pore water salinity (in tidal areas)		○	○											
Redox potential													○	○

[14]Organic matter.

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APPENDIX I: DEEPWATER SWAMPS ANNOTATED BIBLIOGRAPHY

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

Aust, W. M., S. H. Schoenholts, T. W. Zaebst and B. A. Szabo. 1997. Recovery status of a tupelo-cypress wetland seven years after disturbance: silvicultural implications. *Forest Ecology and Management* 90:161-169.

Author Abstract. Three methods of clearing forested wetland vegetation (*Nyssa aquatica – Taxodium distichum*) were done to test their impact on the regeneration of natural vegetation in southwestern Alabama in 1986: clearcutting with helicopter log removal (HELI), HELI followed by rubber-tired skidder traffic simulation (SKID), and HELI followed by glyphosphate application for 2 growing seasons to remove all vegetation (GLYPH). It was believed that woody plant regeneration would be least affected in the HELI-treated areas. However, monitoring measurements taken after seven years showed that the SKID treatment actually had greater total above-ground biomass (65, 979 kg/ha) than the HELI treated area (46,748 kg/ha) and that SKID plots also had a higher proportion of the most desirable timber species (*Nyssa aquatica*). GLYPH areas became freshwater marshes with some invasion of *Salix nigra*. Each of the treatment areas had significant herbaceous vegetation that increased sediment accumulation 70 – 175% relative to an undisturbed reference area. The regrowth of vegetation in treated areas has lowered the water table during the growing season but had minimal impact on soil redox potential and pH. Researchers concluded that, in each case, wetlands were rapidly recovering from logging disturbance seven years ago, although successional trajectories appeared to be quite different.

Barton, C., E. A. Nelson, R. K. Kolka, K. W. McLeod, W. H. Conner, M. Lakly, D. Martin, J. Wigginton, C. C. Trettin and J. Wisniewski. 2000. Restoration of a severely impacted riparian wetland system — The Pen Branch Project. *Ecological Engineering* 15:S3-S15.

The Savannah River Swamp is a 3020 ha forested wetland in the floodplain of the Savannah River. It is located on the Department of Energy's Savannah River Site (SRS) in South Carolina and was severely degraded by high temperatures (~65°C) and high volume discharges of cooling water from nuclear reactors and a coal-fired power plant beginning in the 1950s. Historically, the forest cover of the swamp consisted of approximately 50% bald cypress-water tupelo, 40% mixed bottomland hardwoods, and 10% shrub, marsh, and open water. The increases in water volume and temperature resulted in the overflow of the original stream banks, creation of additional floodplain area, erosion of the original stream corridor, and deposition of a deep silt layer on the newly formed delta. These impacts caused the complete elimination of the original floodplain vegetation. In the years since pumping was reduced (1988), natural regeneration and restoration efforts have occurred in the affected areas. Herbs, grasses, and shrubs dominate and a few hardwood or bald cypress seedlings have been found in regenerating areas. Different methods to reintroduce tree species characteristic of mature forested wetlands were tested.

The following parameters were monitored to assess the impact of the restoration efforts: stream hydrology, seedling survival and competition, aquatic insect community dynamics, revegetation techniques, fish ecology and stream habitat, autotrophic and macroinvertebrate characterization, organic matter decomposition and nutrient mineralization, and terrestrial vertebrate distribution. In most cases, measurements were made in both the restored system and in one or more reference systems. Some studies also included control systems, which experienced a thermal impact similar to that of Pen Branch, but where the hydrology had been restored at an earlier date. Results indicated the return of some forested wetland functions to varying degrees. Some factors, such as plant species diversity were similar to reference sites. Other factors and functions such as canopy closure, contribution of woody debris to streams, or soil organic matter content appeared to be moving in the direction of a mature forested wetland but it would several decades before restored areas fully functioned as mature forests. Other results are presented in individual papers in this annotated bibliography.

Clewell, A. F. and R. Lea. 1990. Creation and restoration of forested wetland vegetation in the southeastern United States, pp. 195-231. In Kusler, J. A. and M. E. Kentula (eds.), Wetland Creation and Restoration: the Status of the Science. Island Press, Washington, D.C.

Author Abstract. This chapter describes forested wetland creation and restoration project experience and establishment methods in the region from Virginia to Arkansas south to Florida and Louisiana. In contrast to marshes, forest replacement is more complex and requires a much longer development period. A wide variety of forest establishment techniques have been employed, some with initial success but none of them proven. Most projects pertain to bottomland hardwood and cypress replacement. The two most significant trends in project activity have been the direct seeding of oaks on abandoned croplands and the replacement of all trees and sometimes the undergrowth at reclaimed surface mines. Although some young projects appear promising in terms of species composition and structure, it is still too early to assess functional equivalency.

Project success depends largely on judicious planning and careful execution. The most critical factor for all projects is to achieve adequate hydrological conditions. Other important factors may include substrate stability, availability of adequate soil rooting volume and fertility, and the control of herbivores and competitive weeds. A checklist of these and other important issues is appended for the benefit of personnel who prepare project plans and review permit applications.

Success criteria for evaluating extant projects throughout the southeast are either inadequately conceived or usually lacking. Emphasis needs to be placed upon the presence of preferred species (i.e., indigenous trees and undergrowth characteristic of mature stands of the community being replaced) and on the attainment of a threshold density of trees that are at least 2 meters tall. Once such a stand of trees is attained, survival is virtually assured and little else could be done that would further expedite project success. At that point, release from regulatory liability should be seriously considered.

Several critical information gaps are also identified.

Conner, W. H. 1989. Growth and survival of baldcypress (*Taxodium distichum* [L.] Rich.) planted across a flooding gradient in a Louisiana bottomland forest. *Wetlands* 9:207-217.

Author Abstract. One-year-old baldcypress (*Taxodium distichum* [L.] Rich.) seedlings were planted across a flooding gradient in a Louisiana bottomland forest in March and September 1985. One half of the seedlings were protected with a chickenwire fence. Survival and height growth were monitored from 1985 through 1987. First year survival was high in all areas for both plantings, except for the unprotected March-planted seedlings, which were destroyed by animals. After three growing seasons, survival of March-planted seedlings in the flooded and intermittently flooded plots was still over 70%. Natural mortality of March-planted seedlings in the unflooded plot was high, with only 40% of the seedlings surviving to the end of the study. Survival of the September-planted seedlings was also best in the flooded and intermittently flooded plots and least in the unflooded plot. Height growth, like survival, was best for seedlings in the flooded and intermittently flooded plots. It seems that baldcypress seedlings can be planted in a swamp and grow well if animal damage is controlled.

Conner, W. H. 1995. Woody plant regeneration in three South Carolina *Taxodium/Nyssa* stands following Hurricane Hugo. *Ecological Engineering* 4:277-287.

Author Abstract. Long-term monitoring began in 1990 to follow community changes resulting from hurricane disturbance. In addition, one-year-old *Taxodium distichum* seedlings were planted to determine if planting was feasible in saltwater-flooded areas. The canopy of the least impacted swamp recovered rapidly, but there were few seedlings growing in the understory. Planted seedlings survived well, but they grew very little. Both lack of seedlings and poor growth of planted seedlings were probably due to intense shading and flooding. Two impacted areas contained a greater number of seedlings, most of which were found growing on raised microsites like *Taxodium* knees. The majority of the seedlings in all areas were shrub species. Planted seedlings grew well (30 cm/yr) where open canopy conditions allowed sunlight to reach the forest floor and no new saltwater has been introduced since the hurricane.

Conner, W. H., L. W. Inabinette and E. F. Brantley. 2000. The use of tree shelters in restoring forest species to a floodplain delta: 5-year results. *Ecological Engineering* 15: S47-S56.

Author Abstract. Without herbivory control, natural seed sources, and seasonal flood events, recovery of the Pen branch delta in South Carolina to former conditions (prior to thermal discharge) may take many years. To assess the recovery process, seedlings of baldcypress (*Taxodium distichum*), water tupelo (*Nyssa aquatica*), swamp blackgum (*Nyssa sylvatica* var. *biflora*), and green ash (*Fraxinus pennsylvanica*) were planted in four areas of the delta in 1994. One-half of the seedlings were protected using tree shelters 1.5 m tall. Heights of seedlings were taken after planting and at the end of each growing season from 1994 to 1998. Survival at the end of 5 years ranged from 67 to 100% for seedlings in tree shelters and 2–90% for those not in tree shelters. Survival of seedlings without tree shelters was generally low, and mortality was attributed mainly to beaver damage. Although water tupelo, swamp blackgum, and green ash seedlings tended to die once clipped by beaver, 85% of the clipped baldcypress resprouted after clipping, and new sprouts grew vigorously. During year 1, height growth of tree shelter seedlings was significantly greater than non-tree shelter seedlings for all species, but once the seedling emerged from the top of the shelter, growth differences declined dramatically. Differences in height growth among areas was highly variable from year to year, and no one species tended to grow better in one area over another throughout the period. Restoration of the Pen branch delta to a baldcypress–water tupelo forest similar to the surrounding forest is possible. Baldcypress and water tupelo seem ideally suited to growing in all areas of the delta equally well, but it may take 10–20 years before the seedlings are of sufficient size to not be affected by herbivory and old enough to produce sufficient quantities of seed to maintain the forest.

Conner, W. H. and M. Ozalp. 2002. Baldcypress restoration in a saltwater damaged area of South Carolina. pp. 356-369. In K. W. Outcalt, Eleventh biennial southern silvicultural research conference. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.

Author Abstract. Bald cypress (*Taxodium distichum* (L.) Rich.) seed was collected in 1992 from nine different estuarine areas in the southeastern United States (Winyah Bay, SC, Ogeechee and Altmaga Rivers in GA, Loftin Creek, FL, Ochlockonee River, FL, Mobile Bay, AL, West Pearl River, LA, Bayou LaBranche, LA, and Lake Chicot, LA.) and planted in Clemson University's Hobcaw nursery in the spring of 1993. Germination ranged from a low of 16 percent for seed from FL to 58 percent for seed from NC. Seedlings were grown in the nursery for two growing seasons, lifted, and planted in an area killed by saltwater introduced by Hurricane Hugo's (1989) storm surge. Half of the seedlings were protected with tree shelters. Seedlings averaged 122 cm tall upon planting. Survival after 6 years was 99 percent. Height growth of seedlings in tree shelters was significantly higher than those not in tree shelters for each year except during year 3. Among the seed sources, seedlings from the Loftin Creek, FL source have shown greatest growth, with and without protection, for all growing seasons except the first year. After 6 years, average height of non-protected seedlings was 81 cm. Tree shelters increase early growth of seedlings, but once they emerged from the tree-shelter, growth differences between shelter and no-shelter treatments decreased and seems to be more related to the degree of deer herbivory experienced by unprotected seedlings.

Keeland, B. D. and W. H. Conner. 1999. Natural regeneration and growth of *Taxodium distichum* (L.) Rich. in Lake Chicot, Louisana after 44 years of flooding. *Wetlands* 19:149-155.

Author Abstract. Lake Chicot, in south central Louisiana, USA, was created in 1943 by the impoundment of Chicot Bayou. Extensive establishment of woody seedlings occurred in the lake during a 1.5 year period, including the growing seasons of both 1986 and 1987, when the reservoir was drained for repair work on the dam. Study plots were established in September 1986 to document woody vegetation establishment and to provide a baseline by which to monitor survival and growth after flooding resumed. *Taxodium distichum* seedlings were the dominant species after one growing season, with a maximum density of 50 seedlings/m2, an average of about 2/m2, and an average height of 75 cm. The lake was reflooded at the end of 1987, bringing water depths at the study plots up to about 1.4 m. Temporary drawdowns were again conducted during the fall of 1992 and

1996. In December 1992, the site was revisited, new plots established, and saplings counted and measured. There was an average of 2.1 *T. distichum* stems/m^2, and the average height was 315 cm. After the 1996 growing season, there was still an average of about 1.9 stems/m^2, and the average height had increased to 476 cm. Preservation of *T. distichum* forests in relatively shallow but continuously flooded areas such as Lake Chicot may be a simple matter of draining the lake after a good seed crop and maintaining the drawdown long enough for the seedlings to grow taller than the typical growing season water level. In the case of Lake Chicot, this period was two growing seasons. This action will mimic natural, drought-related drawdowns of the lake and will allow the seedlings to establish themselves and grow tall enough to survive normal lake water levels.

Kolka, R. K., E. A. Nelson and C. C. Trettin. 2000. Conceptual assessment framework for forested wetland restoration: the Pen Branch experience. *Ecological Engineering* 15:S17-S21.

Author Abstract. Development of an assessment framework and associated indicators that can be used to evaluate the effectiveness of a wetland restoration is critical to demonstrating the sustainability of restored sites. Current wetland restoration assessment techniques such as the index of biotic integrity (IBI) or the hydrogeomorphic method (HGM) generally focus on either the biotic or abiotic components of wetlands. In addition, current methods generally rely on qualitative or semi-quantitative rankings in the assessment. We propose a quantitative, ecosystem level assessment method similar to that developed by the US EPA's Wetland Research Program (WRP approach) that includes both biotic and abiotic metrics. Similar to the IBI and HGM approaches, biotic and abiotic parameters are compared to those of reference communities, however, the proposed comparisons are quantitative. In developing the assessment method, bottomland reference systems at various stages of succession were compared to a recently restored site in South Carolina (Pen Branch). Studies involving hydrology, soil organic matter and nutrient dynamics, vegetation communities, seedling establishment and competition, and avian, small mammal, herpetofauna, fish and macroinvertebrate communities were implemented. In this paper, we discuss the conceptual framework in which we developed our assessment technique.

Middleton, B. 2000. Hydrochory, seed banks, and regeneration dynamics along the landscape boundaries of a forested wetland. *Plant Ecology* 146:169-184.

Author Abstract. Following the environmental sieve concept, the setting in which the recruitment of *Taxodium distichum* occurs in, becomes increasingly restrictive from the seed to seedling stage in an impounded forested wetland. Although a wide elevational band of dispersing seed moves across the boundary of a swamp-field in the water sheet, the zone of germination is relegated to that portion of the forested wetland that draws down during the growing season. Seedling recruitment is further restricted to the uppermost zone of the winter water sheet. These patterns are likely applicable to other species of dominant swamp species, e.g., *Cephalanthus occidentalis* crossed the boundary of a forested wetland and abandonded field in winter flooding (November–December and November–March, respectively) in Buttonland Swamp. The elevation of the boundary was 101.3 m NGVD. While the seeds of at least 40 swamp species were dispersed across the boundary, few viable seeds were dispersed after the winter season. Kriged maps showed seeds of *T. distichum* and *C. occidentalis* dispersed in patches in the water depending on the position of the water sheet. Most species of both water-and gravity-dispersed species had a localized pattern of seed distribution (either spherical or exponential) and this indicated that seeds may not be dispersed for great distances in the swamp. Water-dispersed *T. distichum* and *C. occidentalis* had larger dispersal ranges (A_0 = 225 and 195 m, respectively) than *Bidens frondosa* and *B. discoidea* (A_0 = 14 and 16 m, respectively). Seed dispersal varied with season depending on the availability of seeds. In Buttonland Swamp, viable seeds typically were dispersed for *T. distichum* in November–June, and for *C. occidentalis* in November-July. Low water occurred in August 1993 and high in February 1994 (99.8 and 101.6 m NGVD, respectively). The seed banks along the landscape boundary varied in species composition according to elevation (r_2 0.996). While the similarity of species richness between water-dispersed seeds and the seed bank at elevations that flooded (during June 1993 through May 1995) was high (10–17%), it was low between water-dispersed seeds and the seed bank at elevations that did not flood (5%). *T. distichum* seeds had a short germination window in that seeds germinated within a year following their production in zones that were flooded in the winter followed by drawdown during the next growing season. After 1 year, less than 5% of the *T. distichum* seeds remained viable on the surface of the soil. Germination of *T. distichum* was confined to specific elevations (above 99.3 but below 101.6 m NGVD) during this study with 4.1% of the seedlings surviving for more than 2 years at a mean of 101.4 m NGVD. All seedlings below this elevation died. To maximize natural regeneration along the boundaries of swamps in abandoned farm fields targeted for restoration, this study suggests a flood pulse regime consisting of high water in the winter to maximize dispersal of live seeds followed by low water in the summer to facilitate seed germination and seedling recruitment. Hydrologic restoration could assist in the natural recovery of damaged wetlands if a seed source exists nearby.

Myers, R. S., G. P. Shaffer and D. W. Llewellyn. 1995. Bald cypress (*Taxodium distichum*) restoration in southeast Louisiana: the relative effects of herbivory, flooding, competition, and macronutrients. *Wetlands* 15:141-148.

Author Abstract. In the early 1900s, old-growth bald cypress (*Taxodium distichum*) was completely logged out of what is now the Manchac Wildlife Management Area, located in the Lake Pontchartrain Basin, Louisiana. Natural regeneration of the swamp did not occur; the area is currently dominated by bulltongue (*Sagittaria lancifolia*) marsh. This study was conducted to isolate the major factors prohibiting cypress restoration. Specifically, four hundred bald cypress seedlings were planted in a three-way factoral treatment arrangement that included nutrient augmentation (fertilized vs. unfertilized), management of entangling vegetation (managed vs. unmanaged), herbivore protection (Tubex tree shelters, PVC sleeves, Tanglefoot), and elevation (included as a covariable). Highly significant differences in diameter growth were found for all main effects. For the herbivore protection treatment, relatively inexpensive PVC sleeves were as effective as Tubex Tree Shelters; unprotected trees experienced 100% mortality. Seedlings that received Osmocote 18-6-12 fertilizer showed nearly a two-fold increase in diameter than unmanaged seedlings. However, seedlings that were unmanaged grew nearly two times greater in height than managed seedlings. This study indicates that biotic factors are primarily responsible for the lack of cypress regeneration in southeastern Louisiana, not the prevalent, but largely untested, hypothesis of saltwater intrusion. Moreover, it is likely that, with a combination of management techniques, it is possible to restore swamp habitat in this area. Though labor intensive in the short run (i.e., first few years), once established, these trees may survive for hundreds of years.

Nelson, E. A., N. C. Dulohery, R. K. Kolka and W. H. McKee, Jr. 2000. Operational restoration of the Pen Branch bottomland hardwood and swamp wetlands — the research setting. *Ecological Engineering* 15:S23–S33.

The Savannah River swamp is a 3020 ha forested wetland within the floodplain of the Savannah River. It is located on the Department of Energy's Savannah River site (SRS) near Aiken, South Carolina. The swamp once consisted of stands of approximately 50% bald cypress–water tupelo (*Taxodium distichum–Nyssa aquatica*), 40% mixed bottomland hardwood, and 10% shrub, marsh, and open water. The site was severely degraded by historic high temperature discharges from a nuclear reactor and a coal-fired power plant. These discharges have since ended and the site is in various stages of regeneration augmented with plantings. Plantings were monitored in the short-term using seedling density, abundance, and size. Results showed the most plantings were successful and the sites are on their way toward becoming mature forested wetlands.

Paller, M. H., M. J. M. Reichert, J. M. Dean and J. C. Seigle. 2000. Use of fish community data to evaluate restoration success of a riparian stream. *Ecological Engineering* 15: S171–S187.

Author Abstract. From 1985 to 1988, stream and riparian habitats in Pen Branch and Four Mile branch began recovering from deforestation caused by the previous release of hot water from nuclear reactors. The Pen Branch corridor was replanted with wetland trees in 1995 to expedite recovery and restore the Pen branch ecosystem. Pen branch, Four Mile branch, and two relatively undisturbed streams were electrofished in 1995:1996 to determine how fish assemblages differed between the previously disturbed and undisturbed streams and whether such difference could be used to measure restoration success in Pen branch. Fish assemblages were analyzed using nonparametric multivariate statistical methods and the index of biotic integrity (IBI), a bioassessment method based on measurement of ecologically sensitive characteristics of fish assemblages. Many aspects of fish assemblage structure (e.g. species richness, disease incidence, taxonomic composition at the family level) did not differ between disturbed and undisturbed streams; however, disturbed streams had higher densities of a number of species. These differences were successfully detected with the multivariate statistical methods; whereas, the IBI did not differ between most recovering and undisturbed sampling sites. Because fish assemblages are strongly influenced by instream habitat, and because instream habitat is strongly influenced by the riparian zone, fish assemblages can be used to measure restoration success. Nonparametric ordination methods may provide the most sensitive measure of progress towards restoration goals, although the IBI can be used during early stages of recovery to indicate when certain ecologically important aspects of structure and function in recovering streams have reached levels typical of undisturbed streams.

Sklar, F. H. 1985. Seasonality and community structure of the backswamp invertebrates in a Louisiana cypress-tupelo wetland. *Wetlands* 5:69-86.

Author Abstract. Core and floating "scoop" samples were taken monthly for two years in a Louisiana hardwood swamp for the characterization and identification of the benthic habitats far removed from waterways and bayous. Most backswamp macroinvertebrates have physiological and behavioral adaptations to withstand both desiccation and anoxia. The most ubiquitous taxa included amphipods, oligochaetes, diptera larvae, isopods, and fingernail clams. The biomass and density of backswamp benthic communities were some of the highest recorded for any "unpolluted" freshwater or estuarine soft bottom habitat. The average numbers of invertebrates living in the sediments (5,690/m^2) was significantly less than the numbers living in the floating mats of *Lemna* spp. (10,508/m^2). The biomass distribution was just the opposite. There was a significantly greater invertebrate biomass in the sediments (8.4 g AFDW/m^2) than in the floating vegetation (4.2 g AFDW/m^2). Diversity (H) was relatively low, averaging only 1.8 in the floating vegetation and 1.4 in the sediments. Seasonal changes in density, biomass, and diversity were bimodal with peaks occurring during spring and fall, and were a function of the seasonality of wetland flooding and temperature.

Souther, R. F. and G. P. Schaffer. 2000. The effects of **s**ubmergence and light on two age classes of bald cypress (*Taxodium distichum* (L.) Richard) seedlings. *Wetlands* 20:697-706.

In the early 1900s, baldcypress swamps were harvested *en masse* in coastal Louisiana, USA. In many areas, natural regeneration did not occur; instead, these areas converted to marsh or open water. One of the factors that may have been responsible for the lack of regeneration was shading of newly germinated seedlings by herbaceous vegetation. Alternatively, prolonged flooding or complete submergence may have suppressed germination or growth rates of young seedlings and even caused mortality. This study investigated the effects of complete submergence and variable light regime on two age classes of baldcypress seedlings. Newly germinated seedlings (under two weeks of age) subjected to complete submergence began to show clear signs of stress after approximately one month and substantial mortality following 45 days of submergence. In contrast, one-year-old seedlings submerged for as much as five months experienced up to 75% survival. In a four-way factorial experiment, two age classes of baldcypress seedlings were subjected to five light transmissions (100%, 80%, 50%, 30%, 20%), five flood durations (0 days, 14 days, 25 days, 35 days, 45 days), and two nutrient regimes (fertilized vs. not fertilized). At 100% light transmission, the newly germinated seedlings suffered complete mortality after 35 days of submergence, whereas the one-year-old seedlings were largely unaffected by prolonged flooding or light regime. Fertilized one-year-old seedlings that were submerged for an entire month had considerably greater growth in height and diameter than seedlings grown under mesic conditions without fertilizer. This is particularly important in coastal Louisiana because several re-introductions (i.e., diversions) of Mississippi River water into declining swamps are planned or underway, and these diversions will periodically increase nutrient and flood levels.

Weller, J. D. 1995. Restoration of a south Florida forested wetland. *Ecological Engineering* 5:143-151.

Author Abstract. A rewatering project conducted at Fern Forest Nature Center in Pompano Beach, Florida, USA, has rejuvenated and restored an area of south Florida forested wetland to its pre-drainage condition in three years. Through the removal of undesirable vegetation such as Brazilian pepper (*Schinus terebinthifolius*) and the re-introduction of water, the following have been accomplished: increase in surface water duration time; elevation of groundwater by 70 to 84 cm; rejuvenation of a depressed forested wetland, a deciduous hardwood swamp, and an emergent wetland; and enhancement of a wading bird habitat, a cypress dome, and 3.2 km of shallow stream bed (1.5 m deep or less). These accomplishments have assured the survival of the park's 34 rare and endangered fern species and encouraged the natural return of 16 wetland bird species, 8 fish species, 6 species of turtles, 6 species of snakes, 5 snails, 2 frog species, and even the American alligator (*Alligator mississippiensis*).

This project demonstrates that when certain hydrological criteria are met and vegetation composition and animal resurgence demonstrated, restoration of valuable ecosystem functions can be inferred and may be grounds for declaring a project successful in as short a time as 5 years. This paper focuses on vegetation composition and animal resurgence and touches on the complex task of evaluating ecosystem functions.

Wharton, C. H., W. M. Kitchens, E. C. Pendleton and T. W. Snipe. 1982. The ecology of bottomland hardwood swamps of the Southeast: a community profile, 133 pp. FWS/OBS-81/37, U.S. Fish and Wildlife Service, Biological Services Program, Washington, DC.

Author Abstract. This report is one in a series of community profiles whose objective is to synthesize extant literature for specific wetland habitats into definitive, yet handy ecological references. To the extent possible, the geographic scope of this profile is focused on bottomland hardwood swamps occupying the riverine floodplains of the Southeast whose drainage originates in the Appalachian Mountains/ Piedmont or Coastal Plain. References are occasionally made to studies outside this area, primarily for comparative purposes or to highlight important points. The sections detailing the plant associations and soils in the study area are derived from field investigations conducted specifically for this project.

In order to explain the complexities of the ecological relationships that are operating in these bottomland hardwood ecosystems, this report details not only the biology of floodplains but also the geomorphology and hydrological components and processes that are operating on various scales. These factors, in concert with the biota, dictate both the ecological structure and function of the bottomland hardwood ecosystems. We have utilized the ecological zone concept developed by the National Wetlands Technical Council to organize and explain the structural complexity of the flora and fauna.

The information in this profile will be useful to environmental managers and planners, wetland ecologists, students, and interested laymen concerned with the fate and the ecological nature and value of these ecosystems. The format, style, and level of presentation should make this report adaptable to a variety of uses, ranging from preparation of environmental assessment reports to supplementary or topical reading material for college wetland ecology courses. The descriptive materials detailing the floristics of these swamps have been cross-referenced to specific site locations and give the report the utility of a field guide handbook for the interested reader.

APPENDIX II: DEEPWATER SWAMPS
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.

Allen, J. A., B. D. Keeland and J. A. Stanturf. 2001. A guide to bottomland hardwood restoration, 132 pp. Information and Technology Report USGS/BRD/ITR-2000-0011 General Technical Report SRS-40, U.S. Geological Survey, Biological Resources Division U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC. http://www.srs.fs.fed.us/pubs/viewpub.jsp?index=2813

This guidebook is an essential resource to anyone planning to restore an area of bottomland forest. It briefly introduces the ecology of bottomland forests, their extent, the degree of degradation, and need for restoration. It then guides readers through the entire restoration process from general planning issues such as where to obtain planted material through to post-restoration monitoring and management of existing forests. It instructs readers on how to evaluate sites for restoration, which factors biotic and abiotic need to be taken into consideration before the proper species can be selected and planting begin. It covers: site preparation, seed collection, handling, and storage, and also has chapters on planting seeds vs. seedlings, including the tools and methods used in each. The guidebook also touches on other methods of restoration other than direct planting. It covers the selection and planting of not only canopy species but understory plants as well, something that is otherwise not well documented in the literature. The guidebook also instructs readers on how to control undesirable species and protect the restoration site from animals, fire, and human impacts. Post-restoration monitoring is also covered in this document, what to measure, how to measure it, and what information it tells you is presented clearly and concisely. Lastly, management and rehabilitation of existing bottomland forests is covered for restoration of sites that haven't been completely denuded of trees. The guidebook also has a series of appendixes that include information on different forest cover types, common and scientific names of plant species common to bottomland forests, a partial list of seed and seedling suppliers, as well as species to site relationships for the Midsouth and Southern Atlantic Coastal Plain to aid restoration practitioners in selecting the proper plant materials for their site conditions.

Dane, J. H. and G. C. Topp. 2002. Methods of Soil Analysis: Part 4-Physical Methods, 1692 pp. Soil Society of America, Madison, WI.

Publisher's Description. Due to the rapid and numerous changes in measurement methods associated with soil physical and mineralogical properties, it was decided not to print a third edition of the highly popular Methods of Soil Analysis. Part 1—Physical and Mineralogical Methods. The decision was made to split the volume into two parts. The part containing soil physical measurements is now published as Methods of Soil Analysis: Part 4—Physical Methods. The approach in Part 4 differs substantially from that in Part 1 in that the new book uses a more hierarchical approach. As such it is divided into eight chapters, with each chapter covering a major aspect of soil physical properties. Following the table of contents, the reader can than refine the search until the specific topic or measurement of interest is indicated. Compared with Part 1, new methods have been added and some of the older methods have been updated or deleted.

de Vries, P. G. 1986. Sampling Theory for Forest Inventory: A Teach-Yourself Course. Springer-Verlag, Berlin.

de Vries has attempted to address many of the shortcomings of other statistical sampling texts by simplifying the process of learning advanced statistics and putting them to practical use in forestry sampling. His book covers a variety of sampling techniques including: random sampling, cluster and double sampling, use of points and circular plots, line intersect and list sampling, and a variety of others. de Vries has tried, where ever possible, to provide examples and take readers through the step by step process of how statistical analyses have been developed in order to gain a more thorough understanding of the theory and proper application of different procedures. Several appendices are also included that review many introductory statistical concepts, however, the text is not intended for the uninitiated. An existing background in calculus and introductory statistics is encouraged before using this resource. Upon completion of his book and a short period of time for the new material to sink in, de Vries confidently states that readers will 'experience the satisfaction of mastering some sampling methods widely used in forest inventory, that he will be able to read critically more professional literature than before, and that he will possess a sound basis on which to expand his knowledge of sampling.'

Hoover, J. J., K. J. Killgore and G. L. Young. 2000. Quantifying habitat benefits of restored backwaters, 10 pp. EMRRP Technical Notes Collection ERDC TN-EMRRP-EI-01, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/emrrp

Backwater areas act as important nursery and spawning habitats for fish. This technical report describes methods of quantifying and enhancing fish species that use backwater areas, areas subject to dewatering during low river flows. Brief lists or descriptions of fish species that use backwater habitats and methods to sample young-of-the-year populations are presented. The use of plexiglas light-traps to efficiently sample young-of-year is explained for a variety of circumstances. The development of Habitat Suitability Indexes (HSI) a statistical method useful in determining which species use particular habitats and therefore might benefit from a restoration is presented in greater detail. Example restoration projects where the HIS method was used (Lake Whittington, a Mississippi River oxbow lake and Lake George, a Mississippi delta backwater) are also provided. Contact information of the authors is also included.

Killgore, K. J. and J. J. Hoover. 1992. A guild for monitoring and evaluating fish communities in bottomland hardwood wetlands, 7 pp. WRP Technical Note WRP TN FW-EV-2.2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

This technical note is a summary of the adult and larval fish communities of the Rex Hancock/Black Swamp Wildlife Management Area, Cache River system, Arkansas. Fish communities are classified according to habitat preference and reproductive strategy. Brief descriptions of three habitat categories are given: lentic-oxbow lakes, lentic-floodplain ponds, and lotic-channels. Four reproductive modes are also defined. Tables listing which bottomland forest fish species use which habitats at varying life stages is also presented. By knowing which communities of fish are capable of using each habitat, the classifications provided can be used to select and evaluate fish species for monitoring studies in southern bottomland forest wetlands.

Klute, A. 1986. Methods of Soil Analysis: Part 1-Physical and Mineralogical Methods, 1188 pp. Soil Science Society of America, Madison, WI.

Publisher's Description. Great strides have been made in the conception of physical and mineralogical characteristics of soils and how they relate to each other and to chemical properties. The methods of analyses included here provide a uniform set of procedures that can be used by the majority of soil scientists and engineers.

Kolka, R. K., C. C. Trettin and E. A. Nelson. 1998. Development of an assessment framework for restored forested wetlands. Proceedings of the Conference on Ecosystems Restoration & Creation. Tampa, Florida. May 14-15. http://www.srs.fs.fed.us/pubs/viewpub.jsp?index=1541

Author Abstract. Development of an assessment framework and associated indicators that can be used to evaluate the effectiveness of a wetland restoration is critical to demonstrating the sustainability of restored sites. An interdisciplinary approach was developed to assess how succession is proceeding on a restored bottomland site in South Carolina relative to an undisturbed reference and a naturally agrading site. Comparisons of populations and processes across successional gradients and treatments allows the effect of disturbance and restoration activities to be evaluated. Studies involving vegetation communities, organic matter and nutrient dynamics, seedling establishment and competition, and avian, herpetofauna, fish and macroinvertebrate communities have been implemented. Seedling establishment and competition studies suggest nonchemical and minimal mechanical site preparation techniques, tree shelters and root pruning should be considered as alternatives depending on restoration objectives and site conditions. The restored site contains many of the functional capabilities of a wetland with respect to fauna, however certain species tend to dominate populations in Pen Branch when compared to late successional wetlands. Fish populations show higher population densities in the restored site as compared to the reference site. A conceptual framework for integrating biotic and abiotic processes into a restoration response model will be used to synthesize ecosystem response and to identify indicators for restoration assessments.

McCobb, T. D. and P. K. Weiskel. 2002. Long-term hydrologic monitoring protocol for coastal ecosystems, 93 pp. Protocol, USGS Patuxent Wildlife Research Center, Coastal Research Field Station, University of Rhode Island, Narragnasett, RI. http://science.nature.nps.gov/im/monitor/protocols/caco_hydrologic.pdf

Author Abstract. Long-term monitoring of hydrologic change using a standard data-collection protocol is essential for the effective management of terrestrial, aquatic, and estuarine ecosystems in the coastal park environment.

This study develops a consistent protocol for monitoring changes in ground-water levels, pond levels, and stream discharge using methods and techniques established by the U.S. Geological Survey for use in the Long-term Coastal Monitoring Program at the Cape Cod National Seashore. The protocol establishes a hydrologic sampling network in the four ground-water-flow cells in the Seashore area, and provides justification for the measurement methods selected and for the spatial and temporal sampling frequency. Data collected during the first year of monitoring are included in this report; common hydrologic analyses such as hydrographs for ground-water and pond levels, and rating curves between stream stage and discharge for streamflow, are presented for selected sites. Long-term hydrologic monitoring at the Seashore will aid in interpretation of the findings of other monitoring programs. Developing and initiating long-term hydrologic monitoring programs will provide a better understanding of effects of natural and human-induced change at both the local and global scales on coastal water resources in park units.

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 equipment and 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.

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.

Ryan, T. J., T. Philippi, Y. A. Leiden, M. E. Dorcas, T. B. Wigley and J. W. Gibbons. 2001. Monitoring herpetofauna in a managed forest landscape: effects of habitat types and census techniques. *Forest Ecology and Management* 5739:1-8.

Author Abstract. We surveyed the herpetofaunal (amphibian and reptile) communities inhabiting five types of habitat on a managed landscape. We conducted monthly surveys during 1997 in four replicate plots of each habitat type using several different methods of collection. Communities of the two wetland habitats (bottomland wetlands and isolated upland wetlands) were clearly dissimilar from the three terrestrial communities (recent clearcut, pine plantation, and mixed pine–hardwood forest). Among the three terrestrial habitats, the total herpetofaunal communities were dissimilar ($P<0.10$), although neither faunal constituent group alone (amphibians and squamate reptiles) varied significantly with regard to habitat. Three survey techniques used in the terrestrial habitats were not equally effective in that they resulted in the collection of different subsets of the total herpetofauna. The drift fence technique revealed the presence of more species and individuals in every habitat and was the only one to detect species dissimilarity among habitats. Nonetheless, coverboards contributed to measures of abundance and revealed species not detected by other techniques. We suggest that a combination of census techniques be used when surveying and monitoring herpetofaunal communities in order to maximize the detection of species.

Shiver, B. D. and B. E. Borders. 1996. Sampling Techniques for Forest Resource Inventory. John Wiley and Sons, Inc., New York, NY.

Author Preface. The purpose for writing this book was to create a forest inventory textbook that clearly explains the sampling methods associated with the inventory of forest resources. There are several books available which do a good job of explaining the theory of the various sampling techniques used in forest inventory. However, the transition from theory to practice is not easily made without extensive course work in theoretical statistics and mathematics. This book provides thorough coverage of forest inventory topics for the practitioner rather than the theoretician and should be understandable to undergraduate forest resources students and professionals who must inventory forest resources.

Examples are used extensively throughout the book to illustrate various estimators and to demonstrate different uses for sampling methods. Problems are also included at the end of each chapter to help instructors and students.

Some of the topics discussed, such as point sampling and 3P sampling, were developed specifically for timber inventory. Other topics, such as mark-recapture methods were developed for inventory of mobile wildlife populations. Many of the topics, however, can be utilized to inventory virtually any of the resources in a forest (understory vegetation, soils, water, etc.)

As the book has developed over the last several years, we find that we are using it as a reference as well as a textbook. Some of the topics such as double sampling with point sampling and sampling with partial replacement have been available only in scattered journal articles or in more theoretically oriented textbooks. Inventory is a job which most forest resource managers will use repeatedly throughout their careers. This book should allow them to work confidently in forest inventory regardless of the specific inventory problem.

Sparks, D. L., A. L. Page, P. A. Helmke, R. H.Loeppert, P. N. Soltanpour, M. A. Tabatabai, C. T. Johnson and M. E. Sumner.

1996. Methods of Soil Analysis: Part 3-Chemical Methods. 1358 pp. Soil Science Society of America, Madison, WI.

Publisher's Description. This volume covers newer methods for characterizing soil chemical properties as well as several methods for characterizing soil chemical processes. This book will serve as the primary reference on analytical methods. Updated chapters are included on the principles of various instrumental methods and their applications to soil analysis. New chapters are included on Fourier transform infrared, Raman, electron spin resonance, x-ray photoelectron, and x-ray absorption fine structure spectroscopies.

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, 82 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.

Uranowski, C., Z. Lin, M. DelCharco, C. Huegel, J. Garcia, I. Bartsch, M. S. Flannery, S. J. Miller, J. Bacheler and W. Ainslie. 2003. A regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of low-gradient, blackwater riverine wetlands in peninsular Florida, 590 pp. ERDC/EL TR-03-3, U.S. Army Engineer Research and Development Center, Vicksburg, MS. http://www.wes.army.mil/el/wetlands/wlpubs.html

This manual was prepared for use in assessing the functional capacity of blackwater, forested wetlands on the western coast of Florida using the Hydrogeomorphic (HGM) method. It provides a brief overview of the general HGM method for classification and assessment and explains how the HGM process was implemented for this particular type of forested wetland system and why. Although the equations provided for assessing functions were calibrated using data from western Florida, they can be adapted and re-calibrated using data from other areas. Methods for determining a blackwater forest's ability to perform the functions of temporary surface water storage, maintenance of characteristic subsurface hydrology, cycling of nutrient, removal and sequester of elements and compounds, retention of particles, export of organic matter, maintenance of plant communities, and provision of wildlife habitat are provided in detail. References to additional literature as needed are also provided.

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. 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.

Weaver, R. W., S. Angle, P. Bottomley, D. Bezdicek, S. Smith, A. Tabatabai and A. Wollum. 1994. Methods of Soil Analysis: Part 2-Microbiological and Biochemical Properties. 1121 pp. Soil Science Society of America, Madison, WI.

Publisher's Description. Laboratories outside of soil science will find it advantageous to use the methods contained in this book. They will be particularly relevant and useful to laboratories with interest in environmental microbiology or bioremediation. Analytical methods are essential to progress in science and the methods presented in this book are recognized as being among the best currently available.

APPENDIX III: LIST OF DEEPWATER SWAMP 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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