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.

References

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States, 104 pp. FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, D.C.

Dahl, T. E. 1990. Wetland loss in the United States 1780's to 1980's, United States Department of Interior, Fish and Wildlife Service, Washington, D.C.

ERA. 2000. Estuary Restoration Act of 2000: Report (to accompany H.R. 1775) (including cost estimate of the Congressional Budget Office). Corp Author(s): United States. Congress. House. Committee on Transportation and Infrastructure. U.S. G.P.O., Washington, D.C.

Federal Register. 2002. Final estuary habitat restoration strategy prepared by the estuary habitat restoration council. December 3. 71942-71949.

Galatowitsch, S. M., D. C. Whited and J. R. Tester. 1998-1999. Development of community metrics to evaluate recovery of Minnesota wetlands. *Journal of Aquatic Ecosystem Stress and Recovery* 6:217-234.

Keddy, P. A. 2000. Wetland Ecology: Principles and Conservation. Cambridge University Press, Cambridge, United Kingdom.

Meeker, S., A. Reid, J. Schloss and A. Hayden. 1996. Great Bay Watch: A Citizen Water Monitoring Programpp. UNMP-AR-SG96-7, University of New Hampshire/University of Maine Sea Grant College Program.

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands. Third ed. Van Nostrand Reinhold, New York, NY.

NOAA, Environmental Protection Agency, Army Corps of Engineers, United States Fish and Wildlife Service and Natural Resources Conservation Service. 2002. An Introduction and User's Guide to Wetland Restoration, Creation, and Enhancement (pre-print copy), Silver Spring, MD.

Washington, H., J. Malloy, R. Lonie, D. Love, J. Dumbrell, P. Bennett and S. Baldwin. 2000. Aspects of Catchment Health: A Community Environmental Assessment and Monitoring Manual. Hawkesbury-Nepean Catchment Management Trust, Windsor, Australia.

CHAPTER 9: RESTORATION MONITORING OF SUBMERGED AQUATIC VEGETATION

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INTRODUCTION

Submerged aquatic vegetation (SAV - referred to as Aquatic Bed in Cowardin et al. 1979) is a habitat created by vascular[4] plants that grow below the surface of the water. The plants are usually completely inundated throughout the growing season. Some SAV habitats may also contain a mix of open water and rooted, floating-leaved, and short-emergent vegetation. The distribution of SAV in a particular area is dependent on water depth, turbidity, and wave energy, the presence of grazers, and characteristics of the sediment. Salinity can also be important in tidal areas. Plant species diversity is greater in freshwater SAV habitats than marine habitats. Approximately 500-700 plant species in 50 genera (Sculthorpe 1967) have been cataloged for freshwater areas compared to just 50 species in 12 genera for marine settings (den Hartog, 1970 cited in Stevenson 1988).

SAV (freshwater, brackish, and marine) can greatly alter the physical, chemical, and biological nature of the water column that supports them. Dense stands of SAV slow water velocity, reducing turbidity and increasing sedimentation and nutrient cycling. Through the processes of photosynthesis and respiration of SAV themselves, their attached epiphytes, and the respiration of the animals they attract, SAV beds can have a tremendous influence on the pH, carbon dioxide (CO_2), and dissolved oxygen (DO) concentration of the water column (Wetzel 1983). Even in tidal areas, such as the Potomac River, that are subject to strong physical mixing forces, SAV can strongly influence DO, pH, and temperature differences within the water column of the bed at times of high biomass production (Dale and Gillespie 1977; Carter et al. 1988). The presence of SAV also increases the overall productivity of the water column, compared to unvegetated areas, as SAV brings nutrients up from the sediment into the water column where they can eventually be used by phytoplankton[5]. SAV are often colonized by epiphytes (algae and bacteria) that compete with their host plant for light but may also provide a better food source for herbivores than the host macrophytes[6]. SAV also helps to increase the overall species diversity of the area by creating low energy microhabitats in what might otherwise be a higher energy environment (Carpenter and Lodge 1986 and literature cited therein).

The structural and functional characteristics of SAV presented in this chapter have been compiled using literature from studies in marine, brackish, and freshwater habitats. While the particular plant and animal species that inhabit SAV habitats around the United States and its protectorates are very different, many of the core structural and functional characteristics and the parameters and techniques used to monitor them are quite similar. Light availability, turbidity, water velocity, wave energy, sediment grain size, basin topography, water source, hydroperiod, and nutrient chemistry make up the main structural

[1] 2205 Commonwealth Boulevard, Ann Arbor, MI 48105.
[2] 1305 East West Highway, Silver Spring, MD 20910.
[3] 101 Pivers Island Road, Beaufort, NC 28516.
[4] Some non-vascular plants such as the algae muskgrass (*Chara* spp.) are also often considered SAV.
[5] Algae suspended in the water column.
[6] Literally means 'large plants'. This term is often used as a general term for SAV since it incorporates both vascular and non-vascular plants visible with the naked eye.

characteristics of SAV beds and have similar influences on plant communities regardless of salinity[7]. In our review of the literature, we found occasional gaps in the literature for certain habitat types. By combining the literature we are able to provide the reader with a more comprehensive picture of all the characteristics that may be relevant in a restoration monitoring effort. As used in this chapter, the terms 'SAV' or 'macrophytes' refer to any submerged aquatic vegetation in marine, brackish, or freshwater settings. When information applies to a specific type of SAV and is *not* generally applicable to other forms, specific terms such as 'seagrass' or 'freshwater SAV' will be used. In addition, the term 'seagrasses' is also used to refer to those species found in higher salinities. The term 'freshwater SAV' includes those species that are generally found in freshwater (salinity < 0.5 ppt) as well as brackish areas (salinity 0.5 to 18.0 ppt), as many species can tolerate a wide range in salinity.

When preparing a restoration project and associated monitoring program, practitioners are encouraged to begin monitoring well in advance of implementing a restoration effort (i.e., collect baseline information). Pre-restoration monitoring can be used to select sites most conducive to successful restoration, determine which species to plant, what depths to plant at, which planting methods are most appropriate, whether or not exclosures to limit herbivory are needed, and what is the best time of year to plant. Post-restoration monitoring allows practitioners to document habitat functions and gage progress toward project goals. Without one or two years (or sometimes more) of pre-restoration data on water quality and the locations and abundance of any SAV already growing in or near the restoration site, practitioners cannot accurately evaluate post-implementation project performance.

ORGANIZATION OF INFORMATION

Following the rest of the Introduction, the primary structural characteristics of SAV relevant to restoration monitoring are presented. These characteristics will determine whether or not SAV is able to grow in a particular area or not and how well. Structural characteristics will often be the first ones monitored during a restoration project. Once the proper set of structural characteristics is in place and SAV are growing, functional characteristics (covered later in the chapter) may be added to the monitoring program. At the end of the chapter, readers will find two matrices that will help connect these structural and functional characteristics to the actual parameters that can be used to monitor them. Wherever possible, parameters from this list have been used in the text to help explain how they are used and any potential problems with using them. Following the discussion of each characteristic, sampling suggestions or tips directing practitioners to addition resources or examples are provided. When selecting methods and equipment for a monitoring project, careful consideration of the project goals and data required to assess them needs to take place before any equipment is purchased. Local or regional experts can assist in this process and should be consulted as to the precise method and equipment that could or should be used in any given location. An annotated bibliography of restoration-related SAV literature and a review of technical methods manuals are provided in Appendices I and II respectively to direct practitioners to more detailed information as needed.

HUMAN IMPACTS TO SAV HABITATS

Various human activities impact the survival and health of SAV populations and their ecological communities. Examples of impacts include:

[7] Salinity (in tidal areas) also helps determine which particular species can grow in a particular area and affects many of the functional characteristics common to SAV habitats as well. Unless extremely high levels are reached, however, salinity does not determine whether or not submerged aquatic vegetation can grow in an area.

- Heavy-metals carried in run-off from urban or industrial areas can be absorbed in plant roots and sicken or kill the plants
- Siltation smothers plants and increases turbidity
- Climate change causing erosion by rising sea level, increased storms, and increased ultraviolet irradiance
- Eutrophication increases the growth of algae that competes with SAV
- Mechanical damage from fishing, anchoring, and dredging as part of port or marina construction and maintenance directly removes SAV and increases turbidity, starving the plants of light
- Oil spills (particularly seagrasses), and
- Salinity levels altered due to development and associated changes in hydrology leading to changes in species composition or even death if levels get too high (Hervey Bay Dugong and Seagrass Monitoring Program 1997; Duarte 2002)

Quantitative assessments of SAV loss are hard to find as area estimates are simply not available or, when present, combine SAV and marsh habitats. A few regional examples, however, can be used to illustrate the severity of losses. In 1938, about 715 ha of SAV habitat were present in the Patuxent Estuary of the Chesapeake Bay. By 1990, SAV beds had either been completely destroyed or only small ephemeral beds were present (Stankelis et al. 2003). As of 2003, the Chesapeake Bay as a whole is estimated to have lost approximately 68% of its seagrass acreage (Blankenship 2004). In coastal wetlands along Lake Erie from the Detroit River to Vermillion, Ohio[8] marsh and associated SAV acreage was reduced from 4,000 km^2 (1,544 mi^2) in 1850 to 150 km^2 (58 mi^2) by the late 1980's (Herdendorf and Krieger 1989).

Recreation and commercial watercraft can also impact SAV beds and even lead to their complete destruction (Sargent et al. 1995). Propellers, anchors, trawl nets, and dredge equipment can damage the leaves, stems and roots of plants when dragged across the beds. Boats passing through an area may disturb sediments and increase turbidity or possibly smothering plants completely (Hervey Bay Dugong and Seagrass Monitoring Program 1997). Slow growing species such as turtle grass (*Thalassia testudinum*) do not recover rapidly after physical disturbance to rhizomes (Zieman 1976). Rhizomes are often disturbed by motorboat propellers, not through physical damage but from resuspension of sediments. The resuspension and removal of fine sediments can reduce light levels and lower pH and Eh[9] of the remaining sediment, thus altering conditions that are suitable for seagrass growth. This type of damage is common in shallow areas, between islands and keys, and other areas where boat traffic is high.

Oil spills can also impact SAV by reducing primary productivity and changing associated animal communities (Thorhaug et al. 1986). Thorhaug et al. (1986) studied various concentrations of oil on several seagrass species that dominate the Atlantic subtropical Greater Caribbean basin. The extent of impact varied between seagrass species. While all species tested showed reduced productivity, shoal grass (*Halodule wrightii*) and Manatee grass (*Syringodium filiforme*) were more vulnerable to oil exposure, while turtle grass was more tolerant. Oil spills can also impact other components of the community that depend upon seagrass habitats. For example, oil spills can negatively affect, and in some cases kill, juvenile fish and fish eggs. Fish moving through seagrass habitats that were exposed to very high concentrations of oils may experience acute toxicity resulting in death. The actual level of impact from oil spills varies depending on the type and amount of oil and the plant or animal species exposed.

[8] Approximately 1/3 of the lake's coastline on the U.S. side.
[9] Redox potential, the ability of the soil to perform certain chemical transformations. Covered in detail in Chapter 10.

Eutrophication, often caused by high nutrient inputs from agricultural and urban runoff, is another threat to SAV habitats (Duarte 2002). High nutrient concentrations affect SAV by causing epiphytes that cover the surface of plants and phytoplankton in the water column to grow rapidly, preventing sunlight from reaching submerged macrophytes. As SAV growth decreases the whole community may ultimately be destroyed. Increases in certain nutrients such as ammonium and nitrite can result in increased mortality, stunting, decreased density, and shoot patchiness for seagrasses such as posidon grass (*Posidonia oceanica)* (Pergent-Martini et al. 1995).

Some of the most common impacts to SAV beds have been the draining and diking of coastal wetlands for agriculture, heavy industry, and recreation (Jude and Pappas 1992; Edsall and Charlton 1997). Such practices can completely alter the hydrology and related functions of these systems. Fish, for example, can be cut off from historic spawning and nursery habitats. In addition, material export and nutrient and sediment dynamics can often become disrupted (Wilcox 1995). Sediments and nutrients that were historically filtered through coastal wetlands are then discharged directly into estuaries and other receiving water bodies. As a result, SAV beds can be smothered and the water quality of receiving bodies decreased (Minc 1998).

Water level management of some of the Great Lakes and shoreline stabilization around coastal development have also had an effect on vegetation communities in coastal wetlands, including SAV beds (Jude and Pappas 1992; Wilcox 1995). Stabilizing water levels to facilitate recreational and commercial shipping concentrates the erosive energy of wind and waves at one particular elevation along the shoreline. Although aquatic vegetation can dissipate erosive energy, prolonged erosion at one elevation can eventually overpower SAV and wash it away, leaving shoreline sediments unprotected. In addition, armoring both marine and Great Lakes coastlines with riprap or sea walls to protect urban or residential development only directs the erosive energy of waves downward (Johnson 1991; Tsai et al. 1998; Davis and Streever 1999), leading to the erosion of plants, less mobile animals, sediments, seed banks, and reducing the possibility of regeneration of aquatic vegetation.

RESTORATION EFFORTS

Various coastal restoration projects have been initiated throughout the United States in an effort to increase the amount of SAV acreage and maintain SAV functions in support of coastal ecosystems (Fonseca 1992; Fonseca et al. 1998). Restoration can be done by taking transplants from healthy habitats, using seeds or other propagules, or by natural recolonization once the habitat has suitable environmental conditions (Fonseca 1992; Granger et al. 2002). Transplanting SAV can be very successful if the habitat requirements of SAV are also met. Examples of successful seagrass projects using eelgrass (*Zostera marina*) include projects by Thayer et al. (1985) and Orth et al. (1999). In both projects, restoration efforts involved transplanting shoots with rhizomes by hand into the sediment. Eelgrass habitats were successfully restored based on significant increases in percent cover and shoot density. In addition, the abundance of animals also increased significantly in these areas. Transplanting individual plants by hand, however, can be time consuming and, unless plants are separately grown for the task, requires that plants come from donor areas. Thus impacting these areas as well. The use of seeds and vegetative propagules in marine and freshwater habitats can also be used to re-introduce SAV to new areas without some of the constraints of using transplants alone (Orth et al. 1994; Lundholm and Simser 1999; Rybicki et al. 2001; Granger et al. 2002).

Restoration practitioners interested in learning more about specific SAV restoration projects can find them at NOAA's Restoration Center database of restoration projects. This online, searchable database can be used to help those interested in planning a restoration project contact others in their area and share information. Individual projects or a description of all restoration efforts in the database can be downloaded from: http://restoration.noaa.gov/. The Environmental Protection Agency also maintains a restoration project database at http://yosemite.epa.gov/water/restorat.nsf/rpd-2a.htm. This database, however, is not exclusively devoted to coastal habitat restoration projects and includes descriptions for restoration projects in inland waterways and terrestrial habitats as well.

STRUCTURAL CHARACTERISTICS OF SUBMERGED AQUATIC VEGEGATION

Habitat restoration is the process of re-establishing a self-sustaining habitat that closely resembles a natural condition in terms of structure and function (Pinit and Bellmer 2000). In order to improve restoration efforts and sustain SAV communities, one must consider site selection, which species to plant, the type of propagules to use, the proper care and handling of plant material, the ecological functions performed by the habitat, and any social and economic values associated with it. When planning a program to monitor a restoration effort, however, one of the first steps is to understand the basic structural characteristics of the system and their relationship to project goals. For SAV, these basic structural characteristics include:

Biological

- Habitat created by plants

Physical

- Light availability
- Turbidity
- Temperature
- Sediment
  - Grain size
  - Nutrient concentration
  - Organic matter
- Topography/Bathymetry
  - Geomorphology
  - Elevation/Slope

Hydrological

- Current velocity
- Water sources
- Wave energy, and
- Tidal regime or hydroperiod

Chemical

- Salinity
- Nutrient concentration

Since the physical, hydrological, chemical characteristics of an area determine where SAV can grow; practitioners must first monitor these structural characteristics to ensure conditions are suitable for SAV restoration. Once plants are established, the focus of monitoring can change to the functions SAV habitats perform such as providing fish habitat and improving water quality. This change in monitoring focus from structural to functional characteristics as the restoration matures, dictates where monitoring will take place. Pre-restoration monitoring, to determine baseline conditions, will often occur in areas where SAV is absent or degraded. Post-restoration monitoring will occur within and above the SAV bed with results compared to associated, unvegetated areas or other reference conditions[10] to show the effects of the restoration. The focus of this section is on the structural characteristics of SAV, examples of parameters that can be used to measure these structural characteristics are also provided. A more complete list of suggested parameters for monitoring the structural characteristics of SAV can be found at the end of this chapter and in abbreviated form in *Volume One*. Sampling methods for suggested parameters can be found using resources in the second appendix of this chapter the *Review of Technical Methods Manuals*.

BIOLOGICAL

Habitat Created by Plants

SAV beds provide important feeding, spawning, and nursery grounds for fish, aquatic invertebrates, and many species of waterfowl (Wilcox and Whillans 1989; Wilcox 1995). The ability of a particular SAV bed to perform these functions depends upon the architecture,

[10] See Chapter 15 for a discussion of methods to selection reference conditions for restoration monitoring programs.

diversity, and density of the plant species present (Orth et al. 1983). A few examples of common, dominant species, the types of habitat created by seagrasses and other SAV, and how those habitats are used by various animal species, are provided here. A more thorough description of habitat-related functions and methods to monitor animal use of SAV habitats is given in the Functional Characteristics section below.

Seagrasses

Seagrasses are very productive vascular plants that provide habitat for many other marine plant and animal species such as epiphytes, crabs, fish, and benthic invertebrates. Although seagrasses are found in a variety of locations throughout the coastal United States, southern Florida with 14,633 km^2 of seagrasses is home to one of the largest beds in the world (Fourqurean 2002). These flowering plants typically grow in soft sediments submerged in shallow waters of estuaries, bays and lagoons. Some species of surfgrass (*Phyllospadix* spp.), however, attach to rocky habitats on the Pacific coast. Seagrass ecosystems also protect coastal shorelines and improve water quality. Many species of seagrass have extremely wide ranges and are found throughout the world. A few examples of seagrass species and their geographic range are given below. This list is only of a few examples of common species and is by no means a complete listing, many other species are also found throughout the coastal areas of the United States and its protectorates (Hemminga and Duarte 2000; Green and Short 2003).

Eelgrass (*Zostera marina)* North Atlantic, Mediterranean Sea, western and eastern Pacific
Shoal grass (*Halodule wrightii)* Caribbean
Turtle grass (*Thalassia testidinum)* Caribbean
Dwarf eelgrass (*Zostera japonica)* temperate west Pacific
Manatee grass (*Syringodium filiforme)* Caribbean
Johnson's seagrass (*Halophila johnsonii)* coastal waters of southeastern Florida
Surfgrass (*Phyllospadix japonicus)* temperate west Pacific

Other plants that may be present in seagrass habitats can include *Caulerpa taxifolia,* an invasive, marine, green algae found in the Mediterranean Sea and off the coast of California. *Caulerpa* spreads by fragmentation as pieces of the plant break off and become established in new areas. This species is able to dominate seagrass habitats by secreting a toxic substance that prevents sea urchins and other large herbivores from feeding on it. As a result, it is able to out-compete native seagrasses to the detriment of fisheries and other marine organisms dependent upon seagrass habitats (Williams and Grosholz 2002).

Freshwater SAV

Submerged species that dominate freshwater areas include the algae muskgrass (*Chara* spp.) and vascular plants such as:

Pondweeds (*Potomageton* spp.)
Waterweed (*Elodea* spp.)
Naiads (*Najas* spp.)
Bladderworts (*Utricularia* spp.), and
Coontails (*Ceratophyllum* spp.) (Cowardin et al. 1979)

Some species such as Sago pondweed (*Stuckenia pectinata*) are also tolerant of brackish conditions up to 20 ppt. Invasive species such as Eurasian water-milfoil (*Myriophyllum spicatum* hereafter milfoil) and *Hydrilla verticillata*[11] (hereafter hydrilla) are also common in many freshwater and brackish systems. These non-native species

[11] Exotic species such as milfoil and hydrilla were once considered nuisances and subject to extensive control measures but are now generally tolerated in the mid-Atlantic region (Orth, 1994). This may have more to do with the inability to establish native species in these areas than a new found love for these exotics. A similar phenomenon is occurring in marshes on the coast of Louisiana with *Phragmites australis*. In addition, some invasives such as milfoil have started to naturalize and cause less disturbance than before. Methods to eradicate invasives can also be extremely damaging to native plants as well.

can form dense canopies preventing most other species from growing in an area. They can be a nuisance to boaters and swimmers and can alter the structure and diversity of habitat available to fish, invertebrates, and waterfowl.

Freshwater SAV beds can often have much greater structural complexity than marine systems. This is due to the greater diversity of plant species adapted to freshwater conditions and to lower amounts of physical energy found in freshwater areas compared to marine environments. Lower tidal and wave energy in freshwater habitats means less stress for plants. Freshwater SAV can therefore contribute less energy to root structures and repairing damage than marine species typically need to (Stevenson 1988) and put more energy into above-ground growth where it can be more readily utilized by other organisms. Due to increased stress associated with tides and waves, marine species typically have basal growth[12], ribbon-like or roseate leaves and grow in 'meadows' lower in the water column (Figure 1). Many freshwater species, on the other hand, have a more complex, dissected leaf structure, apical[13] growth, and lie on or reach near the surface of the water to maximize photosynthesis[14] (Wetzel 1983; Stevenson 1988). This leads to the formation of complex underwater canopies in freshwater SAV beds much like those of terrestrial forests (Stevenson 1988). This structural complexity increases the number and types of habitats available to fish and invertebrates.

Figure 1. This lush meadow of ribbon-like seagrass from the Philippines consists mostly of *Thalassia hemprichii* and *Syringodium isoetifolium*. Photo courtesy of Ronald C. Phillips, NOAA Coastal Services Center.

The presence and abundance of all SAV communities can be extremely variable over time. Dominant species and entire plant communities can appear and disappear in response to changes in structural characteristics such as upstream land use, climate, water quality, exotic species introductions, disease, herbivores, sediment deposition, and turbidity (Bates and Smith 1994; Carter and Rybicki 1994; Titus 1994). This high level of natural variation in SAV communities highlights the need for monitoring reference sites in conjunction with restoration projects to determine which post-restoration observations result from restoration activities and which are caused by natural variability beyond the control of the restoration practitioner.

Seeds and other propagules

One characteristic of SAV that may be of use in restoration projects is their tendency to grow from vegetative propagules as well as from seed. Vegetative propagules such as dislodged plants, stems, rhizomes, and tubers may be carried into new areas with currents, settle on the sediment, and become established. For example, Rybicki et al. (2001) studied the availability and survivability of SAV propagules in freshwater tidal areas of the Potomac River. They found that some unvegetated areas were subject to a relatively consistent supply of propagules and seeds from adjacent or upstream areas. Due to poor water quality, improper sediment grain size, or low nutrient availability, plants did not always become established in areas so supplied. Knowing where propagules are naturally

[12] Apical growth can also occur in some species, often during flowering.
[13] From the tips of the plants.
[14] Wild celery, a common freshwater plant, is an exception to this pattern of growth as it has ribbon-like leaves and basal growth.

available could help guide the selection of sites for restoration projects (Rybicki et al. 2001). In areas that have an existing supply of propagules but where plants have not become established, other factors such as poor water quality or sediment nutrient concentration may be limiting SAV growth. These areas should not be the focus of additional planting efforts as plants are unlikely to survive until factors limiting growth can be addressed. In unvegetated areas without an existing source of propagules but with sufficient light and nutrient availability for SAV to grow, planting may be an appropriate way to bring about a successful restoration (Rybicki et al. 2001).

Another freshwater example comes from a SAV regeneration study in Cootes Paradise, a Great Lakes coastal marsh on the Canadian shore of Lake Ontario (Lundholm and Simser 1999). Submerged vegetation in the area had been repressed by the presence of carp foraging for plant tissues and associated increases in turbidity. Once carp were excluded from the system, dense beds of SAV regenerated despite the fact that earlier seedbank studies had shown little viable seed present in the sediment (Whillans 1996; Westcott et al. 1997). Perennial SAV species had regenerated through vegetative structures buried in the sediment that had not been previously observed. Although little is known about the longevity, viability, or species diversity of these vegetative structures (Lundholm and Simser 1999), they may provide a cost effective means of revegetating an area without new planting. Species composition in these regenerated areas may, however, be skewed to those plants that are more tolerant of disturbance and/or have longer-lived vegetative propagules. Depending on the goals of the restoration project, the regeneration of species with these characteristics may or may not be acceptable. In any event, this study provides an excellent example of a successful restoration project where the cause of degradation (i.e., carp) was eliminated, allowing the system to regenerate on its own.

In marine areas, seagrasses rely on both vegetative growth (through rhizome elongation) and propagation from seedlings to maintain and expand existing beds and colonize new areas. Seeds of some species such as eelgrass, however, do not travel far (less than a few meters) before settling out and becoming incorporated in the sediment (Orth et al. 1994). Seeds from eelgrass plants and other similarly heavy-seeded species can be collected and stored for use in restoration projects (Granger et al. 2002).

Sampling

Sampling some characteristics of SAV such as percent cover, stem density, or productivity can be challenging. In areas where plants do not grow all the way to the water's surface and sufficient light is available, divers can collect information on species presence and percent cover (Figure 2). Diving or snorkeling in areas where plants form a complete canopy to the surface of the water, however, is not recommended as swimmers and equipment can become seriously entangled. In these situations, it may be possible to estimate percent cover from the surface with the use of a glass bottom boat or a 'fish eye'[15]. Both of these methods eliminate the glare off the surface of the water and make it easier to see the plants and animals below. When

Figure 2. A diver sampling a seagrass bed. Photo courtesy of NOAA Center for Coastal Monitoring and Assessment, Silver Spring, MD.

[15] Also called an aqua scope, it is a large, hollow tube with a piece of glass on one end that is placed in the water.

Figure 3. Searching for SAV in the Tred Avon River with a bamboo shrub rake. Part of an annual Bay-wide ground-truthing effort. Photo from the NOAA Photo Library.

plant samples are needed for identification or estimating productivity[16], divers can cut plants or plants can be collected with a rake (Figure 3) or with a grab sampler (Dromgoole and Brown 1976). Readers interested in specific methods to monitor vegetative characteristics are referred to the second appendix of this chapter, a *Review of Technical Methods Manuals*.

PHYSICAL

Light Availability

Light availability is the single greatest factor affecting SAV growth (Carter and Rybicki 1990; Carter and Rybicki 1994). Knowing the amount of light available at different depths allows practitioners to select those depths at which certain species can be planted (Miller and McPherson 1995). The amount of light available to SAV is affected by a variety of inter-related phenomena[17] including:

- Tidal regime
- Hydroperiod
- Day length
- Cloud cover
- Nutrient loads
- Suspended sediment and particulate loads
- Dissolved organic material
- Chlorophyll-*a* concentration in the water column
- The presence of epiphytes growing on SAV
- The amount of fetch, and
- The frequency of large storms (Carter and Rybicki 1994; Orth 1994)

SAV growth in response to light availability varies by species and location. Generally somewhere between 5% and 25% of the amount of light available at the water's surface is required for SAV to grow. Bulthuis (1983) reviewed the light requirements of freshwater and marine SAV and found that the minimum amount of light required for growth and survival ranged from 5% to 15% of the total amount of light available at the water's surface. If measured precisely, this corresponds to approximately 100 – 250 $\mu E\ m^{-2}\ s^{-1}$ * (Carter and Rybicki 1990 and literature cited therein). Other researchers found that seagrasses needed 15% - 25% of light available at the water's surface to survive (Kenworthy and Haunert 1991; Dennison et al. 1993). In a study of subtropical and tropical waters, Fourqurean et al. (1995) found that turtle grass dominated waters where the percent of light at the surface was greater than 10% and shoal grass dominated darker areas where the percent of light was less than 10% of that at the surface.

By measuring the amount of light available, practitioners can also assess whether or not their plants are receiving enough light or if other factors might be responsible for poor plant performance. In a study of the growth and survival of transplanted eelgrass and environmental conditions in a southwestern tributary of the Chesapeake Bay, Moore et al. (1996) observed no long-term survival of

[16] Methods to measure productivity are discussed in the Functions section below.

[17] Monitoring of these parameters, in conjunction with measurements of available light may help practitioners better interpret their light availability data and discover cause-and-effect relationships impacting a restoration project.

* Irradiance is measured in units called einsteins. In English, the notation given here translates to 100 – 250 micro einsteins per square meter per second. Most quantum sensors provide output in einsteins.

transplants at any restored sites. Transplants died due to high turbidity and associated low light levels. Maintaining good water clarity and quality is critical to long-term eelgrass survival and successful recolonization (Moore et al. 1996). This highlights the need to obtain pre-restoration monitoring data to ensure that conditions are conducive to SAV establishment and growth before placement of additional plant materials is attempted (Batiuk 1992; Batiuk et al. 2000).

Turbidity

Although not a direct measure of all light available for photosynthesis, turbidity does affect the amount of light available to SAV. Thus helping to determine the presence and abundance of plants. Turbidity is a combination of:

- The color of the water, which changes with varying amounts of dissolved organic matter
- The concentration of suspended sediments and particles, and
- The concentration of phyto- and zooplankton, which also varies seasonally (Sculthorpe 1967)

Many freshwater SAV plants are canopy formers and have the ability to morphologically adapt to conditions of high turbidity and low light availability. Under these conditions, some plants such as milfoil and hydrilla elongate more quickly in an attempt to reach higher in the water column where light availability is greater (Barko and Smart 1981a; Barko et al. 1991). Other common dominant plants such as wild celery (*Vallisneria americana*) do not elongate rapidly under low light circumstances (Barko et al. 1991). For restoration purposes then, wild celery may not be the best choice for planting in areas with high turbidity and low light availability. Many canopy formers (including milfoil and hydrilla), however, are exotic in the United States and thus should not be used in restoration projects. A native canopy former that has been planted with success in some Chesapeake Bay projects is redhead grass (*Potamogeton perfoliatus*).

Changes in land use from forested to agriculture or urban cover types can lead to increases turbidity and changes in the species composition of SAV beds (Minc 1998). Native, canopy-forming plants such as waterweed and pondweed are intolerant of high turbidity. Plants such as coontail, milfoil, and hydrilla are well adapted to turbid conditions and displace less tolerant species (Minc 1998). These changes in dominant vegetation change the vertical structure of the habitat available to invertebrates and fish and thus alter faunal species composition (Wilcox and Meeker 1992; Brazner 1997; Grenouillet and Pont 2001; Valley and Bremigan 2002).

In addition to increases in turbidity caused by humans, animals can also affect the amount of turbidity and light available for SAV. Filter feeders, such as mussels and oysters, can help keep turbidity levels low to the benefit of SAV. For example, one of the effects of the invasive zebra mussel (*Dreissena polymorpha)* in the Great Lakes has been an increase in the amount of submerged aquatic vegetation in shallow areas such as Saginaw Bay (Skubinna et al. 1995). As the mussel colonies filter out vast quantities of suspended organic matter, the water gets less turbid and light is able to reach greater depths, thus providing energy for photosynthesis to a larger area of the lake bottom than before (Knapton and Scott 1999). The loss of historical oyster populations in the Chesapeake Bay has been linked to increased turbidity and the decline of SAV in the Bay. Other species, such as the common carp, can stir up sediments through their feeding behavior, also increasing turbidity and limiting the amount of light available to SAV (Wilcox 1995).

The duration of high turbidity levels can also affect SAV growth. In a study comparing two locations on a Chesapeake Bay tributary where seagrasses were planted, Moore et al. (1997) found that turbidity levels were low during winter at both upriver and downriver locations and eelgrass was growing well. After eight months of continuous growth, however, eelgrass transplants at the upriver site declined and eventually died as turbidity increased during summer months. Interestingly, turbidity increases on the downriver site were more severe but of shorter duration than at the upriver site and transplants survived. Plants were apparently able to tolerate very high yet short-term pulses of turbidity but more moderate increases in turbidity over longer periods of time resulted in the loss of vegetation (Moore et al. 1997).

Submerged aquatic vegetation not only benefits from low turbidity but it helps to maintain it by reducing water velocity, thus promoting settling of suspended solids, and through a complex relationship with phyto- and zooplankton. The effect SAV has on phytoplankton concentration comes from the lowering of water velocity[18] and by providing refuge for zooplankton that feed on phytoplankton (Jones 1990). When fish that feed on zooplankton are not present, small phytoplanktivores such as the freshwater *Daphnia* live out in the water column, feeding on suspended phytoplankton. When zooplanktivorus fish are present, however, zooplankton hide in the complex canopy created by SAV (Daldorph and Thomas 1995; Perrow et al. 1999). These relationships are discussed in greater detail in separate sections on invertebrate and fish use of SAV as refuge and feeding grounds in the Functional Characteristics section of this chapter below.

Sampling

PAR - The amount of light available for photosynthesis can be directly measured as photosynthetically available radiation (PAR) or indirectly by measuring turbidity or water clarity. PAR is the portion of visible light between 400 and 700 nm (Kirk 1994). The exact wavelengths used for photosynthesis will vary among different species. PAR can be measured using a device called a quantum sensor at the water surface and throughout the water column to determine how much light is absorbed by the water column and is then left available for SAV growth (Miller and McPherson 1995; Batiuk et al. 2000). Quantum sensors can be connected to dataloggers[19] and left in place allowing for the continuous measurement of PAR over time. This has the benefit of measuring random events such as storms or large river flows that can temporarily increase turbidity and that might be missed with less-frequent, manual sampling. For continuous deployments, a spherical (4 Pi) PAR sensor must be used to reduce fouling from settling sediments, while for measurements taken by lowering the sensor from a boat or pier, a flat (2 Pi) sensor is normally used to minimize the amount of light reflected off the boat that reaches the sensor. PAR measurements made by the two types of sensors are not directly comparable because they receive light from different angles. Estimates of light extinction (see equation below) that result from PAR measurements will also vary depending on the depths at which measurements are taken. There is no known single agreed protocol for the depths at which PAR is measured.

PAR can also be measured manually at various depths by using Beer's law (Carr et al. 1997):

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

Where I_o equals PAR at the surface, k is the light extinction coefficient of the water and associated dissolved material, and z is the depth. Unless referenced to mean tidal level (see chapter 8 in Batiuk et al. 2000), continuous monitoring of water level fluctuation in tidal and Great Lake areas subject to seiches may be required if PAR is to be determined in this manner. These hydrodynamic processes change a key input to the equation, depth (z). They may also affect

[18] Moving water helps keep phytoplankton suspended in the water column.
[19] An electronic device that continually records data over time.

values for *k* as well by changing the amount and type of dissolved material in the water, thus requiring additional monitoring of dissolved materials over time.

Turbidity - A simple, inexpensive way to measure turbidity is with a secchi disc, a weighted black and white circle, typically made of plastic, lowered slowly from the shady side[20] of a boat or dock (Figure 4). As light travels through the water column, it is absorbed or scattered by suspended and dissolved material. The remaining light reflects off the secchi disc and travels back through the water column where more is absorbed. The light that remains is what we see as the disc[21]. As the disc is lowered in the water, it gets harder to see as more of the light is absorbed. The depth at which the disc disappears from sight, is the depth at which all the light is being absorbed as it passes down and back up through the water column. This is recorded as the secchi disc depth (Tyler 1968). The frequency of using a secchi disk to sample turbidity should account for tidal regime and hydroperiod and include post-storm measurements whenever possible as these will affect water depth and clarity. More precise, electronic methods for measuring turbidity are also commercially available.

Figure 4. Lake Springfield water volunteer demonstrates the use of a Secchi disk. Photo courtesy Illinois EPA. http://www.epa.state.il.us/gallery/lake-monitoring.

Temperature

Water temperature, in part, determines the growing season for SAV and thus determines when SAV habitats should be monitored. Temperature also controls the rate at which chemical reactions take place and can thus affect primary productivity and plant species composition (Kirk 1994). Most plants and animals have a specific temperature range within which they perform most efficiently. As temperature deviates from the optimum, performance decreases (Thornton and Lessem 1978; McFarland and Barko 1987). Although chemical reactions take place at a faster rate at warmer temperatures and should theoretically increase productivity, extreme heat, as can occur in shallow areas with black sediments, may lead to metabolic stress, and reduce productivity. Colder climates or areas with strong, cold groundwater discharge may also experience reduced productivity (Wilcox 1995). Species temperature preferences may also change seasonally or geographically (Madsen and Adams 1989). This highlights the need for plant propagules and animals introduced as part of a restoration project to come from as local a source as possible since local populations should be best adapted to local environmental conditions.

Changes in weather patterns from one year to the next can also affect species presence or abundance. Some freshwater species such as the invasive hydrilla require high temperature and light availability during the spring when the dominant growth pattern for the plant is prostrate along the sediment. If spring temperatures are too low or turbidity too high during this period, hydrilla does not grow enough to come

[20] To avoid glare off the water's surface.
[21] Sunglasses should NOT be worn while taking a secchi disc measurement.

to dominate the canopy later in the summer (Carter and Rybicki 1994). Relationships of this sort, however, have not been worked out for all SAV species.

Dense beds of SAV in areas with low water velocity have been shown to help set up strong vertical temperature gradients in inland lakes (Dale and Gillespie 1977; Wetzel 1983) and in shallow, coastal areas of the Great Lakes (Suzuki et al. 1995). The ability of SAV to influence temperature in tidal areas, however, is not as clear. Some researchers have shown that temperature differences do exist within dense beds of SAV particularly during the warmest part of the day (Carter et al. 1988). Carter et al. (1988) and Carter et al. (1991) found temperature gradients throughout the water column to be as much as 5˚C. Water temperatures at the surface tended to be higher within areas of SAV than in adjacent unvegetated areas. Bottom temperatures in vegetated areas, however, were much more variable compared to unvegetated areas. Jones (1990), however, found no vertical temperature differences in SAV beds in tidal areas. Although the relationship between tides, wind, available sunshine, and SAV is not completely understood (Carter et al. 1991), it seems likely that in areas with strong tidal exchange, the ability of SAV to limit mixing and set up vertical temperature gradients is much lower than in areas with weaker tides.

Sampling

A variety of manual and electronic methods are commercially available to measure temperature. If only temperature needs to be recorded as part of a study, small, inexpensive temperature loggers can be used inside waterproof cases.

Sediment

Grain size

The physical and chemical characteristics of sediments directly affect wetland vegetation and organisms inhabiting the area. SAV in turn affects local sediment characteristics by slowing current velocity and increasing the deposition of suspended sediments. In areas that are prone to flooding and/or large storms, sediment grain size and associated nutrient concentrations may change from time to time as sediments are moved into and out of an area. Conditions may temporarily arise that are conducive or detrimental to SAV growth and indeed SAV populations have been shown to fluctuate greatly over time in relation to these events (Orth and Moore 1984; Carter and Rybicki 1986; Bates and Smith 1994; Nichols 1994; Titus 1994). In SAV habitats where sediment accretion is rapid (such as coastal Louisiana) or where sediment accretion is a primary goal of restoration, sediment grain size or bulk density can be measured to determine whether or not the rooting medium for SAV is adequate for plant establishment. In areas that are not exposed to relatively rapid changes in sediment level, these sediment characteristics may not need to be monitored after the initial assessment of their condition for plant species selection purposes.

Koch (2001) compiled a list of common SAV species and their known preferences for percent silt and clay (i.e., fines) in sediment. She found that SAV grew in a wide range of % fines from 0.4% to 72%. Freshwater species tended to prefer a greater percentage of fines than did marine species. Koch along with Barko and Smart (1986) theorize that this has more to do with sediment geochemical processes such as oxygen concentration, chemical diffusion, or the build up of toxic sulfides in anaerobic marine sediments[22] than simply the physical characteristics of the sediment.

Nutrient concentration in sediment porewater

Submerged plants obtain most of their nutrients (i.e., nitrogen and phosphorus) from the sediments where concentrations of these nutrients are typically higher than in the water

[22] Sulfide accumulation is not a common characteristic of freshwater areas.

column (Carignan and Kalff 1980; Barko and Smart 1981b). Phosphorus, for example, binds to the surface of organic matter and mineral sediments in the presence of oxygen. In anaerobic environments, such as wetland sediments, phosphorus becomes soluble and available for uptake by plants (Mortimer 1941; Mortimer 1942). Nitrogen, in the form of ammonia, is also more readily available in anaerobic sediments than from the more oxygenated water column.

Sediment types (organic, sand, silt-clay, and rock) vary in level of nutrient availability, contributing to the establishment of different plant communities (Kiorboe 1980). Sediments dominated by silts and clays, for example, are typically nutrient rich. Sandy sediments or bedrock areas are typically nutrient poor. Sediments with high concentrations of organic matter may be rich or poor depending on the local hydrodynamics and mineral sediment content. Areas prone to large storms or flooding events that change sediment grain size and associated nutrient concentration may also exhibit variability in the presence and abundance of SAV (Terrell and Canfield 1996). Areas with sandy sediments may have nutrient concentrations that are too low for SAV to become successfully established. In these areas, it is not recommended that additional nutrients be added to the water column (since SAV typically does not get a majority of its nutrients from the water column) nor should nutrients be added to the sediment since sandy sediments do not have the ability to hold nutrients for plant use and nutrients could simply be leached away.

Organic matter

Organic matter accumulates in SAV areas through deposition of fine sediments as a result of lowered water velocities and through the production and burial of rhizomes and roots (Koch 2001). A vast majority of healthy SAV beds are limited to areas with a percent soil organic matter below 5% dry weight (Koch 2001). The mechanism behind the limitation has not been completely explained but the relationship is clear. She recommends that SAV not be planted in areas with organic matter content higher than 5% until additional studies have been completed to better explain the mechanism behind this relationship and methods are developed to overcome it. Barko and Smart (1986) also found that SAV grew poorly in low-density, high organic soils and also in high-density, sandy sediments. The poor growth in sandy sediments has been generally attributed to the nutrient-poor nature of sandy sediments (Kiorboe 1980). Poor growth in sediments with high organic content (when nutrient levels should be high) and low bulk density was explained as being caused by the low rate of diffusion in these types of sediments (Barko and Smart 1986). Thus, the nutrients were present and attached to soil particles but the plants could not get to them efficiently due to the high porosity of low-density soils.

The type and decomposition of organic matter in the sediment also contributes to the nutrient cycling process. In a study of decomposition of sediment organic matter in beds of the seagrasses blume (*Rhizophora apiculata*) and sea fruit *(Enhalus acoroides)*, Holmer and Bachmann (2002) found that the stems and leaves of seagrasses contributed relatively more nitrogen than carbon to the water column than did the rhizomes of the same species. Thus, the type of detritus available (e.g., leaves or rhizomes) influences sediment nutrient concentrations and nutrient cycling dynamics and may need to be sampled as well if a comprehensive understanding of nutrient cycling and the role of organic matter is desired.

Measuring and Monitoring Methods

Sediment grain size can be measured directly by drying and sifting samples through a series of different sized sieves (Poppe et al. 2003). It can also be measured indirectly through measuring bulk density. Bulk density is the dry weight of the sediment per unit of volume (Steyer et al. 1995). It is generally low (e.g., 0.2 to 0.3 g/cm^3)

for sediments with high organic matter content and high (e.g., 1.0 to 2.0 g/cm^3) for sediments with high mineral content (Mitsch and Gosselink 2000). Detailed methods for sampling sediment characteristics such as grain size, nutrient concentration, and organic content can be found in Folk (1974), Gosselink and Hatton (1984), Liu and Evett (1990), and Steyer et al. (1995) as well as other resources listed in the second appendix of this chapter.

Topography/Bathymetry

Acreage of habitat

Monitoring the area of SAV created as part of a restoration project over time can be used as an indicator of whether the habitat has deteriorated or improved. The spatial and temporal distribution of seagrass beds (primarily eelgrass) in Barnegat Bay, New Jersey, for example, has been studied by combining existing historical mapped survey information (Lathrop et al. 2001). Maps from the 1960s, 1970s, 1980s, and 1990s were digitized and assembled in a geographic information system (GIS). Comparisons were then made between earlier maps and a survey conducted in the 1990s that showed a decrease of about 2,000 to 3,000 ha in seagrass beds over time. Aerial photography, remote sensing, side scan solar, and acoustic sounder systems are also convenient methods for mapping and monitoring changes in the acreage of SAV over time (Ackleson and Klemas 1987; Ferguson and Korfmacher 1997; Malthus and George 1997; Weinstein et al. 2001; Mumby and Edwards 2002; Sabol et al. 2002; Dierssen et al. 2003). Ground truthing to verify SAV presence and species composition is a very valuable supplement to any mapping done by aerial photography or other remote sensing method. For a description of the use of ground surveys by the Virginia Institute of Marine Science (VIMS) in its 2002 survey of Chesapeake SAV, see: http://www.vims.edu/bio/sav/sav02/report/ground_surveys_page.html.

Geomorphology

Geomorphology is the study of the physiographic features of the earth's surface. By understanding the shape of a particular feature on the landscape and how it was formed, insights into the functions an area can perform can be better understood. Geomorphic features are delineated based on the shape and geologic history of an area, the degree of protection from wave energy, and the amount of hydrologic exchange with their receiving water body. A given geomorphic feature may contain a variety of vegetation communities (i.e., habitats) within it. For example, the geomorphic feature of a drowned river mouth (see Figure 5) may contain a mix of riverine forest, marsh, SAV, and open water habitats. All of these habitat types are subject to similar physical forces such as bidirectional flow and water level fluctuations tied to receiving body of water because of their location within the drowned river mouth. In addition, the physical forces that act upon a SAV community within a drowned river mouth are different than those that affect a SAV community along an open coast. Thus, some of the functions the drowned river mouth community can perform may be different than those of an SAV community along an open coastline.

The basic geomorphic types of coastal wetlands are outlined in Figure 5. They are: open, drowned river mouths, and protected. Although the particular type of geomorphic setting a SAV habitat is in will not change over time, each type has characteristic influences on other structural and functional characteristics that will be monitored. In addition, short-term differences in the connection between the wetland and the receiving body of water such as the formation of temporary barrier beaches can also affect many wetland structural and functional characteristics. Therefore, when developing a restoration monitoring plan, the geomorphic type of the coastal wetland as a whole needs to be taken into consideration[23].

Open Coastal Wetlands

Open coastal wetlands are subject to more wave energy and hydrologic exchange than drowned river mouths or protected wetlands. Open wetlands have direct chemical and hydrologic connects to the water body they are associated with. They may also have upland water sources such as small streams. They typically do not have as much sediment organic matter accumulated as drowned river mouths or protected wetlands (Keough et al. 1999). Plants and animals that live in open wetlands must be tolerant of higher rates of erosion caused by waves and ice and daily water level fluctuations from tides or seiches compared to other geomorphic types of wetlands (Keough et al. 1999).

Drowned River Mouths

Drowned river mouths were formed during the last ice age when water levels of the Great Lakes and oceans were much lower than they are today. As the lakes and oceans rose to present levels, deep river valleys filled with sediment creating linear wetland complexes chemically and hydrologically dominated by both the rivers moving through them and their receiving body of water. Many of the estuaries in the United States such as the Chesapeake and Delaware Bays on the east coast, Coos and Siletz Bays in Oregon, and those in the Great Lakes such as Muskegon Lake in Michigan are drowned river

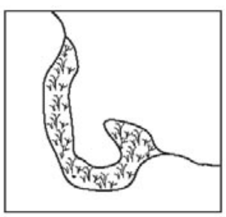
Type	Physical	Hydrologic	Biological	Chemical
Open 	Variable inorganic substrate (clay to gravel). Thin to non-existent organic substrate. Moderate to high wave climate. Low rate of sediment supply. Gentle offshore and underlying-surface slopes. May or may not have offshore bars of sand to gravel.	Direct surface-water connection to the receiving body of water. Ground-water flow-system directly influenced by elevation of receiving body of water.	Plant morphometry adapted to hydraulic stress. Vegetation aligned with shoreline bars and dunes. Vegetation sensitive to wave climate and protective dunes, ridges, bars, and points. Plant species preferring inorganic substrates. Stray estuarine fauna. Biota tolerant of ice action.	Strongly influenced by constituents of the receiving body of water. Low turbidity. Vegetation may isolate nearshore water from mixing with the receiving body of water.
Drowned River 	Variable inorganic substrate (clay to gravel). Variable thickness of organic substrate. Low to moderate wave climate. Low to moderate rate of sediment supply from coast and river.	Direct surface-water connection to river and the receiving body of water. Ground-water flow-system influenced by elevation of the receiving body of water and the river. Many local flow systems. Seiches transmitted upstream.	Plants and animals of riverine, lagoonal, and coastal habitats. Mud-flat annuals, and plants preferring organic sediments. Warm-water fish. Biota tolerant of flooding and high turbidity.	Upstream-downstream gradient in water constituents caused by seiches mixing of river water with water from the receiving body of water and reversal of currents. Variable turbidity.
Protected 	Uniform inorganic substrate (sand to gravel). Thick organic substrate. High rate of sediment supply to shoreline.	May or may not have a surface-water connection to receiving body of water. Ground-water flow-system may or may not be influenced by the elevation of the receiving body of water. Many local flow systems.	Peatland vegetation is often present in northern areas. Ridges and swales show successional patterns. Warm-water fish in lagoons. Plants preferring organic substrates.	Organic matter may dominate water chemistry if limited riverine inflow. High water temperatures in summer. Ground-water seepage may cause temeprature gradients. Low turbidity. Ground water may dominate chemistry where inputs are high.

Figure 5. Three main types of coastal wetland geomorphology, open, drowned river mouth, and protected. The specific type of geomorphology has direct effects on the physical hydrological, biological, and chemical characteristics of the whole wetland and associated SAV habitats. Modified from Keough et al. 1999.

[23] Some aspects of geomorphology *within* habitats such as the pattern of tidal creeks, however, can change as habitats mature (Weinstein, M. P., J. M. Teal, J. H. Balletto and K. A. Strait. 2001. Restoration principles emerging from one of the world's largest tidal marsh restoration projects. *Wetlands Ecology and Management* 9:387-407). These within-habitat patterns and structures can be monitored using aerial photography but are not the main topic covered here.

mouths. During periods of low flow, barrier beaches may form over the river mouth. This increases the retention time of water within the wetland, increasing the potential for sediment deposition and nutrients uptake but preventing the migration of fish. During severe storm events or high water levels, these protective structures can be eroded away and flow through the wetland increased, thus reducing retention time and flushing accumulated sediments, nutrients, and organic matter into the receiving body of water.

Protected Coastal Wetlands

Protected coastal wetlands are located behind some sort of barrier (often an island) that protects them from the full force of waves coming off the main water body. It may also isolate them from water level fluctuations if the barrier is complete. The extent of the barrier has direct effects on the accumulation of organic matter, water chemistry, and other physical and biological characteristics as well by altering the flow and retention time of water through the wetland. As with barriers on drowned river mouths, barriers for protected wetlands can be temporary, completely isolating, or open to allow some hydrologic exchange with the receiving body of water.

Elevation and Slope

Slight topographic differences in the wetland substrate[24] create habitat for different plant species and plant communities to grow. All other things being equal, SAV beds with uniform substrate elevations will have a much more uniform vegetative community with lower species diversity than will beds with a topographically complex substrate. Sedimentation rates, water level changes, and subsidence can change the depth of water to the substrate and thus change the vegetation community (Hatton et al. 1983; Wilcox and Whillans 1989; Wilcox and Meeker 1995; Minc 1997). In any restoration project involving planting or seeding, careful measurement of depth to substrate, substrate elevations, and topographic diversity will need to be done in order for the proper plant species to be selected. In projects using dredge material or dike removal, for example, practitioners may need to monitor substrate elevations and topographic diversity for a period after project implementation and before planting to determine if the planned-for elevations have been achieved. Once sediments have settled into place and final elevations of the substrate are known, final selections of plant species can be made and placed in the field.

The slope of the sediment surface can influence the primary production of SAV (Duarte and Kalff 1986). This effect is related to the rate and quality of sediment deposition and the slumping of sediments that can stress plant roots. Gently sloped areas (e.g., slope < 5.0%[25]) have more stable sediments and greater deposition of fine, nutrient-rich sediments than areas with steeper slopes that tend to be areas of erosion and sediment transport (Hakanson 1977). As will be shown in the discussion of wave energy below, the slope of the substrate in relation to wave energy and light availability directly affects the spatial location of SAV communities within a particular area.

Sampling

The bathymetric features on an SAV bed can be sampled using a boat and a method to measure depth such as a weighted rope, pole, or radar. Depending on the amount of detail desired and the size of the habitat being mapped, this method may be adequate. For larger areas or where more detail is desired, remote sensing techniques can be used. High-resolution aerial imagery can be used to create detailed maps of bathymetry over large areas that would be hard to sample with traditional methods. Imagery can also be analyzed to distinguish different sediment types

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[24] Underwater topography is referred to as bathymetry.

[25] Hakanson's study was conducted in a lake. Since sediments in freshwater tidal and coastal areas of the Great Lakes may experience greater energy stress than inland lakes due differences in hydrodynamics, deposition and stability of sediments within SAV communities may require even smaller slopes in these environments.

(Lee et al. 2001; Dierssen et al. 2003; Louchard et al. 2003). Results need to be referenced to accurate tidal reference data so the depths can be referenced to mean low water levels. To do this the time of day needs to be recorded with each measurement, so they can be compared to measured water levels at the nearest reference station. NOAA provides a variety of water level data free to the public that may be of use; see http://co-ops.nos.noaa.gov/data_res.html.

HYDROLOGICAL

Current Velocity

SAV affects and is affected by the current velocity of the water column. Areas of high energy and strong current velocities such as those with large tidal exchanges or high freshwater flow areas tend to be dominated by SAV with linear, ribbon-like leaves. Areas with lower current velocities are dominated by species with bushier, more complex canopies (Stevenson 1988; Dudgeon and Johnson 1992; Sand-Jensen and Mebus 1996; Dodds and Biggs 2002). These differences in canopy type and structure further alter the flow and mixing of water through the bed. SAV beds with higher canopy complexity slow water to a greater extent than do beds with lower density and/or less complex canopy structure (Figure 6 - Dodds and Biggs 2002). Dense stands of SAV can slow water velocity by as much as 2 to 10 times that found in adjacent unvegetated areas and can even dampen tidal exchange (Ackerman 1983; Madsen and Warncke 1983; Carter et al. 1988; Gambi et al. 1990; Rybicki et al. 1997; Heiss et al. 2000).

Figure 6. This dense canopy of SAV growing in the Mississippi River Delta creates friction and slows water velocity. Photo courtesy of Teresa McTigue http://www.photolib.noaa.gov/coastline/line1211.htm

Reductions in water velocity due to SAV can result in:

- Decreased sediment transport and increased sediment deposition (Fonseca et al. 1982; Bulthuis et al. 1984; Ward et al. 1984)
- Less vertical mixing of water in thermally stratified lakes and impoundments (Suzuki et al. 1995)
- Changes in nutrient uptake and biomass production (Fonseca et al. 1982; Dodds and Biggs 2002), and
- Increases in animal diversity by creating low-energy habitats in otherwise high-energy environments (Suren 1991)

SAV also benefits from its own effect of reducing water velocity. These benefits include:

- Reduction in self shading
- Lower shear forces at the sediment surface reducing sediment resuspension
- Increased sedimentation and deposition of organic and fine inorganic particles
- Longer residence time of water within the bed, facilitating greater nutrient uptake, and
- An increase in the settling of algal spores and other larvae resulting in higher biodiversity (Koch 2001)

Current velocity also affects primary productivity and biomass production (Butcher 1933). Each plant species is adapted to a particular range of velocities within which it functions best (see review in Carr et al. 1997). Water velocities within the plant bed as slow as 5 cm/s have been shown to increase productivity, while velocities of 50-100 cm/s or more can stress plants and limit productivity (Chambers et al. 1991; Koch 2001). The velocity of water also influences productivity by affecting the diffusion of nutrients and waste products through plant leaves. The flow of water across the leaf surface facilitates the exchange of dissolved substances by replenishing nutrient and carbonate concentrations and removes accumulated sediment and waste products from leaves (Odum 1956).

Sampling

A variety of manual and automated flow meters are commercially available for use in determining water velocity within and around vegetated areas. Equipment costs and sophistication range from low-tech, manual methods that measure flow at one point and time to electronic meters that can be left in place for weeks or months.

Water Sources

The amount and source of water to an area also has an effect on SAV. Changes in the amount of freshwater discharge to estuarine and marine areas or fluctuations of the water level of the Great Lakes can change the specific location of the habitat from year to year. Certain species may dominate vegetation communities one year and give way to others the next. Whole communities can appear and disappear in response to changes in upstream flow (Klarer and Millie 1992), land use (Carter et al. 1994), and associated changes in water quality. For example, a strong storm surge along an ocean coast can bring salt water upstream to areas that are typically freshwater. If the saltwater is not quickly flushed from the area, it can kill the established species and create conditions for more salt-tolerant species to grow.

Wave Energy

Wave energy can directly and indirectly impact SAV communities and limit their ability to grow at shallower depths. Waves as small as 0.1 meter in height can significantly damage plants (Stewart et al. 1997). Direct effects of wave energy include washout and burial of seedbanks, damage and uprooting of individual plants, and reduced survival of seedlings and developing winterbuds (Doyle 2001). These effects can be seen from storm-induced waves (Figure 7 - Terrell and Canfield 1996) as well as from waves caused by boats (Stewart et al. 1997). Moderate amounts of wave energy can actually be beneficial to SAV by reducing the epiphyte layer, thus enhancing photosynthesis and increasing rates of diffusion at the plant

Best Management Practices

The type of land cover in upstream areas producing runoff can also influence SAV. Exposed soil from agricultural land or construction projects can wash into water bodies during rain events. This can harm SAV in two ways, first by increasing turbidity and second by literally burying plants if sediment loads are high enough. The use of vegetated buffer strips in upstream areas can reduce the amount of sediment entering waterways from non-point source areas such as farm fields. Urban best management practices (BMPs) can be used to minimize the impact of point sources or urban stormwater systems on aquatic systems. Many local governments around the country have BMP guides that practitioners can obtain free-of-charge to learn more. Some examples include Prince George's County's Design manual for use of bioretention in stormwater management (Engineering Technologies Associates Inc. and Biohabitats Inc. 1993) and Cost estimating guidelines: best management practices and engineered controls from the Rouge Program Office in Wayne County, Michigan (Ferguson et al. 1997). Schueler et al. (1992) have also developed a series of commercially available guidelines for implementing BMPs into urban stormwater management programs. The US Environmental Protection Agency (EPA) also provides stormwater BMPs for the protection of wetlands. This document is available at: http://www.epa.gov/owow/wetlands/pdf/protecti.pdf. Additional resources are also available from the EPA that cover a variety of land use situations. These resources can be found by searching the EPA's website http://www.epa.gov.

Figure 7. Horned pondweed (*Zannichellia palustrus)* generally grows in shallow, calm areas but can be killed by high water temperatures where it floats to the surface and is washed up on shore by high waves. Photo courtesy of Mary Hollinger, NOAA Photo Library. http://www.photolb.noaa.gov/coastline/line0763.htm

surface (Wetzel 1992). Moderate levels of wind exposure and wave energy are also correlated with higher species diversity (Bailey 1988).

By monitoring wave energy on plants and at the sediment surface, restoration practitioners will be better able to understand and address the physical impacts to their restored area and better select plant species tolerant of such conditions during the planning process. Canopy forming plants such as milfoil suffer greater damage than ribbon-like plants such as wild celery. Even plants such as wild celery adapted to higher energy environments, however, can be negatively affected by waves. Waves 0.15 m in height can produce shear velocities around 1.4 meters per second on the surface of the plants and impact the ability of canopy-forming freshwater plants to reproduce (Doyle 2001). Wave energies of this magnitude can easily be produced by recreational watercraft in shallow water (Doyle 2001). SAV beds in higher energy environments or meadow-forming species growing deeper in the water column may be able to tolerate much larger waves without the same level of impact. SAV species that have a shorter, meadow forming growth form that overwinters, and that develop longer branched reproductive shoots in the summer, may remain in the short form all summer in high wave energy environments. In Chesapeake Bay this has been observed in horned pondweed, widgeongrass, and sago pondweed (Bergstrom pers. comm.).

Indirect effects of wave energy on SAV communities often involve the impact of waves on sediments. Wave energy can sort sediments, resuspending and removing finer silts and clays, leaving behind sands and coarser materials with lower nutrient availability (Spence 1982; Wilson and Keddy 1985). Wave energy can also maintain turbidity levels high enough to prevent SAV from re-establishing in areas it had previously dominated (Engel and Nichols 1994). Wave energy near the shoreline also

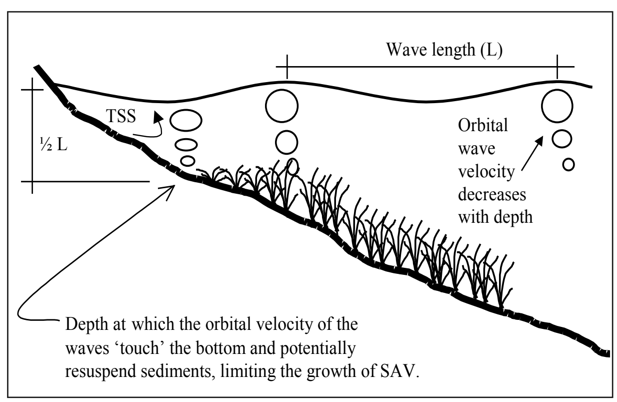

Figure 8. Cross section of a SAV bed showing the depth limitation imposed by waved energy reaching the sediment surface and increasing total suspended solids, eroding plants and decreasing light availability. TSS = Total Suspended Solids (i.e., sediments). Modified from Koch 2001.

limits SAV to deeper water, below the area of wave-induced sediment resuspension (Figure 8 - Chambers 1987). The relationship between wave energy and limiting the spread of SAV can be more easily seen in areas with steeper slopes (Chambers 1987). Areas with more gently sloping substrates have a more complicated interaction of wave energy and sediment resuspension, the details of which have not been well studied (Koch 2001).

Sampling

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

Tides/Hydroperiod

The magnitude, frequency, timing, and duration of water level fluctuations are all important characteristics in determining the location and species composition of SAV (Wilcox and Meeker 1995). Water level fluctuations may occur daily, seasonally, or on annual/decadal cycles. These patterns are driven by tidal patterns and/or changes in weather. Humans can also control water level fluctuations through the use of dikes and dams. In coastal marine areas, tides are the major force responsible for circulating water within SAV beds and between a bed and adjacent habitats (Carter et al. 1991). In both freshwater and marine habitats, seiches can also drastically change water depth and mix lake or bay water far into coastal wetland systems (Wilcox and Meeker 1995). They can also move material such as sediments, nutrients, and organic material back and forth between the wetland and open body of water (Keough et al. 1999). While extreme low water levels may stress plants and animals, longer-term cycles of high and low water levels are necessary to maintain healthy, diverse SAV habitats. For example, Wilcox and Meeker (1992) studied regulated lakes in Minnesota. They found that water level management schemes that did not mimic natural water level fluctuations of similar lakes resulted in a loss of SAV species, abundance, cover, and structural diversity. Changes in the structural characteristics of SAV habitats can impact invertebrate communities, waterfowl, and fish use.

Natural inter-annual variation in the surface elevation of the Great Lakes has a tremendous impact on SAV communities. Increases in water level can deprive deeper plants of light but also create conditions for SAV to grow further inland in areas that may have once been dominated by marsh vegetation. During prolonged droughts or lowering of Great Lakes water levels, freshwater habitats may move farther downstream or out into the lake basin. These system dynamics must be taken into consideration during the preparation of restoration goals and monitoring plans (Wilcox et al. 2002). Estuarine and marine habitats typically have more predictable water levels over time than do Great Lakes habitats, although sea levels are rising worldwide (Warrick 1993).

Tidal regime, wave energy, and light availability-at-depth determine which specific locations may be most conducive to a successful restoration effort. SAV are intolerant of desiccation and are therefore restricted to sub-tidal areas (Cowardin et al. 1979; Koch 2001). The upper limit of SAV growth is then determined by the effect of tides and wave action as previously described as well as the effects of ice, grazing, and other disturbance in shallow water. The lower extent of SAV is limited by light availability (Figure

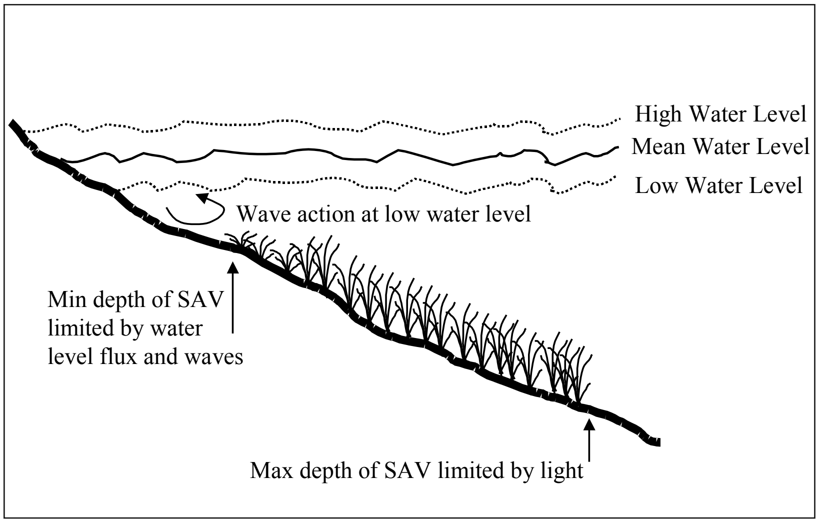

Figure 9. The minimum depth SAV can colonize is limited by low water levels and wave action. The maximum depth is limited by light availability. Modified from Koch 2001.

9 - Dennison et al. 1993; Koch 2001 and literature cited therein). The horizontal extent of SAV growth is then limited by the slope of the substrate.

Sampling

Tide tables for most of the United States and its protectorates are available from the National Oceanic and Atmospheric Administration (NOAA) at http://tidesonline.nos.noaa.gov/ and http://co-ops.nos.noaa.gov/data_res.html. The United States Geological Survey also operates a series of gaging stations on rivers throughout the country. Historical and real-time data on hydroperiod and characteristics of the watershed are available for many areas at http://water.usgs.gov/waterwatch/. If the restoration site is reasonably close to a listed site, monitoring of the tidal period as part of the restoration monitoring may not be necessary. Smaller coastal rivers, however, may not have gaging stations requiring that restoration practitioners implement other methods to collect this information. A variety of manual and electronic gages are commercially available. Gages that are read manually and checked during site visits can be attached to metal poles and driven into the substrate. Mechanical gages that record maximum and minimum water level since the last site visit can also be useful. Electronic gages can be set up and left in place to continually record water level fluctuation data over time as well. This method has the advantage of recording data that might otherwise be missed by manual sampling alone.

CHEMICAL

Salinity

Salinity plays a role in the zonation and distribution of SAV. By definition, only seagrass species can tolerate the salinity of full strength seawater. Different species of seagrasses, however, tolerate different salinity levels (Lirman and Cropper 2003). Factors that contribute to changes in salinity levels include industrial and agricultural inputs (typically increase salinity) and changes in weather patterns that increase or decrease inputs of freshwater. Increasing the amount of impervious surfaces in a watershed tends to lower salinity as a greater percentage of rainfall is delivered to rivers and streams instead of infiltrating into the groundwater. High salinity levels can result in lower seagrass productivity. Salinity levels also influence fauna zonation within seagrass habitats (Ingram and Dawson 2001). Salinity should therefore be monitored in tidal areas subject to changing salinity levels. Some tidal freshwater areas can also become brackish during drought years thus requiring salinity to be monitored. In strictly freshwater areas, monitoring salinity is not necessary.

Nutrient Concentration

While the main source of nutrients (nitrogen and phosphorus) to submerged macrophytes is sediment porewater (Carignan and Kalff 1980; Barko and Smart 1981b; Fourqurean et al. 1992), they can absorb small amounts of nutrients from the water column through their leaves. Despite their ability to remove nutrients from the sediment and water column, excessive amounts of nutrients can disrupt SAV habitats and result in habitat degradation. When nutrient concentrations in the water column are too high, SAV cannot absorb them before phytoplankton and epiphytic algae do. These microscopic plants can then grow fast enough and thick enough in the water column and on the surfaces of macrophytes that they outcompete SAV for light, killing the host plant.

Under certain circumstances, SAV can also increase the concentration of nitrogen and phosphorus in the water column. Rooted plants move nutrients from the sediment to the upper portions of the plant (Carignan and Kalff 1980). Plants then lose nutrients through four possible mechanisms: leaching, excretion, autolysis, and decomposition (Barko and Smart 1981b). Only a small amount (if any) nitrogen and phosphorus, however, is lost through excretion during active growth of plants. The vast majority of nutrients lost by SAV result from plants dying or having pieces broken off. As plant tissues begin to break down, nutrients are leached into the water column. As plants continue to decay, cell walls are broken down (autolysis) and their nutrient-rich contents are spilled into the water, the remaining plant materials are then colonized by fungi and microbes. These organisms complete the decomposition and nutrient cycling processes. As nutrients become available in the water column, they can be quickly absorbed by phytoplankton (Stevenson 1988). Thus, in temperate climates at least, a seasonal cycle of water column nutrient concentrations can be seen in areas with large beds of SAV. Nutrient concentrations in the water column can be high in spring, low during the growing season and high again in the fall and winter.

Sampling

Detailed methods for sampling salinity, nutrient concentrations, and other characteristics of the water column that may affect the growth of SAV are covered in the American Public Health Association's, *Standard Methods for the Examination of Water & Wastewater* (APHA 1999) and in a variety of methods manuals listed in Appendix II of this chapter. Bergstrom (2002) has also compared several methods for measuring salinity. Results of this study are available online at http://www.epa.gov/volunteer/winter02/volmon.pdf.

Many of the physical and chemical functions performed by SAV were covered with the associated structural characteristics above.

FUNCTIONAL CHARACTERISTICS OF SUBMERGED AQUATIC VEGEGATION

The following sections focus on the biological functions of freshwater and marine SAV. A list of common functional characteristics of SAV includes:

Biological

- Contributes to 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

Physical

- Affects transport of suspended/dissolved material
- Alters turbidity
- Reduces erosion potential
- Reduces wave energy
- Modifies water temperature

Chemical

- Supports nutrient cycling
- Modifies chemical water quality
- Modifies dissolved oxygen

The SAV literature, and particularly the marine SAV literature, is quite extensive. Wherever possible, a marine and/or freshwater example is used below to illustrate each characteristic function and parameter(s) that may be useful in monitoring restoration projects. The examples provided, however, are only a few of the many available. In topics where literature is particularly abundant, sources are cited at the end of the section to guide readers to additional information. Readers are also encouraged to use the *Annotated Bibliography* and *Review of Technical Reference Manuals* in the appendices to find additional information, examples, and resources.

BIOLOGICAL

Contributes to Primary Productivity

SAV are primary producers, using the sun's energy to produce organic material that can then be used by other organisms. In the process, they utilize and recycle nutrients in the water column and sediments (McRoy and Helffreich 1977) and help to increase water clarity and quality. SAV also contribute to the overall productivity of the area in a variety of other ways. They often increase the amount of nutrients available to epiphytes, phytoplankton, and other meio- and benthic flora, increasing the productivity of these plants as well.

The energy produced by submerged macrophytes and their associated flora, can be used by animals directly or indirectly. A simplified version of the process is illustrated in Figure 10. The movement of dead plant and animal material (black arrows) along with that of SAV, epiphytes, and phytoplankton (green arrows) that are not directly eaten by grazers, is toward the detrital pool in the sediment. This forms the basis of the detrital food web. These materials are then eaten (red arrows) by decomposers such as fungi and bacteria. These microorganisms are then eaten by meiofauna in the sediment such as worms and nematodes. Meiofauna are then fed upon by omnivores such as shrimp and crayfish. Grazers and omnivores such as crayfish, sea urchins, and other benthic fauna, fish, turtles, manatees, and waterfowl can also eat live plant material. That said, relatively few species, compared to the total number found in SAV habitats, feed directly on living macrophytes. The small number of direct grazers may be linked to the greater

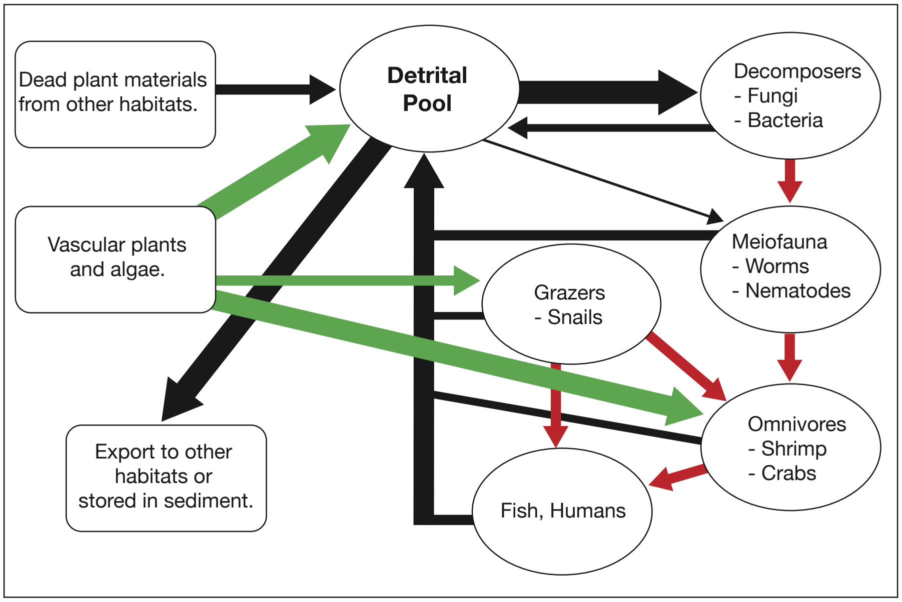

Figure 10. An example of a food web in SAV habitats. Green arrows represent the flow of live plant material, black arrows represent dead plant and animal material, red arrows represent predation. Although arrows are sized to represent relative amounts, exact amounts of energy moving from one component to the next will vary among individual areas. Figure by David H. Merkey, NOAA Great Lakes Environmental Research Laboratory.

availability of nitrogen compounds from other food sources such as the epiphytes that grow on SAV, the presence of tough cell walls in many SAV species, and toxic or inhibitory chemicals (Thayer et al. 1983). Only a small amount of the energy produced by submerged vegetation enters the food web as live material. Most of the energy produced by SAV is available to animals only through the detrital food web. Grazers and omnivores are, in turn eaten by waterfowl, fish, and humans. At all stages, there is a possibility that individual animals will not be eaten but instead die and add their bodies to the detrital pool to be recycled. Some detritus never enters the food web but is exported to other habitats or stored in the sediment. This example is very simplified, additional components and examples could be added as well as additional arrows drawn between different components.

Epiphytes and benthic algae

As stated previously, algal species and epiphytes play an important role in SAV ecosystems by contributing to primary production (Bologna and Heck 1999). If SAV growth is reduced, it will not only affect the algae and epiphyte community but also the epifaunal community that relies upon these food sources. Epiphytic algae contribute approximately 50% of the primary productivity of SAV habitats (Moncreiff and Sullivan 2001). Measuring and monitoring the growth and productivity of SAV, algae, and epiphytes can be an important component of many restoration monitoring projects concerned with increasing productivity levels.

Sampling

Carpenter and Lodge (1986) and Stevenson (1988) reviewed the literature for techniques used to measure productivity in SAV. Methods discussed included leaf marking, O_2 and CO_2 exchange, and aboveground dry weight. Another method to estimate belowground productivity is rhizome tagging as described by Short and Duarte (2001). Each of the methods, however, underestimates the total primary productivity of submerged vegetation (Carpenter and Lodge 1986; Stevenson 1988). A more accurate assessment of macrophyte biomass production could be derived using a variety of measurements and taking many small samples over time instead of a few large ones (Stevenson 1988). Standard methods for measuring the productivity rates, weight or light attenuation effects of epiphytes, however, have not been established. Researchers at the University of Maryland Center for Environmental Science Chesapeake Biology

Laboratory have been working on methods to assess these characteristics[26]. Additional methods for measuring primary productivity may be found in resources listed in the second appendix of this chapter.

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

SAV provides a variety of wildlife habitat and physical functions[27]. SAV habitats support a complex trophic structure and often have high biodiversity compared to unvegetated areas. SAV provides surfaces for:

- Algae and microbes to colonize
- Invertebrates to graze, hide from predators, and deposit eggs; and
- Fish to spawn, protect young, and feed

SAV (particularly freshwater species) create vertical structure that shades lower portions of the water column, setting up temperature and light availability gradients, thus, vertically diversifying habitats. SAV also provide important biochemical functions by transporting oxygen to the sediment and in return, transporting nutrients from the sediment into the water column (Wilcox 1995). Although specific relationships have only been worked out for a small number of species, some generalizations at the community level can be made for fish, birds, and invertebrates (Maynard and Wilcox 1997). Marine SAV, for example, provides foraging areas for fish, shrimp, dugongs, sea turtles, and a host of benthic organisms (Dunton 1998). Shrimp, fish, and crab larvae inhabit seagrass beds to avoid predation from larger animals (Day et al. 1989). Stem density and structural characteristics of the particular plant species present determine the species and abundance of animals that are able to use the habitat (Wilcox and Meeker 1992; Brazner 1997; Grenouillet and Pont 2001; Harrel et al. 2001; Spence-Cheruvelil et al. 2002; Valley and Bremigan 2002). As such, any natural or man-made change to SAV species composition can affect the abundance and distribution of animals and other plants found in the area (Sheridan et al. 1997; Wyda et al. 2002).

Breeding, nursery, and feeding grounds (including productivity and refuge)

Many species of fish, birds, and invertebrates use SAV habitats as feeding, breeding, and nursery areas. Many different types of invertebrates such as shrimp, crabs, snails, insects, and zooplankton use SAV to hide from predators, feed, and lay their eggs. Small fish species and juveniles of larger species use SAV to forage on invertebrates that tend to be more abundant in SAV areas than in open water. Smaller fish (and their invertebrate prey) also use SAV to hide from predators (Rozas and Odum 1987a). Herbivorous and piscivorous birds also feed in SAV habitats. Even mammals such as dugongs (*Dugong dugons*) and West Indian manatees (*Trichichus manatus*) and reptiles such as the green turtle (*Chelonia mydas*) use seagrass habitats as feeding grounds.

Invertebrates

SAV provides refuge for small and juvenile animals from predation. The distribution and abundance of micro- and macroinvertebrates, zooplankton, and zoobenthos are directly related to the presence, abundance, and complexity of habitat structure supplied by SAV. Macro- and microinvertebrates depend upon SAV to provide holdfasts, places to hunt and graze, and protect from predators. These invertebrates are often the basis of the food chain for larval fish and older stages of numerous species (Krieger 1992).

Marine Invertebrates

A variety of macroinvertebrates, many of them commercially important, use seagrass habitats

[26] http://cblcbos1.cbl.umces.edu/sone/

[27] For a detailed discussion of physical and habitat functions specific to seagrasses, readers are referred to Thayer, G. W., M. S. Fonseca and W. J. Kenworthy. 1985. Restoration of seagrass meadows for enhancement of nearshore productivity. pp. 259-278. Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution and Productivity. Rio Grande, Brazil.

at some point in their lifecycle (see Orth et al. 1983 for a more thorough review). A few examples include:

Marine shrimps (*Penaeus semisulcatus*)
Molluscs such as sea snails (*Aplysia californica*)
Bay scallops (*Argopecten irradians*)
Conch (*Strombus peruvianus*)
Pink shrimp (*Farfantepenaeus duorarum*)
Blue crabs (*Callinectes sapidus)*, and
Spiny lobsters (*Panulirus* spp.)

Increased Productivity - Seagrass habitats have been shown to significantly increase the productivity of invertebrate populations. Perkins-Visser et al. (1996), for example, studied the role of seagrass beds as nursery habitat for blue crabs in the lower York River, Virginia. First-stage crabs were placed into the vegetated and unvegetated, predator-free, enclosures. Juvenile blue crabs within eelgrass beds grew more rapidly than crabs in enclosures placed outside the eelgrass beds. Juvenile crab survival was also significantly greater in vegetated enclosures. A study of seagrass beds in lower Chesapeake Bay, Virginia encorporated a number of trophically important species including isopods, decapods, percarids, and molluscs. The studied seagrass beds (140-ha) also produced as much as 4.8 metric tons dry weight of invertebrates at any one time and 55.9 metric tons of invertebrates over the course of a year (Fredette et al. 1990).

Protection From Predation - The density of seagrasses helps hide some invertebrates from predators. A study on two species of clams (Mercenaria mercenaria and Chione cancellata) in Bogue Sound, North Carolina showed that after seagrass was experimentally removed, both clam species experienced high death rates. The clams were not dependent upon seagrasses for food but for protection from whelk (Busycon carica, B. contrarium, and B. canaliculatum), one of their main predators (Peterson 1982). Leber (1985) also studied the effect of seagrasses in protecting epifauna from larger predatory invertebrates. Some bivalve mollusks also use SAV as an attachment substrate. For example, zebra mussels attach to milfoil stems and are sometimes dispersed that way, wrapped around boat propellers. Small dark false mussels (Mytilopsis leucophaeata) in Chesapeake Bay have also been found attached to the more delicate slender pondweed (Potamogeton pusillis) stems (Bergstrom pers. comm.)

Seasonal Differences - The use of SAV by different types of organisms changes seasonally. This will affect the timing of monitoring activities for certain species. Sea urchins (Lytechinus variegates), for example do not significantly affect the turtle grass populations in the summer. Increased urchin densities in the winter, however, lead to significant reductions in seagrass cover (Macia 2000).

Additional literature practitioners interested in invertebrate communities may find useful include:

- van Montfrans et al. (1983) who reviewed the literature on epiphyte-grazer relationships in seagrass meadows, and
- Zieman and Zieman (1989) who provide a thorough review of invertebrate use of seagrass habitats

Freshwater Invertebrates

Feeding Grounds - Omnivorous crayfish can have serious direct and indirect impacts on SAV. Crayfish (*Orconectes rusticus*) feed on freshwater SAV. In doing so, they can alter species diversity, and reduce the density of individuals and overall biomass (Lodge et al. 1994 and review therein). They have even been known to completely eliminate SAV in some lakes (see review in Carpenter and Lodge 1986). Crayfish also feed on snails that feed on the periphyton that grows on SAV. Lodge et al. (1994) showed that by reducing snail populations, crayfish indirectly increase the amount of periphyton growing on submerged plants, decreasing the amount of light available to them. In areas of high crayfish abundance, it may be necessary to protect newly planted SAV with exclosures to keep crayfish out until plants become established. This would only be a temporary fix though if overall crayfish population and numbers of other herbivores remained high.

Snails help maintain healthy SAV beds by feeding on periphyton[28] (Reavell 1980; Daldorph and Thomas 1995). Periphyton compete with their host plants for light. If periphyton populations get too high, as is possible under nutrient rich conditions, SAV can become light starved and die. If snail populations are too low as a result of disease or predation from fish, SAV communities may decline. At higher populations, however, snails have also been shown to graze on SAV. Pip and Stewart (1976) showed that herbivory on SAV by snails (*Physa*) could also significantly reduce biomass and species diversity. Intense herbivory by invertebrates or waterfowl may affect the timing and amount of nutrient cycling by SAV and directly influence the amount of biomass that enters the detrital food chain. It may also impact the success of restoration projects if methods to control herbivore populations are not implemented.

Refuge From Predation - Freshwater plants with complex structure, such as *Elodea* and milfoil, harbor a greater diversity and higher population densities of zooplankton than do less structurally complex species such as wild celery (Spence-Cheruvelil et al. 2002). These differences are largely attributed to the greater protection from predation and larger surface area for attachment that structurally complex plants offer. The function of providing refuge for zooplankton has an important benefit for SAV communities. Submerged macrophytes compete with phytoplankton for light (Jones et al. 1983). By providing refuge areas for zooplankton that feed on phytoplankton (Fryer 1957; Zaret 1980; Twilley et al. 1985), SAV benefit by decreased turbidity and increased light availability. The community structure (species presence and abundance) of freshwater fish can also have complex interactions with SAV canopy cover and with zooplankton diversity and abundance. Perrow et al. (1999), examined the function of SAV as refuge for zooplankton in lakes. They looked at SAV bed characteristics such as percent cover, diversity, and plant height in association with zooplankton abundance and behavior in the presence of zooplanktivorous and piscivorous fish communities. In general, zooplankton preferred to feed in open water areas. In the presence of open water-feeding fish such as roach (*Rutilus rutilus*), however, a percent cover value of 30-40% SAV seemed sufficient to maintain refuge for populations of zooplankton. Species such as perch (*Perca fluviatilis*), however, are more efficient at feeding in SAV stands requiring a greater density of plant material to maintain zooplankton populations. Similarly, if the density of any zooplanktivorous fish species exceeds a high enough level (1 per m^2 is suggested) then no amount of SAV cover can protect populations of large zooplankton from being wiped out. Perrow et al. (1999) also theorized that piscivorous fish species such as pike (*Esox lucius*) can apply enough pressure on populations of zooplanktivores to enhance the refuge effect of SAV on zooplankton communities.

Sampling

Since macroinvertebrate communities change seasonally (Thorp et al. 1997), sampling should be conducted during the same season from one year to the next to make comparisons. As with fish, invertebrate communities also respond to episodic events and natural variability imposed by water level changes. Care must be taken to ensure that any changes in invertebrate community measured during the course of a restoration monitoring effort take these factors into account.

[28] Algae that attaches to SAV.

Benthic invertebrates – Benthic invertebrates are responsive to some forms of degradation and could be useful in monitoring SAV restoration activities (Krieger 1984). Benthic communities can, however, respond to a variety of environmental factors not directly associated with the presence, absence, or health of SAV communities, making interpretation of monitoring efforts challenging. Cole and Weigmenn (1983) found that benthic communities differed little between vegetated and unvegetated sites. Brady (1992), on the other hand, found greater diversity and productivity of invertebrates in the sediments of vegetated areas than in the sediments at unvegetated sites. The use of invertebrates to monitor the success or failure of efforts to restore SAV may be more useful if directed at sampling the invertebrate community of the water column and those within/upon the vegetation than focusing on the sediment surface.

Stove-pipe core samplers can be used to collect benthic invertebrates and sediment samples (Cuffney et al. 1993). These instruments are referred to as quantitative corers that are use to collect samples primarily in shallow-water habitats with rooted vascular plants. Stove-pipe cores are used by manually pushing the sampler into the sediment and then removing the SAV and coarse materials. The sample is then mixed and dispensed through a floating sieve where benthic invertebrates are collected and identified. This method is best used in slower moving waters. Van Veen samplers and ponar grab samplers can also be used to sample benthic invertebrates (Cuffney et al. 1993). The Van Veen grab sampler contains jaw-like structures that penetrate into sediments. Long arms attached to the Van Veen sampler increase leverage for penetrating into sediments. Weights can also be added to the Van Veen jaws to increase penetration in sediments (Bowman et al. 2000).

Insects – Although there are many methods with which to sample insect communities in freshwater SAV (see *Appendix II*: Review of Technical Methods Manuals), two types are commonly used to reduce effort in sorting insects and other invertebrates from sediments and detritus. Funnel traps can be placed over the surface of the water to capture any insects that emerge from the water and ultraviolet blacklight traps. The latter technique has been used to capture adult caddisflies (Order: Tricoptera) to differentiate between healthy and impacted Great Lake's coastal wetlands (Armitage et al. 2001).

The US EPA has put together a publicly available manual for using invertebrates to assess environmental conditions in wetlands. Although this manual is geared toward the development of Indices of Biological Integrity, many of the sampling methods and issues are similar to sampling for monitoring purposes. This reference *Methods for Evaluating Wetland Condition: Developing an Invertebrate Index of Biological Integrity for Wetlands* is available at http://www.epa.gov/ost/standards and at http://www.epa.gov/owow/wetlands/bawwg (EPA 2002b). The U.S. Geological Survey also has a variety of manuals for monitoring invertebrates and other aspects of SAV habitats. These can be found at http://water.usgs.gov/nawqa/protocols/bioprotocols.html.

Fish

A host of fish species use SAV habitats as feeding, breeding, and nursery grounds, many of which are completely dependent upon SAV at some point in their lifecycle. Species of small bodied fish and juveniles of larger species use SAV to forage on invertebrates that tend to be more abundant in SAV areas than in open water (Rozas and Odum 1987a). Others, such as the freshwater species of northern pike and largemouth bass (*Micropterus salmoides*) are able to navigate and exploit openings in SAV habitats to hunt for prey (Bry 1996; Trebitz et al. 1997; Valley and Bremigan 2002).

The extreme diversity and total number of marine fishes that use SAV habitats throughout the United States and its protectorates makes a comprehensive listing of all species well beyond the scope of this document. Those listed, as well as those presented below, are just a few examples to give practitioners an idea of the types of fish that use SAV and how the habitat is used. Any restoration effort with a fisheries component will need to find more local or regional literature to assist them in designing and monitoring their particular restoration project. Materials in Appendix I, and contacts listed in Appendix II may assist in this process.

Marine Fishes

A variety of fish species use seagrass habitats at some point in their lifecycle including many commercially important species such as:

Red snapper (*Lutjanus campechanus*)
Spotted seatrout (*Cynoscion regalis*)
Barracuda (*Sphyraena argentea*)
Snook (*Centropomus* spp.), and
Tarpon (*Megalops atlanticus*)

Nursery Ground

Nagelkerken et al. (2002) discussed the importance of seagrass beds as nursery habitats for juvenile fish near coral reefs. They noted previous studies showing that juveniles of 17 Caribbean reef-fish species were significantly associated with bay areas containing seagrass beds whereas bays without seagrass had very few juveniles, if any. Nagelkerken et al. (2002) also compared the densities of the 17 fish species between Caribbean island reefs with and without seagrass beds. Reefs without seagrass showed a complete absence or very low densities of 11 of the 17 fish species. Researchers concluded that seagrass played an important role as nursery habitat for these fish species and fisheries in general. In addition, if seagrass habitats are degraded or lost, then reef-fish stocks will be significantly affected.

Productivity

Deegan et al. (1997) used trawls to test the development of a fish-based Estuarine Biotic Integrity (EBI) index for SAV habitats. Of 15 possible metrics, they chose eight for inclusion in the EBI: total number of species, dominance, fish abundance (number or biomass), number of nursery species, number of estuarine spawning species, number of resident species, proportion of benthic-associated fishes, and proportion abnormal or diseased. They found that fish communities at the low-quality sites had fewer species and lower density and biomass compared with medium-quality sites. They also found that the EBI results based on number of species performed as well as results calculated from biomass that is more time consuming to obtain and that the extra work to obtain biomass numbers was not warranted in this case.

Freshwater Fishes

Freshwater SAV habitats provide spawning, nursery, and feeding areas for many coastal species as well (Figure 11 - Jude and Pappas 1992). Of the roughly 200 fish species found in the Great Lakes, about 90% are directly dependent on coastal wetlands (including areas of SAV) during some aspect of their life cycle (Whillans 1987; Stephenson 1990).

Productivity

SAV support the highest biomass, density, and diversity of fish compared to other available aquatic habitats (Keast et al. 1978). Estimates of fish productivity can be twice as high in vegetated vs. unvegetated areas (Randall et al. 1996). The number of fish species also increases with increasing stream order and related increases in the distribution of SAV (Rozas and Odum 1987b). Diversity and abundance of different species has also been shown to be higher in undeveloped areas compared to developed areas of Green Bay (Brazner 1997). This, coupled with the fact that about 75% of the original coastal wetland area of the Great

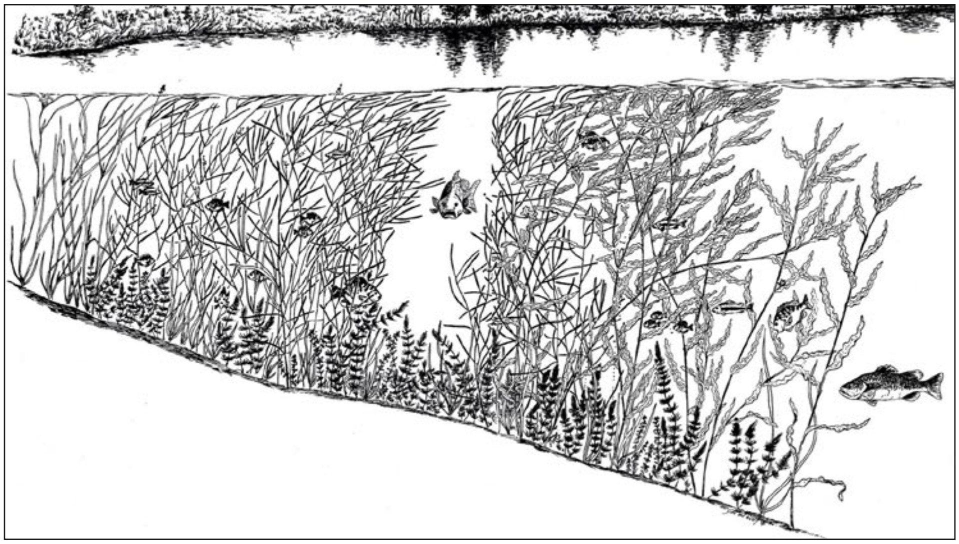

Figure 11. The diverse canopy created by freshwater SAV allows fish to use a variety of microhabitats. Smaller fish hide from predators within the vegetation, while large predacious fish cruise through gaps (lanes) in the vegetation or along the edge of the bed hunting for smaller fish. Figure modified from Engel 1985.

Lakes has been lost (Jude and Pappas 1992), highlights the importance of preserving the remaining areas for standing fish stocks and of restoring additional habitat if fish productivity is to increase.

Feeding

Grass carp (*Ctenopharyngodon idella*), an exotic introduced from Asia, is one of the few fish species in North America that feed directly on freshwater SAV (Mitzner 1978). Carp have been shown to dramatically reduce SAV and in the process increase turbidity thus contributing to further impacts to submerged plant species. The scarcity of SAV in some Great Lakes coastal wetlands has been attributed to increases in turbidity as a result of carp feeding activity (Klarer and Millie 1992). Effects of carp on water quality are worst when adult carp become trapped in a wetland. If carp are allowed free access to exit the wetland in the fall, damage to water quality and plants is minimal (Wilcox 1995).

It may, however, be desirable to exclude carp altogether (while allowing native fish access to the marsh for feeding and spawning) for newly planted/seeded material to establish. Gate-like structures have been demonstrated that keep adult carp out of coastal marshes and could be used for restoration projects (French et al. 1999). As constructed, the gate excludes adult carp but allows smaller fish to pass freely between open-lake and wetland waters.

Sampling Methods

A myriad of techniques and equipment are available for sampling fish populations in marine and freshwater environments. Many of the more common ones such as seining and electroshocking can, however, be problematic in SAV habitats and may underestimate fish biomass by as much as half. Fish also move from resting areas to foraging areas with the tides, time of day (Robertson 1980; Serafy et al. 1988), and between seasons (Stephenson 1990; Gelwick et al. 2001). This means that if sampling of fish is to be incorporated as part of restoration monitoring, very specific questions about the goal of the project and the timing of sampling need to be answered before fieldwork is conducted. The positives and negatives of using techniques such as trawling, seining, electroshocking, trapnets, hoopnets, gillnets, and visual assessment in areas of dense SAV are discussed below. In addition to these examples, the use of popnets, seines, and electroshocking techniques to sample fish in and around SAV habitats is discussed in Killgore et al. (1989) and Morgan et al. (1988).

There is no single perfect method for sampling the fish community in a given area. Different

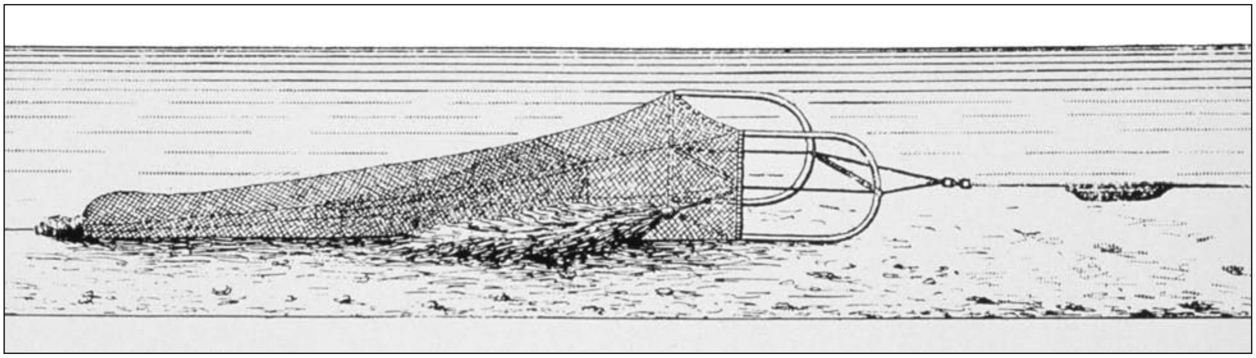

Figure 12. Trawls such as this are pulled behind a boat to collect samples. The example shown here is a Hirondelle sled or bottom trawl. Other styles are available for use throughout the water column. Photo courtesy of the Oceanographic Museum of Monaco and the NOAA Central Library. http://www.photolib.noaa.gov/ships/ship4113.htm

methods must be employed depending on the particular goal of the restoration effort and question to be answered. Typically several different methods used in combination will be the most effective approach. The methods described here as well as other passive and active techniques to sample fish communities can be found in Murphy and Willis' (1996) *Fisheries Techniques* published by the American Fisheries Society.

Trawls - Trawls are cone shaped nets that are towed through the water with the use of a boat (Figure 12). They can be used to sample either along the bottom (bottom trawls) or through the water column (midwater trawls). As the nets are pulled through the water, fish enter them, eventually tire and are held against the cod end of the net. Trawls are often tied shut on the cod end so that when the net is retrieved, the end can be untied and the fish more easily removed. Trawls are commonly used for scientific research because they are able to sample a known quantity of water (if you know the area of the trawl opening and the distance through the water it was pulled) and thus can be used to obtain information that can then be projected over a wider area. A large variety of trawls can be found, many with adaptations for specific species and habitats (Murphy and Willis 1996). As with other forms of nets, trawls work best in areas with open water above SAV communities. Trawls pulled through dense beds of SAV will quickly become clogged ruining the sample, destroying SAV habitat and possibly damaging the net and boat motor as well.

Electroshocking - Electroshocking does not work well in dense beds of SAV for several reasons. Smaller fish, that tend to be more abundant in SAV, are not as greatly affected by shocking as are larger fish (Zalewski and Cowx 1990). Dense vegetation also tends to hide fish that are fleeing or trap fish that are stunned, thus contributing to lower catch rates. This means that measures of fish abundance and levels of production are likely to be underestimated using this method (Randall et al. 1996). Electroshocking also does not work in deeper-water, seagrass habitats.

Gill nets - Gill nets can be used to sample fish in both fresh and marine waters. Gill nets consist of smaller panels that are connected together with bridles so that the net can be extended to any desired size (Figure 13 - Adkins and Bourgeois 1982). The nets contain a floatline, consisting of air filled structures that keep the net afloat and a sinker or leadline that contains weights that keep the bottom of the net below the water surface. Once the net is deployed, fish swim into the mesh where they become trapped as their

Figure 13. A gill net being retrieved for analysis. Photo courtesy of Chris Doley. http://www.photolib.noaa.gov/habrest/r0022603.htm.

head fits through the mesh but gills become trapped when they try to pull out (Adkins and Bourgeois 1982).

Although gillnets are destructive to fish, if particular size classes of fish are of interest, they can be an effective method for collecting samples (Pratt and Fox 2001). Nets of different mesh sizes can also be tied together to increase sampling efficiency, as gill nets tend to undersample smaller fish species. Gill nets, as other types of nets, can also become entangled in SAV making retrieval difficult.

Seines - Seines (also called beach seines) are nets attached to poles and are operated by two people walking through shallow water (Figure 14 - Meador et al. 1993). One person stands on or near the shore while the other (usually the taller and stronger of the two) wades out into the area to be sampled. Once the net is completely stretched open, the person out in the water sweeps the net back in toward the shore keeping it stretched open at all times. Once that person reaches the shore, the contents of the net can be lifted onto the shore and sorted. Beach seines tend to capture a large number of small, slow fish such as juveniles and forage fish (Hintz 1999). Larger, faster adult fish and those typically used for sport such as crappie (Pomoxis spp.), channel catfish (Ictalurus punctatus), and

Figure 14. A beach seine being taken near Galveston, Texas. Photo from the NOAA Photo Library. http://www.photolib.noaa.gov/fish/fish0814.htm

walleye (Stizostedion vitreum) are often able to escape the net and are thus underrepresented with this method. Additional problems with seines derive from hydrodynamics, particularly those of the Great Lakes. Seiches and inter-annual water level fluctuations of the lakes can erode sampling stations or make water too deep to sample safely. Thus, making year-to-year comparisons impossible. Seines may also get clogged with SAV and cannot be used where there is much woody debris, as the nets will get snagged.

Entrapment gear - Entrapment gear such as hoop nets, fyke nets (Figure 15), and trap nets capture fish in enclosed mesh traps. Like gill nets they come in various mesh sizes to capture different sizes and age classes of fish. Unlike gill nets, however, fish caught using these gear can be released with a minimum of harm (Meador et al. 1993; Murphy and Willis 1996).

Figure 15. A small fyke net such as this one can be used to sample for juvenile fish as well as macroinvertebrates invertebrates. Larger versions are also available for sampling larger, adult fish. Photo courtesy of Doug Wilcox, US Geological Survey.

Visual assessment - Visual assessment methods have also been developed for use by snorkelers and divers[29] to sample fish communities (Keast and Harker 1977; Jones and Thompson 1978; Bohnsack and Bannerot 1986; Pratt and Fox 2001). These methods include point counts and transect surveys among others (Murphy and Willis 1996; Hodgson et al. 2004). Point-count surveys are performed by scuba divers who observe and record fish within a particular area during a set interval of time. Transect surveys can be used to identify and estimate fish abundance and diversity. In transect surveys, divers move along a transect placed on the substrate and count and record fish within the sample area. This method has proven to be very effective and is being used in ecological and restoration monitoring by various environmental organizations such as NOAA Center for Coastal Monitoring and Assessment. Visual assessment methods can sample more species and life stages in moderate to dense stands of SAV compared to gillnetting but overall abundance can be underestimated. Cryptic and pelagic species also tend to be underrepresented by visual assessment. Despite these drawbacks, visual sampling methods are better than gillnetting for assessing certain characteristics of the fish community, namely species diversity and different life stages.

Physical characteristics of the water column such as turbidity and temperature can affect the success of these sampling methods. Reductions in visibility will obviously affect visual estimation methods but high turbidity has also been shown to alter fish behavior (Wright and O'Brien 1984; Hansson and Rudstam 1995) thus affecting other sampling methods as well. Temperature can also affect the accuracy of fish sampling. Fish tend to be less active at colder temperatures and are less likely to be caught in nets or noticed visually (Hillman et al. 1992).

Birds

Birds that use SAV habitats can be broken into two groups: herbivores that eat SAV and piscivores that hunt for small fish, amphibians, and other small animals in SAV habitats. The type of birds used in a monitoring program will depend upon the goals of the restoration effort as well as the availability of each type of food and adjacent habitats suitable for nesting.

Herbivores

A variety of waterfowl eat SAV. Swans (Figure 16), coots, and herbivorous diving ducks feed on tubers, seeds stems and leaves of freshwater SAV (Jupp and Spence 1977; Kiorboe 1980; Carter and Rybicki 1985; Blindow 1986; Prince et al. 1992; Mitchell and Wass 1996; Perry and Deller 1996; Knapton and Scott 1999). Waterfowl with longer necks such as swans can reach more SAV and thus do more damage. Also mute swans tend to pull up SAV by the roots which is much more destructive than feeding by other waterfowl that tend to only crop the portions of the plants they can reach. Resident waterfowl such as mute swans and non-migratory Canada geese are also more destructive to SAV since they are present

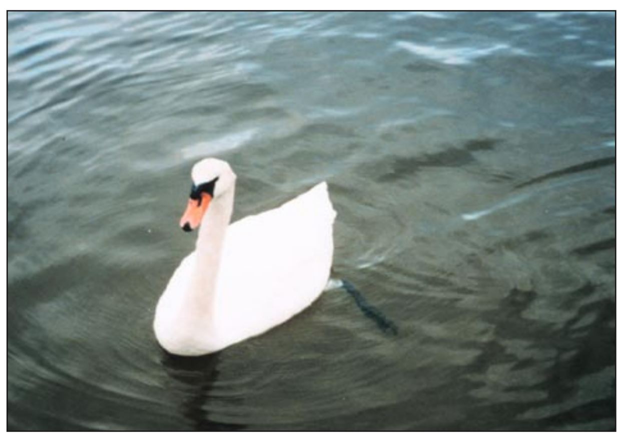

Figure 16. Mute swans commonly feed on SAV. Although beautiful, they are very aggressive and should never be approached, especially when their young are present. They are also an invasive species in the United States. Photo courtesy of Mary Hollinger, NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0598.htm.

[29] If diving is not feasible, the use of underwater cameras may also be a useful technique for monitoring fish species presence and interactions in relation to SAV of different densities (Harrel, S. L., E. D. Dibble and K. J. Killgore. 2001. Foraging behavior of fishes in aquatic plantpp. APCRP Technical Notes Collection ERDC TN-APCRP-MI-06, U.S. Army Engineer Research and Development Center, Vicksburg, MS).

when SAV is actively growing and reproducing. In contrast, wintering waterfowl can only eat storage structures such tubers of as wild celery and sago pondweed (Bergstrom pers. comm.). Plants most commonly used as food include wild celery, muskgrass, pondweed, smartweed, and naiads (Knapton and Scott 1999). Waterfowl have been known to consume as much as 50% of the total annual biomass produced by SAV, however, most observed herbivory occurs at the end of the growing season when plants are dying (Kiorboe 1980). Although this herbivory and the small amount that occurs throughout the growing season may be enough to prevent the total domination of a system by aquatic macrophytes, and may alter species composition in future years as birds feed on reproductive structures, it is generally not thought to severely impact or control the growth of SAV in total (Kiorboe 1980; Mitchell and Wass 1996; Perrow et al. 1997; Knapton and Scott 1999; Noordhuis et al. 2002).

Piscivores

Piscivorous birds also use SAV habitats as foraging areas (Kersten et al. 1991; Prince et al. 1992). Juvenile egrets, for example, congregate in unvegetated shallow pools within aquatic macrophytes beds to feed on larval fish during early morning hours (Figure 17 - Kersten et al. 1991). Nocturnal respiration of macrophytes reduces dissolved oxygen to low enough levels to force fish into unvegetated shallows, and eventually to congregate and respire directly at the surface where they are vulnerable to predation. After sunrise, when photosynthesis returns dissolved oxygen to tolerable levels, remaining fish flee and the egrets disperse. High rates of primary production and abundant epiphytic algae provide food for a variety of crustaceans and mollusks that are also fed upon by other waterfowl and wading birds (Prince et al. 1992).

Measuring and Monitoring Methods

The EPA has developed a manual for using birds to assess environmental conditions in wetlands including SAV habitats. Although this manual is geared toward the development of Indices of Biological Integrity, many of the sampling methods and issues are similar when sampling for restoration monitoring purposes. This reference *Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds* is available at http://www.epa.gov/ost/standards and at http://www.epa.gov/owow/wetlands/bawwg (EPA 2002a).

PHYSICAL

Filters and Stabilizes Sediments

The physical water quality functions provided by SAV habitats include increased sediment stabilization and deposition (Hemminga and Duarte 2000). Seagrass beds, in particular, have thick underground mats made of roots, shoots, and stems that trap sediment particles. Water velocity and wave energy in coastal areas can be significantly diminished by the presence of SAV (Carter et al. 1988; Heath 1992; Carter et al. 1994; Madsen et al. 2001). This contributes to an increase in sedimentation rates and a

Figure 17. A greater egret (*Ardea alba*) fishing in a tidal pond. Photo courtesy of John White http://elib.cs.berkeley.edu/cgi/img_query?seq_num=121483&one=T.

decrease in turbidity, thus increasing the depth to which light can reach, further stimulating SAV growth (Gacia and Duarte 2001). Dense beds of SAV decrease the amount of shear stress that wave energy and current velocities can have on sediment surfaces. Winds as weak as ~12 km/hr are sufficient to resuspend sediments when SAV is absent (James and Barko 1994). When dense beds of SAV are present, wind velocity needs to be much higher in order to resuspend sediments (~20 km/hr). The frequency of resuspension events and the total amount of sediment discharged to downstream areas decreases as sediments are retained within the bed (Gacia and Duarte 2001). Even during high winds (e.g., > 30 km/hr), shear stress at the sediment surface can be near zero within beds of common watermilfoil (*Myriophyllum sibiricum*), muskgrass, and seagrasses when biomass levels were high (>200g/m^2 - Gacia and Duarte 2001; James et al. 2001). Interestingly, common water milfoil and muskgrass have very different architecture types. Common water milfoil forms dense canopies near the surface of the water while muskgrass forms meadows along the sediment surface. Both plants were effective at mitigating wave-induced shear stress and associated sediment resuspension. In areas where boating and other recreational activities are present, the planting of meadow-forming species such as muskgrass that reduces shear stress but also allows for a volume of open water above may accommodate both uses of the area more effectively than planting of canopy-forming species.

Practitioners needing additional detail on the importance of SAV for stabilizing sediments, increasing biological productivity, and reducing coastal erosion are directed to Fonseca et al. (1982).

Measuring and Monitoring Methods

Methods for measuring soil characteristics such as accretion, deposition, resuspension, sediment grain size, % organic matter, bulk density, and others can be found in the literature cited above, the previous section on Structural Characteristics: Physical, and in the second appendix of this chapter.

CHEMICAL

Modifies Water Quality

SAV enhances coastal water quality by reducing the amount of suspended material in the water column and by absorbing dissolved nutrients. The ability of SAV to reduce water velocity and increase sedimentation rates was also previously discussed. Short and Short (1984) evaluated previous studies and compared results to suspended sediment and dissolved nutrient removal experiments in culture tanks with and without SAV present. They monitored the addition and removal of nutrients in the tanks and determined that materials were removed from the water more readily in tanks with macrophytes present. Other researchers, however, found that macrophytes obtained more of their nutrients from the sediment rather than from the water column (Carignan and Kalff 1980; Barko and Smart 1981b; Fourqurean et al. 1992). Although macrophytes themselves obtain most of their nutrients from the sediment, they provide surfaces for epiphytes that do obtain the majority of their nutrients from the water column. Epiphytes can contribute almost half of the total primary productivity of SAV habitats (Moncreiff and Sullivan 2001). Thus, the mere presence of SAV as an attachment surface for epiphytes increases the overall primary productivity of the area and reduces the amount of available nutrients from the water column, thus helping to improve water quality.

Measuring and Monitoring Methods

Methods for measuring nutrient concentrations, turbidity, light availability, and other water quality characteristics in SAV habitats were previously covered in the Structural Characteristics section of this chapter

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS

The matrices of structural and functional parameters for restoration monitoring presented below were developed through extensive review of the restoration and ecological monitoring-related literature. Additional input was received from recognized experts in the field of coastal SAV ecology. These lists are not exhaustive and are merely intended as a starting point to help practitioners develop monitoring plans for SAV restoration projects. Parameters with a closed circle (●) are those that, at a minimum, should be considered in monitoring restoration projects. 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 previous text and in the literature cited herein. Literature directing readers toward additional information on the ecology of submerged aquatic vegetation, restoration case studies, and sampling strategies and techniques can be found in *Appendix I: An Annotated Bibliography of SAV* and *Appendix II: A Review of Technical Methods Manuals*, respectively.

Parameters to Monitor the Structural Characteristics of SAV

Parameters to Monitor	Structural Characteristics — **Biological**: Habitat created by plants	**Physical**: Sediment grain size[30]	Topography / Bathymetry	Turbidity	**Hydrological**: Tides / Hydroperiod	Water Sources	Current velocity	Wave energy	**Chemical**: Nutrient concentration	pH, salinity, toxics, redox, DO[31]
Geographical										
Acreage of habitat types	●									
Biological										
Plants										
Species, composition, and %cover of:										
Algae	❍									
Epiphytes	❍									
Herbaceous vascular	●									
Canopy extent and structure	❍									
Interspersion of habitat types	❍		❍							
Plant height	❍									
Seedling survival	❍									
Stem density	❍									
Hydrological										
Physical										
PAR[32]				●						
Secchi disc depth				●						
Shear force at sediment surface							❍	❍		
Temperature						❍				
Upstream land use						❍				
Water column current velocity							●			
Water level fluctuation over time					●	●				
Chemical										
Dissolved oxygen										❍
Groundwater indicator chemicals[33]						❍				
Nitrogen and phosphorus									❍	
Salinity (in tidal areas)					●	●				●
Toxics										❍
Soil/Sediment										
Physical										
Basin elevations			❍							
Geomorphology (slope, basin cross section)			●		●					
Organic content		●							●	
Percent sand, silt, and clay		❍								
Sedimentation rate and quality		❍	❍							
Chemical										
Pore water nitrogen and phosphorus									❍	
Redox potential										❍

30 Including organic matter content.
31 Dissolved oxygen.
32 Photosynthetically active radiation.
33 Calcium and magnesium.

Parameters to Monitor the Functional Characteristics of SAV

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	Physical: Affects transport of suspended/dissolved material	Alters turbidity	Reduces erosion potential	Reduces wave energy	Modifies water temperature	Chemical: Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Geographical																	
Acreage of habitat types	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Biological																	
Plants																	
Species, composition, and % cover of:																	
Algae	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍	❍		❍	❍	❍
Epiphytes	❍	❍			❍		❍	❍		❍					❍		❍
Herbaceous vascular	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Invasives			❍	❍	❍	❍	❍	❍									
Canopy extent and structure		❍	❍	❍	❍	❍	❍		❍	❍	❍		❍	❍			
Interspersion of habitat types		❍	❍	❍	❍	❍	❍	❍		❍	❍	❍	❍	❍			
Plant health (herbivory damage, disease[34])					❍												
Plant height	❍	❍												❍			
Plant weight (above and/or below ground parts)	❍	❍			❍												
Rate of canopy closure	❍	❍												❍			
Seedling survival[34]												❍	❍				
Stem density				❍		❍		❍	❍	❍	❍	❍	❍	❍			

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

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	Physical: Affects transport of suspended/dissolved material	Alters turbidity	Reduces erosion potential	Reduces wave energy	Modifies water temperature	Chemical: Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Biological																	
Animals																	
Species, composition, and abundance of:																	
Birds		○	○	○	○	○	○	○									
Fish		○	○	○	○	○	○	○									
Invasives		○		○	○	○	○										
Invertebrates		○	○	○	○	○	○	○									
Hydrological																	
Physical																	
Fetch										○	○	○	○				○
PAR	●	●								●	●						
Secchi disc depth	●	●								●	●						
Shear force at sediment surface										○	○	○	○				
Temperature			○	○										○		○	○
Trash										○							
Upstream land use										○	○					○	
Water column current velocity										○	○	○					
Water level fluctuation over time			●	●	●	●				●	●	●			●		●

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

Parameters to Monitor	Functional Characteristics — 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	Physical: Affects transport of suspended/dissolved material	Alters turbidity	Reduces erosion potential	Reduces wave energy	Modifies water temperature	Chemical: Supports nutrient cycling	Modifies chemical water quality	Modifies dissolved oxygen
Hydrological																	
Chemical																	
Dissolved oxygen			❍	❍			❍	❍							❍	❍	❍
Groundwater indicator chemicals																❍	
Nitrogen and phosphorus	❍	❍									❍				❍	❍	
pH																❍	
Salinity (in tidal areas)							❍									❍	❍
Toxics			❍	❍	❍											❍	
Soil/Sediment																	
Physical																	
Basin elevations			❍	❍	❍	❍	❍		❍	❍				❍			
Geomorphology (slope, basin cross section)			●	●	●	●	●		●	●	●	●		●		●	●
Sediment grain size (OM[35]/sand/silt/clay/gravel/cobble)		❍							❍	❍	❍	❍	❍		❍	❍	❍
Sedimentation rate and quality							❍			❍	❍	❍					
Chemical																	
Organic content in sediment		❍			❍		❍	❍		❍	❍				❍	❍	❍

[35] Organic matter.

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References

Ackerman, J. D. 1983. Current flow around *Zostera marina* plants and flowers: Implications for submarine pollination. *Biological Bulletin (Woods Hole)* 5:504.

Ackleson, S. G. and V. Klemas. 1987. Remote sensing of submerged aquatic vegetation in Lower Chesapeake Bay: A comparison of Landsat MSS to TM imagery. *Remote Sensing of Environment* 22:235-248.

Adkins, G. and M. J. Bourgeois. 1982. An evaluation of gill nets of various mesh sizes, 59 pp. Report Number 36, Louisiana Dept. of Wildlife and Fisheries, New Orleans, LA.

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

Armitage, B. J., P. L. Hudson and D. A. Wilcox. 2001. Caddisflies (Insecta: Trichoptera) of fringing wetlands of the Laurentian Great Lakes. *Verhandliungen-Internationale Vereinigung fur Theorietische und Angewandte Limnologie* 27:3420-3424.

Bailey, R. C. 1988. Correlations between species richness and exposure: Freshwater molluscs and macrophytes. *Hydrobiologia* 162:183-191.

Barko, J. W. and R. M. Smart. 1981a. Comparative influences of light and temperature on the growth and metabolism of selected submersed freshwater macrophytes. *Ecological Monographs* 51:219-235.

Barko, J. W. and R. M. Smart. 1981b. Sediment-based nutrition of submersed macrophytes. *Aquatic Botany* 10:339-352.

Barko, J. W. and R. M. Smart. 1986. Sediment-related mechanisms of growth limitation in submersed macrophytes. *Ecology* 67:1328-1340.

Barko, J. W., R. M. Smart and D. G. McFarland. 1991. Interactive effects of environmental conditions on the growth of submersed aquatic macrophytes. *Journal of Freshwater Ecology* 6:199-207.

Bates, A. L. and C. S. Smith. 1994. Submersed plant invasions and declines in the Southeastern United States. *Lake and Reservoir Management* 10:53-55.

Batiuk, R. A., P. Bergstrom, W. M. Kemp, E. W. Koch, L. Murray, J. C. Stevenson, R. Bartleson, V. Carter, N. B. Rybicki, J. M. Landwehr, C. L. Gallegos, L. Karrh, M. Naylor, D. J. Wilcox, K. A. Moore, S. Ailstock and M. Teichberg. 2000. Chesapeake Bay submerged aquatic vegetation water quality and habitat-based requirements and restoration targets: A second technical synthesis. United States Environmental Protection Agency for the Chesapeake Bay Program.

Batiuk, R. A., R. J. Orth, K. A. Moore, W. C. Dennison, J. C. Stevenson, L. W. Staver, V. Carter, N. B. Rybicki, R. E. Hickman, S. Kollar, S. Bieber and P. Heasly. 1992. Chesapeake Bay Submerged Aquatic Vegetation Habitat Requirements and Restoration Targets: A Technical Synthesis, 248 pp. CBP/TRS 83/92, Chesapeake Bay Program, Annapolis, MD.

Bergstrom, P. 2002. Salinity methods comparison: Conductivity, hydrometer, refractometer. *The Volunteer Monitor* 14:20.

Bergstrom, P. 2004. First look comments on SAV monitoring chapter. Email September 20. Ann Arbor, MI.

Blankenship, K. 2004. Bay's SAV fell off almost 30% in 2003. June. pp. 6. Bay Journal: The Chesapeak Bay Newspaper, Seven Valleys, PA. http://www.bayjournal.com/04-06/index.htm

Blindow, I. 1986. Underwater vegetation and birds. *Fauna och Flora (Stockholm)* 81:235-244.

Bohnsack, J. A. and S. P. Bannerot. 1986. A stationary visual census technique for quantitatively assessing community structure of coral reef fishes, 15 pp. National Marine and Fisheries Technical Service Report 41, U.S. Department of Commerce, National Oceanographic and Atmospheric Administration.

Bologna, P. A. X. and K. L. Heck. 1999. Macrofaunal associations with seagrass epiphytes. Relative importance of trophic and structural characteristics. *Journal of Experimental Marine Biology and Ecology* 242:21-39.

Bowman, M. L., J. Gerristen, G. R. Gibson, Jr., and B. D. Snyder. 2000. Estuarine and coastal marine waters: Bioassessment and biocriteria technical guidancepp. EPA 822-B-00-024, US Environmental Protection Agency, Office of Water, Washington, D.C.

Brady, V. J. 1992. The invertebrates of a Great Lakes coastal marsh, 132 pp. Michigan State University, Lansing, MI.

Brazner, J. C. 1997. Regional, habitat, and human development influences on coastal wetland and beach fish assemblages in Green Bay, Lake Michigan. *Journal of Great Lakes Research* 23:36-51.

Bry, C. 1996. Role of vegetation in the life cycle of pike, pp. 45-156. In Craig, J. F. (ed.) Pike: Biology and Exploitation. Chapman and Hall, London.

Bulthuis, D. A. 1983. Effects of *in situ* light reduction of densit and growth of the seagrass *Heterozostera tasmanica* (Martens ex Aschers.) den Hartog, in Western Port Victoria, Australia. *Journal of Experimental Marine Biology and Ecology* 67:91-103.

Bulthuis, D. A., G. W. Brand and M. C. Mobley. 1984. Suspended sediments and nutrients in water ebbing from seagrass-covered and denuded tidal mudflats in a southern Australian embayment. *Aquatic Botany* 20:257-266.

Butcher, R. W. 1933. Studies on the ecology of rivers: I. on the distribution of macrophytic vegetation in the rivers of Britain. *Journal of Ecology* 21:58-91.

Carignan, R. and J. Kalff. 1980. Phosphorus sources for aquatic weeds: Water or sediments? *Science* 207:987-989.

Carpenter, S. R. and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26:341-370.

Carr, G. M., H. C. Duthie and W. D. Taylor. 1997. Models of aquatic plant productivity: A review of the factors that influence growth. *Aquatic Botany* 59:195-215.

Carter, V., J. W. Barko, G. L. Godshalk and N. B. Rybicki. 1988. Effects of submersed macrophytes on water quality in the tidal Potomac River, Maryland. *Journal of Freshwater Ecology* 4:493-501.

Carter, V. and N. Rybicki. 1986. Resurgence of submersed aquatic macrophytes in the tidal Potomac River, Maryland, Virginia, and the District of Columbia. *Estuaries* 9:368-375.

Carter, V. and N. B. Rybicki. 1985. The effects of grazers and light penetration on the survival of transplants of *Vallisneria americana* Michx in the tidal Potomac River, Maryland. *Aquatic Botany* 23:197-213.

Carter, V. and N. B. Rybicki. 1990. Light attenuation and submersed macrophyte distribution in the tidal Potomac River and estuarty. *Estuaries* 13:441-452.

Carter, V. and N. B. Rybicki. 1994. Invasions and declines of submersed macrophytes in the tidal Potomac River and estuary, the Currituck Sound-Back Bay system, and the Pamlico River Estuary. *Lake and Reservoir Management* 10:39-48.

Carter, V., N. B. Rybicki and R. Hammerschlag. 1991. Effects of submersed macrophytes on dissolved oxygen, pH, and temperature under different conditions of wind, tide, and bed structure. *Journal of Freshwater Ecology* 6:121-133.

Carter, V., N. B. Rybicki, J. M. Landwehr and M. Turtora. 1994. Role of weather and water quality in population dynamics of submersed macrophytes in the tidal Potomac River. *Estuaries* 17:417-426.

Chambers, P. A. 1987. Nearshore occurrence of submerged aquatic macrophytes in relation to wave action. *Canadian Journal of Fisheries & Aquatic Sciences* 44:1666-1669.

Chambers, P. A., E. E. Prepas, H. R. Hamilton and M. L. Bothwell. 1991. Current velocity and its effect on aquatic macrophytes in flowing waters. *Ecological Applications* 1:249-257.

Cole, R. A. and D. L. Weigmann. 1983. Relationships among zoobenthos, sediments, and organic matter in littoral zones of the western Lake Erie and Saginaw Bay. *Journal of Great Lakes Research* 9:568-581.

Cowardin, L. M., V. Carter, F. C. Golet and E. T. LaRoe. 1979. Classification of wetlands and deepwater habitats of the United States, 104 pp. FWS/OBS-79/31, U.S. Fish and Wildlife Service, Washington, DC.

Cuffney, T. F., M. E. Gurtz and M. R. Meador. 1993. Methods for collecting benthic invertebrate samples as part of the National Water Quality Assessment Programpp. Open File Report 93-406, U.S. Geological Survey, Raleigh, NC.

Daldorph, P. W. G. and J. D. Thomas. 1995. Factors influencing the stability of nutrient-enriched freshwater macrophyte communities: The role of sticklebacks *Pungitius pungitius* and freshwater snails. *Freshwater Biology* 33:271-289.

Dale, H. M. and T. J. Gillespie. 1977. The influence of submersed aquatic plants on temperature gradients in shallow water bodies. *Canadian Journal of Botany* 55:2216-2225.

Davis, J. E. and B. Streever. 1999. Wetland erosion protection structures: How low can you go? *Wetlands Research Bulletin* CRWRP-1:5-8.

Day, J. W., Jr., C. A. S. Hall, W. M. Kemp and A. Yanez-Arancibia. 1989. Estuarine Ecology. John Wiley and Sons, NewYork.

Deegan, L. A., J. T. Finn, S. G. Ayvazian, C. A. Ryder-Kieffer and J. Buonaccorsi. 1997. Development and validation of an Estuarine Biotic Integrity Index. *Estuaries* 20:601-617.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *BioScience* 43:86-94.

Dierssen, H. M., R. C. Zimmerman, R. A. Leathers, T. V. Downes and C. O. Davis. 2003. Ocean color remote sensing of seagrass and bathymetry in the Bahamas Banks by high-resolution airborne imagery. *Limnology and Oceanography* 48:444-455.

Dodds, W. K. and B. J. F. Biggs. 2002. Water velocity attentuation by stream periphyton and macrophytes in relation to growth form and architecture. *Journal of the North American Benthological Society* 21:2-15.

Doyle, R. D. 2001. Effects of waves on the early growth of Vallisneria americana. *Freshwater Biology* 46:389-397.

Dromgoole, F. I. and J. M. A. Brown. 1976. Quantitative grab sampler for dense beds of aquatic macrophytes. *New Zealand Journal of Marine and Freshwater Research* 10:109-118.

Duarte, C. M. 2002. The future of seagrass meadows. *Environmental Conservation* 29:192-206.

Duarte, C. M. and J. Kalff. 1986. Littoral slope as a predictor of the maximum biomass of submerged macrophyte communities. *Limnology and Oceanography* 31:1072-1080.

Dudgeon, S. R. and A. S. Johnson. 1992. Thick vs. thin: Thallus morphology and tissue mechanics influence differential drag and dislodgement of co-dominant seaweeds. *Journal of Experimental Marine Biology and Ecology* 165:23-43.

Dunton, K. 1998. Seagrass a forest beneath the waves: Seagrass beds are the cornerstone of a healthy bay system. University of Texas

Marine Science Institute, The Coastal Bend and Estuary Program. http://www.sci.tamucc.edu/ccbnep/Newsletters/v3.3/seagrasses.htm

Edsall, T. A. and M. N. Charlton. 1997. Nearshore waters of the Great Lakes, 179 pp. SOLEC Working Paper presented at State of the Great Lakes Ecosystem Conference EPA 905-R-97-015a, U.S. Environmental Protection Agency, Chicago, IL.

Engel, S. 1985. Aquatic community interactions of submerged macrophytespp. Technical Bulletin No. 156, Department of Natural Resources, Madison, WI.

Engel, S. and S. A. Nichols. 1994. Aquatic macrophyte growth in a turbid windswept lake. *Journal of Freshwater Ecology* 9:97-109.

Engineering Technologies Associates Inc. and Biohabitats Inc. 1993. Design manual for use of bioretention in stormwater management, 43 pp, plus appendicees. Prince George's County Government, Landover, MD.

Ferguson, R. L. and K. Korfmacher. 1997. Remote sensing and GIS analysis of seagrass meadows in North Carolina, USA. *Aquatic Botany* 58:241-258.

Ferguson, T., R. Gignac, M. Stoffan, A. Ibrahim and J. Aldrich. 1997. Cost estimating guidelines: best management practices and engineered controls. Rouge Program Office, Wayne County, MI.

Folk, R. L. 1974. Petrology of Sedimentary Rocks. Hemphill Publishing Company, Austin, TX.

Fonseca, M., J. Kenworthy and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters, 222 pp. Decision Analysis Series 12, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, NOAA Coastal Ocean Office, Silver Spring, Maryland.

Fonseca, M. S. 1992. Restoring seagrass systems in the United States, pp. 79-104. In Thayer, G. W. (ed.) Restoring The Nation's Marine Environment. Maryland Sea Grant College, College Park, MD.

Fonseca, M. S., J. S. Fisher, J. C. Zieman and G. W. Thayer. 1982. Influence of the seagrass, *Zostera marina* L., on current flow. *Estuarine, Coastal and Shelf Science* 15:351-364.

Fourqurean, J. W., et al. 2002. Seagrass distribution in south Florida: a multi-agency coordinated monitoring program, 1000 pp. In Porter, J. W. and K. G. Porter (eds.), The Everglades, Florida Bay, and Coral Reefs of the Florida Keys: An Ecosystem Sourcebook. CRC Press, Boca Raton, FL.

Fourqurean, J. W., G. V. N. Powell, J. Kenworthy and J. C. Zieman. 1995. The effects of long-term manipulation of nutrient supply on competition between the seagrasses *Thalassia testudinum* and *Halodule wrightii* in Florida Bay. *Oikos* 72:349-358.

Fourqurean, J. W., J. C. Zieman and G. V. N. Powell. 1992. Relationships between porewater nutrients and seagrasses in a subtropical carbonate environment. *Marine Biology* 114:57-65.

Fredette, T. J., R. J. Diaz, J. van Monterans and R. J. Orth. 1990. Secondary production within a seagrass bed (*Zostera marina* and *Ruppia maritima*) in lower Chesapeake Bay. *Estuaries* 13:431-440.

French, J. R. P., III, D. A. Wilcox and S. J. Nichols. 1999. Passing of northern pike and common carp through experimental barriers designed for use in wetland restoration. *Wetlands* 19:883-888.

Fryer, G. 1957. The feeding mechanisms of some freshwater cyclopoid copepods. *Proceedings of the Zoological Society of London* 129:1-25.

Gacia, E. and C. M. Duarte. 2001. Sediment retention by a Mediterranean *Posidonia oceanica* meadow: The balance between deposition and resuspension. *Estuarine, Coastal and Shelf Science* 52:505-514.

Gambi, M. C., A. R. M. Nowell and P. A. Jumars. 1990. Flume observations on flow dynamics in *Zostera marina* (eelgrass) beds. *Marine Ecology Progress Series* 61:159-169.

Gelwick, F. P., S. Akin, D. A. Arrington and K. O. Winemiller. 2001. Fish assemblage structure in relation to environmental variation in a Texas Gulf coastal wetland. *Estuaries* 24:285-296.

Gosselink, J. G. and R. S. Hatton. 1984. Relationship of organic carbon and mineral content to bulk density in Louisiana marsh soils. *Soil Science* 137:177-180.

Granger, S., M. Traber, S. W. Nixon and R. Keyes. 2002. A practical guide for the use of seeds in eelgrass (*Zostera marina* L.) restoration. Part I. Collection, processing, and storage. 20 pp. Rhode Island Sea Grant, Narrangansett, RI. http://nsgl.gso.uri.edu/riu/riuh02001.pdf

Green, E. P. and F. T. Short. 2003. World Atlas of Seagrasses. University of California Press, Berkeley, CA.

Grenouillet, G. and D. Pont. 2001. Juvenile fishes in macrophyte beds: Influence of food resources, habitat structure and body size. *Journal of Fish Biology* 59:939-959.

Hakanson, L. 1977. The influence of wind, fetch and water depth on the distribution of sediments in Lake Vanern, Sweden. *Canadian Journal of Earth Science* 14:397-412.

Hansson, S. and L. G. Rudstam. 1995. Gillnet catches as an estimate of fish abundance: A comparison between vertical gillnet catches and hydroacoustic abundances of Baltic Sea herring (*Clupea harengus*) and sprat (*Sprattus sprattus*). *Canadian Journal of Fisheries & Aquatic Sciences* 52:75-83.

Harrel, S. L., E. D. Dibble and K. J. Killgore. 2001. Foraging behavior of fishes in aquatic plant. 7 pp. APCRP Technical Notes Collection ERDC TN-APCRP-MI-06, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Hatton, R. S., R. D. DeLaune and W. H. Patrick, Jr. 1983. Sedimentation, accretion, and subsidence in marshes of Barataria Basin, Louisiana. *Limnology and Oceanography* 28:494-502.

Heath, R. T. 1992. Nutrient dynamics in Great Lakes coastal wetlands: Future directions. *Journal of Great Lakes Research* 18:590-602.

Heiss, W. M., A. M. Smith and P. K. Probert. 2000. Influence of the small intertidal seagrass *Zostera novazelandica* on linear water flow and sediment texture, New Zealand. *Journal of Marine and Freshwater Research* 34:689-694.

Hemminga, M. A. and C. M. Duarte. 2000. Seagrass Ecology. Cambridge Inc. Press, Cambridge, Massachusetts.

Herdendorf, C. E. and K. A. Krieger. 1989. Overview of Lake Erie and its estuaries within the Great Lakes ecosystem, pp. 1-34. In Krieger, K. A. (ed.) Lake Erie Estuarine Systems: Issues, Resources, Status, and Management. NOAA Estuarine Programs Office, Washington, D.C.

Hervey Bay Dugong and Seagrass Monitoring Program. 1997. Seagrass. Bay Connect, Ten Bideford Street, Torquay, P.O. Box 424, Torquay, Qld 4655. Contact information: Ph # (07) 4125 5565. http://www.bayconnect.com.au/seagrass/seagrass.htm

Hillman, T. W., J. W. Mullan and J. S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. *North American Journal of Fisheries Management* 12:598-603.

Hintz, A. 1999. Monitoring fishery response to wetland restoration in wester Lake Erie: A survey of the temporal fish community in the Crane Creek Estuary: 1997 Progress Report, 27 pp. Progress Report, U.S. Fish and Wildlife Service, Alpena, MI.

Hodgson, G., W. Kiene, J. Mihaly, J. Liebeler, C. Shuman and L. Maun. 2004. Reef check instruction manual: A guide to reef check coral reef monitoring, 85 pp. Reef Check, Institute of the Environment, University of California at Los Angeles, Los Angeles, CA.

Holmer, M. and O. A. Bachmann. 2002. Role of decomposition of mangrove and seagrass detritus in sediment carbon and nitrogen cycling in a tropical mangrove forest. *Marine Ecology Progress Series* 230:87-101.

Ingram, J. C. and T. P. Dawson. 2001. The impacts of a river effluent on the coastal seagrass habitats of Mahe, Seychelles. *South African Journal of Botany* 67:483-487

James, W. F. and J. W. Barko. 1994. Macrophyte influences on sediment resuspension and export in a shallow impoundment. *Lake and Reservoir Management* 10:95-102.

James, W. F., J. W. Barko and M. G. Butler. 2001. Shear stress and sediment resuspension in canopy- and meadow-forming submersed macrophyte communities, 16 pp. APCRP Technical Notes Collection ERDC TN-APCRP-EA-03, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

Johnson, C. N. 1991. Structural shore protection in the Great Lakes: A costly myth. pp. 149. Proceedings of the 34th Conference of the International Association for Great Lakes Research. Buffalo, NY. June 2-6

Jones, R. C. 1990. The effect of submersed aquatic vegetation on phytoplankton and water quality in the tidal freshwater Potomac River. *Journal of Freshwater Ecology* 5:279-288.

Jones, R. C., K. Walkti and M. S. Adams. 1983. Phytoplankton as a factor in the decline of the submersed macrophyte Myriophyllum spicatum L. in Lake Wingra, Wisconsin, USA. *Hydrobiologia* 107:213-219.

Jones, R. S. and M. J. Thompson. 1978. Comparison of Florida reef fish assemblages using a rapid visualization technique. *Bulletin of Marine Science* 28:159-172.

Jude, D. J. and J. Pappas. 1992. Fish utilization of Great Lakes coastal wetlands. *Journal of Great Lakes Research* 18:651-672.

Jupp, B. J. and D. H. N. Spence. 1977. Limitations of macrophytes in a eutrophic lake, Loch Leven: II. wave action, sediments and waterfowl grazing. *Journal of Ecology* 65:431-446.

Keast, A. and J. Harker. 1977. Strip counts as a means of determining densities and habitat utilization patterns in lake fishes. *Environmental Biology of Fishes* 1:181-188.

Keast, A., J. Harker and D. Turnbill. 1978. Nearshore fish habitat utilization and species associations in Lake Opinicon (Ontario, Canada). *Environmental Biology of Fishes* 3:173-184.

Kenworthy, J. and D. E. Haunert. 1991. The light requirements of seagrasses, 181 pp. NOAA Technical Memorandum NMFS-SEFC 287, U.S. National Marine Fisheries Service, Beaufort Laboratory, Beaufort, NC.

Keough, J. R., T. A. Thompson, G. R. Guntenspergen and D. A. Wilcox. 1999. Hydrogeomorphic factors and ecosystem responses in coastal wetlands of the Great Lakes. *Wetlands* 19:821-834.

Kersten, M., R. H. Britton, P. J. Dugan and H. Hafner. 1991. Flock feeding and food intake in little egrets: The effects of prey distribution and behavior. *Journal of Animal Ecology* 60:241-252.

Killgore, K. J., R. P. Morgan II and N. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101-111.

Kiorboe, T. 1980. Distribution and production of submerged macrophytes in Tipper Grund (Ringkobing Fjord, Denmark), and the impact of waterfowl grazing. *Journal of Applied Ecology* 17:675-687.

Kirk, J. T. O. 1994. Light and Photosynthesis in Aquatic Ecosystems. 2nd ed. Cambridge University Press, Cambridge, England.

Klarer, D. M. and D. F. Millie. 1992. Aquatic macrophytes and algae at Old Woman Creek estuary and other Great Lakes coastal wetlands. *Journal of Great Lakes Research* 18:622-633.

Knapton, R. W. and P. Scott. 1999. Changes in distribution and abundance of submerged macrophytes in the inner bay at Long Point, Lake Erie: Implications for foraging waterfowl. *Journal of Great Lakes Research* 24:783-798.

Koch, E. W. 2001. Beyond light: Physical, geological, and geochemical parameters as possible submersed aquatic vegetation habitat requirements. *Estuaries* 24:1-17.

Krieger, K. A. 1992. The ecology of invertebrates in Great Lakes coastal wetlands: Current knowledge and research needs. *Journal of Great Lakes Research* 18:634-650.

Krieger, K. K. 1984. Benthic macroinvertebrates as indicators or environmental degradation in the southern nearshore zone of the central basin of Lake Erie. *Journal of Great Lakes Research* 18:651-672.

Lathrop, R. G., R. M. Styles, S. P. Seitzinger and J. A. Bognar. 2001. Use of GIS mapping and modeling approaches to examine the spatial distribution of seagrasses in Barnegat Bay, New Jersey. *Estuaries* 24:904-916.

Leber, K. M. 1985. The influence of predatory decapods, refuge, and microhabitat selection on seagrass communities. *Ecology* 66:1951-1964.

Lee, Z., K. L. Carder, R. F. Chen and T. G. Peacock. 2001. Properties of the water column and bottom derived from Airborne Visible Infrared Imaging Spectrometer (AVIRIS) data. *Journal of Geophysical Research: Oceans* 106:11639-11651.

Lirman, D. and W. P. Cropper, Jr. 2003. The influence of salinity on seagrass growth, survivorship, and distribution within Biscayne Bay, Florida: Field, experimental, and modeling studies. *Estuaries* 26:131-141.

Liu, C. and J. B. Evett. 1990. Soil Properties: Testing, Measurement, Evaluation. 2nd ed. Prentice Hall, Englewood Cliffs, NJ.

Lodge, D. M., M. W. Kershner, J. E. Aloi and A. P. Covich. 1994. Effects of an omnivorous crayfish (*Orconectes rusticus*) on a freshwater littoral food web. *Ecology* 75:1265-1281.

Louchard, E. M., R. P. Reid, F. C. Stephens, C. O. Davis, R. A. Leathers and T. V. Downes. 2003. Optical remote sensing of benthic habitats and bathymetry in coastal environments at Lee Stocking Island, Bahamas: A comparative spectral classification approach. *Limnology and Oceanography* 48:511-521.

Lundholm, J. T. and W. L. Simser. 1999. Regeneration of submerged macrophyte populations in a disturbed Lake Ontario coastal marsh. *Journal of Great Lakes Research* 25:395-400.

Macia, S. 2000. The effects of sea urchin grazing and drift algal blooms on a subtropical seagrass bed community. *Journal of Experimental Marine Biology and Ecology* 246:53-67.

Madsen, J. D. and M. S. Adams. 1989. The light and temperature dependence of photosynthesis and respiration in *Potamogeton pectinatus* L. *Aquatic Botany* 36:23-31.

Madsen, J. D., P. A. Chambers, W. F. James, E. W. Koch and D. F. Westlake. 2001. The interaction between water movement, sediment dynamics and submersed macrophytes. *Hydrobiologia* 444:71-84.

Madsen, T. V. and E. Warncke. 1983. Velocities of currents around and within submerged aquatic vegetation. *Archiv fur Hydrobiologie* 97:389-394.

Malthus, T. J. and D. G. George. 1997. Airborne remote sensing of macrophytes in Cefni Reservoir, Anglesey, UK. *Aquatic Botany* 58:317-332.

Maynard, L. and D. Wilcox. 1997. Coastal wetlands, 114 pp. SOLEC Working Paper presented at State of the Great Lakes Ecosystem Conference EPA 905-R-97-015b, U.S. Environmental Protection Agency, Chicago, IL.

McFarland, D. G. and J. W. Barko. 1987. Effects of temperature and sediment type on growth and morphology of monoecious and dioecious Hydrilla. *Journal of Freshwater Ecology* 4:245-252.

McRoy, C. and C. Helffreich. 1977. Seagrass nutrition, pp. 65-68. In McRoy, C. and C. Helffreich (eds.), Seagrass Ecosystems: A Scientific Perspective. Markel and Dekker, Inc., New York, NY.

Meador, M. R., T. F. Cuffney and M. E. Gurtz. 1993. Methods for sampling fish communties as part of the National Water-Quality Assessment Programpp. Open-File Report 93-104, U.S. Geological Survey, Raleigh, NC.

Miller, R. L. and B. F. McPherson. 1995. Modeling light available to seagrasses in Tampa Bay, Florida. *Florida Scientist* 58:116.

Minc, L. D. 1997. Vegetative response in Michigan's coastal wetlands to Great Lakes water-level fluctuations, 135 pp. A Report to Michigan Natural Features Inventory, Lansing, Michigan.

Minc, L. D. 1998. Great Lakes coastal wetlands: An overview of controlling abiotic factors, regional distribution, and species composition (in 3 parts), 307 pp. Michigan Natural Features Inventory, Lansing, MI.

Mitchell, S. F. and R. T. Wass. 1996. Grazing by black swans (*Cygnus atratus* Latham), physical factors, and the growth and loss of aquatic vegetation in a shallow lake. *Aquatic Botany* 55:205-215.

Mitsch, W. J. and J. G. Gosselink. 2000. Wetlands. Third ed. Van Nostrand Reinhold, New York, NY.

Mitzner, L. 1978. Evaluation of biological control of nuisance aquatic vegetation by grass carp. *Transactions of the American Fisheries Society* 107:135-145.

Moncreiff, C. A. and M. J. Sullivan. 2001. Trophic importance of epiphytic algae in subtropical seagrass beds: Evidence from multiple stable isotope analyses. *Marine Ecology Progress Series* 215:93-106.

Moore, K. A., H. A. Neckles and R. J. Orth. 1996. *Zostera marina* (eelgrass) growth and survival along a gradient of nutrients and turbidity in the lower Chesapeake Bay. *Marine Ecology Progress Series* 142:247-259.

Moore, K. A., R. L. Wetzel and R. J. Orth. 1997. Seasonal pulses of turbidity and their relations to eelgrass (*Zostera marina* L.) survival in an estuary. *Journal of Experimental Marine Biology and Ecology* 215:115-134.

Morgan, R. P., K. J. Killgore and N. H. Douglas. 1988. Modified popnet design for collecting fishes in varying depths of submersed aquatic vegetation. *Journal of Freshwater Ecology* 4:533-539.

Mortimer, C. H. 1941. The exchange of dissolved substances between mud and water in lakes. *Journal of Ecology* 29:280-329.

Mortimer, C. H. 1942. The exchange of dissolved substances between mud and water in lakes. *Journal of Ecology* 30:147-201.

Mumby, P. J. and A. J. Edwards. 2002. Mapping marine environments with IKONOS imagery: Enhanced spatial resolution can deliver greater thematic accuracy. *Remote Sensing of Environment* 82:248-257.

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

Nagelkerken, I., C. M. Roberts, G. van der Velde, M. Dorenbosch, M. C. van Riel, E. C. de la Moriniere and P. H. Nienhuis. 2002. How important are mangroves and seagrass beds for coral-reef fish? The nursery hypothesis tested on an island scale. *Marine Ecology Progress Series* 244:299-305.

Nichols, S. A. 1994. Evaluation of invasions and declines of submersed macrophytes for the Upper Great Lakes region. *Lake and Reservoir Management* 10:29-33.

Noordhuis, R., D. T. van der Molen and M. S. van den Berg. 2002. Response of herbivorous water-birds to the return of Chara in Lake

Veluwemeer, The Netherlands. *Aquatic Botany* 72:349-367.

Odum, H. T. 1956. Primary production in flowing waters. *Limnology and Oceanography* 1:102-117.

Orth, R. J. 1994. Chesapeake Bay submersed aquatic vegetation: Water quality relationships. *Lake and Reservoir Management* 10:49-52.

Orth, R. J., M. C. Harwell and J. R. Fishman. 1999. A rapid and simple method for transplanting eelgrass using single, unanchored shoots. *Aquatic Botany* 64:77-85.

Orth, R. J., K. L. Heck, Jr. and J. van Montfrans. 1983. Faunal communities in seagrass beds: A review of the influence of plant structure and prey characteristics on predator-prey relationship. *Estuaries* 7:339-350.

Orth, R. J., M. Luckenbach and K. A. Moore. 1994. Seed dispersal in a marine macrophyte: Implications for colonization and restoration. *Ecology* 75:1927-1939.

Orth, R. J. and K. A. Moore. 1984. Distribution and abundance of submerged aquatic vegetation in Chesapeake Bay: An historical perspective. *Estuaries* 7:531-540.

Pergent-Martini, C., V. Rico-Raimondino and G. Pergent. 1995. Nutrient impact on *Posidonia oceanica* seagrass meadows: Preliminary data. *Marine Life* 5:3-9.

Perkins-Visser, E., T. G. Wolcott and D. L. Wolcott. 1996. Nursery role of seagrass beds: Enhanced growth of juvenile blue crabs (*Callinectes sapidus* Rathbun). *Journal of Experimental Marine Biology and Ecology* 198:155-173.

Perrow, M. R., A. J. D. Jowitt, J. H. Stansfield and G. L. Phillips. 1999. The practical importance of the interactions between fish, zooplankton and macrophytes in shallow lake restoration. *Hydrobiologia* 395-396:199-210.

Perrow, M. R., J. H. Schutten, J. R. Howes, T. Holzer, F. J. Madgwick and A. J. D. Jowitt. 1997. Interactions between coot (*Fulica atra*) and submerged macrophytes: The role of birds in the restoration process. *Hydrobiologia* 342-343:241-255.

Perry, M. C. and A. S. Deller. 1996. Review of factors affecting the distribution and abundance of waterfowl in shallow-water habitats of Chesapeake Bay. *Estuaries* 19:272-278.

Peterson, C. H. 1982. Clam predation by whelks (*Busycon* spp.): Experimental tests of the importance of prey size, prey density, and seagrass. *Marine Biology* 66:159-170.

Pinit, P. T. and R. Bellmer. 2000. Habitat restoration monitoring toward success: A selective annotated bibliographypp. NOAA Technical Memorandum NMFS-F/SPO-42, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Silver Spring, MD.

Pip, E. and J. M. Stewart. 1976. The dynamics of two aquatic plant - snail associations. *Canadian Journal of Zoology* 54:1192-1205.

Poppe, L. J., A. H. Eliason, J. J. Fredericks, R. R. Rendigs, B. D. and C. F. Polloni. 2003. Grain-size analysis of marine sediments: Methodology and data processing, 58 pp. In USGS East-coast Sediment Analysis: Procedures, Databases, and Georeferenced Displays. US Geological Survey Open-File Report 00-358.

Pratt, T. C. and M. G. Fox. 2001. Comparison of two methods for sampling a littoral zone fish community. *Archiv fur Hydrobiologie* 152:687-702.

Prince, H. H., P. I. Padding and R. W. Knapton. 1992. Waterfowl use of the Laurentian Great Lakes. *Journal of Great Lakes Research* 18:673-699.

Randall, R. G., C. K. Minns, V. W. Cairns and J. E. Moore. 1996. The relationship between an index of fish production and submerged macrophytes and other habitat features at three littoral areas in the Great Lakes. *Canadian Journal of Fisheries & Aquatic Sciences* 53 (Suppl. 1):35-44.

Reavell, P. E. 1980. A study of the diets of some British freshwater gastropods. *Journal of Conchology* 30:253-271.

Robertson, A. I. 1980. The structure and organization of an eelgrass fish fauna. *Oecologia* 47:79-82.

Rozas, L. P. and W. E. Odum. 1987a. Fish and macrocrustracean use of submerged plant beds in tidal freshwater marsh creeks. *Marine Ecology Progress Series* 38:101-108.

Rozas, L. P. and W. E. Odum. 1987b. Use of tidal freshwater marshes by fishes and macrofaunal crustations along a marsh stream-order gradient. *Estuaries* 10:36-43.

Rybicki, N. B., H. L. Jenter, V. Carter, R. A. Baltzer and M. Turtora. 1997. Observations of tidal flux between a submersed aquatic plant stand and the adjacent channel in the Potomac River near Washington, DC. *Limnology and Oceanography* 42:307-317.

Rybicki, N. B., D. G. McFarland, H. A. Ruhl, J. T. Reel and J. W. Barko. 2001. Investigations of the availability and survival of submersed aquatic vegetation propagules in the tidal Potomac River. *Estuaries* 24:407-424.

Sabol, B. M., R. E. Melton, Jr., R. Chamberlain, P. Doering and K. Haunert. 2002. Evaluation of a digital echo sounder system for detection of submerged aquatic seagrasses. *Estuaries* 25:133-141.

Sand-Jensen, K. and J. R. Mebus. 1996. Fine-scale patterns of water velocity within macrophyte patches in streams. *Oikos* 76:169-180.

Sargent, F., T. Leary, D. W. Crewz and C. R. Cruer. 1995. Scarring of Florida's seagrasses: Assessment and management options, 37 pp. Technical Report FMRI TR-1, Florida Marine Research Institute, Florida Department of Environmental Protection, St. Petersburg, FL.

Schueler, T. R., J. Galli, L. Herson, P. Kumble and D. Shepp. 1992. Developing effective BMP systems for urban watersheds. In Anacostia Restoration Team (ed.) Watershed Restoration Sourcebook. Metropolitan Washington Council of Governments.

Sculthorpe, C. D. 1967. The biology of aquatic vascular plants. St. Martin's Press, New York, NY.

Serafy, J. E., R. M. Harrell and J. C. Stevenson. 1988. Quantitative sampling of small fishes in dense vegetation: Design and field testing of portable "pop-nets". *Journal of Applied Ichthyology* 4:149-157.

Sheridan, P., G. McMahan, G. Conley, A. Williams and G. Thayer. 1997. Nekton use of macrophyte patches following mortality of turtlegrass, Thalassia testudinum, in shallow waters of Florida Bay (Florida, USA). *Bulletin of Marine Science* 61:801-820.

Short, F. A. and C. M. Duarte. 2001. Methods for the measurement of seagrass growth and production, pp. 155-182. In Short, F. and R. G. Coles (eds.), Global Seagrass Research Methods. Elsevier, Amsterdam.

Short, F. T. and C. A. Short. 1984. The seagrass filter: Purification of estuarine and coastal waters. pp. 395-413. Proceedings of the The Estuary As a Filter, 7th Biennial Conference of the Estuarine Research Federation. Virginia Beach, Virginia.

Skubinna, J. P., T. G. Coon and T. R. Batterson. 1995. Increased abundance and depth of submersed macrophytes in response to decreased turbidity in Saginaw Bay, Lake Huron. *Journal of Great Lakes Research* 21:476-488.

Spence, D. H. N. 1982. The zonation of plants in freshwater lakes. *Advances in Ecological Research* 12:37-125.

Spence-Cheruvelil, K., P. A. Soranno, J. D. Madsen and M. J. Roberson. 2002. Plant architecture and epiphytic macroinvertebrate communities: The role of an exotic dissected macrophyte. *Journal of the North American Benthological Society* 21:261-277.

Stankelis, R. M., M. D. Naylor and W. R. Boynton. 2003. Submerged aquatic vegetation in the mesohaline region of the

Patuxent Estuary: Past, present, and future status. *Estuaries* 26:186-195.

Stephenson, T. D. 1990. Fish reproductive utilization of coastal marshes of Lake Ontario near Toronto. *Journal of Great Lakes Research* 16:71-81.

Stevenson, J. C. 1988. Comparative ecology of submersed grass beds in freshwater, estuarine, and marine environments. *Limnology and Oceanography* 33:867-893.

Stewart, R. M., D. G. McFarland, D. L. Ward, S. K. Martin and J. W. Barko. 1997. Flume study investigations of navigation-generated waves on submersed aquatic macrophytes in the Upper Mississippi River, 62 pp. ENV Report 1, Upper Mississippi River - Illinois Waterway System Navigation Study.

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.

Suren, A. M. 1991. Bryophytes as invertebrate habitat in two New Zealand alpine rivers. *Freshwater Biology* 26:399-418.

Suzuki, N., S. Endoh, M. Kawashima and Y. Itakura. 1995. Discontinuity bar in a wetland on Lake Huron's Saginaw Bay. *Journal of Freshwater Ecology* 10:111-123.

Terrell, J. B. and D. E. Canfield, Jr. 1996. Evaluation of the effects of nutrient removal and the "Storm of the Century" on submersed vegetation in Kings Bay - Crystal River, Florida. *Journal of Lake and Reservoir Management* 12:394-403.

Thayer, G. W., K. A. Bjorndal, J. C. Ogden, S. L. Williams and J. C. Zieman. 1983. Role of larger herbivores in seagrass communities. *Estuaries* 7:351-376.

Thayer, G. W., M. S. Fonseca and W. J. Kenworthy. 1985. Restoration of seagrass meadows for enhancement of nearshore productivity. pp. 259-278. Proceedings of the International Symposium on Utilization of Coastal Ecosystems: Planning, Pollution and Productivity. Rio Grande, Brazil.

Thorhaug, A., J. Marcus and F. Booker. 1986. Oil and dispersed oil on subtropical and tropical seagrasses in laboratory studies. *Marine Pollution Bulletin* 17:357-361.

Thornton, K. W. and A. S. Lessem. 1978. A temperature algorithm for modifying biological rates. *Transactions of the American Fisheries Society* 107:284-287.

Thorp, A. G., R. C. Jones and D. P. Kelso. 1997. A comparison of water-column macroinvertebrate communities in beds of differing submersed aquatic vegetation in the tidal freshwater Potomac River. *Estuaries* 20:86-95.

Titus, J. E. 1994. Submersed plant invasions and declines in New York. *Lake and Reservoir Management* 10:25-28.

Trebitz, A., S. Carpenter, P. Cunningham, B. Johnson, R. Lillie, D. Marshall, T. Martin, R. Narf, T. Pellet, S. Stewart, C. Storlie and J. Unmuth. 1997. A model of bluegill-largemouth bass interactions in relation to aquatic vegetation and its management. *Ecological Modelling* 94:139-156.

Tsai, C., J. Wang and C. Lin. 1998. Downrush flow from waves on sloping seawalls. *Ocean Engineering* 25:295-308.

Twilley, R. R., W. M. Kemp, K. W. Staver, J. Court-Stevensen and W. R. Boynton. 1985. Nutrient enrichment of estuarine submersed vascular plant communities. 1. Algal growth and effects on production of plants and associated communities. *Marine Ecology Progress Series* 23:179-191.

Tyler, J. E. 1968. The secchi disc. *Limnology and Oceanography* 13:1-6.

U.S. Army Coastal Engineering Research Center. 1984. Shore protection manual: Volume Ipp., Corps of Engineers, Waterways Experiment Station, Vicksburg, MS.

U.S. EPA. 2002a. Methods for Evaluating Wetland Condition: Biological Assessment Methods for Birds, 22 pp. EPA-822-R-02-

023, Office of Water, U.S. Environmental Protection Agency, Washington, DC.

U.S. EPA. 2002b. Methods for Evaluating Wetland Condition: Developing an Invertebrate Index of Biological Integrity for Wetlands., 57 pp. EPA-822-R-02-019., Office of Water, U.S. Environmental Protection Agency, Washington, DC.

Valley, R. D. and M. T. Bremigan. 2002. Effects of macrophyte bed architecture on largemouth bass foraging: Implications of exotic macrophyte invasions. *Transactions of the American Fisheries Society* 131:234-244.

van Montfrans, J., R. L. Wetzel and R. J. Orth. 1983. Epiphyte-grazer relationships in seagrass meadows: Consequences for seagrass growth and production. *Estuaries* 7:289-309.

Ward, L. G., W. M. Kemp and W. R. Boynton. 1984. The influence of waves and seagrass communities on suspended sediment dynamics in an estuarine embayment. *Marine Geology* 59:85-103.

Warrick, R. A. 1993. Climate and sea level change: A synthesis, pp. 3-21. In Warrick, R. A., E. M. Barrow and T. M. L. Wigley (eds.), Climate and Sea Level Shange: Observations, projections and Implications. Cambridge University Press, Cambridge, MA.

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

Westcott, K., T. H. Whillans and M. G. Fox. 1997. Viability and abundance of seeds of submerged macrophytes in the sediment of disturbed and reference shoreline marshes in Lake Ontario. *Canadian Journal of Botany* 75:451-456.

Wetzel, R. G. 1983. Limnology. 2nd ed. Saunders, Philadelphia, PA.

Wetzel, R. G. 1992. Wetlands as metabolic gates. *Journal of Great Lakes Research* 18:529-532.

Whillans, T. H. 1987. Wetlands and aquatic resources, pp. 321-356. In Healey, M. C. and R. R. Wallace (eds.), Canadian Aquatic Resources, Canadian Bulletin of Fisheries and Aquatic Sciences 215. Department of Fisheries and Oceans, Ottawa.

Whillans, T. H. 1996. Historic and comparative perspectives on rehabilitation of marshes as habitat for fish in the lower Great Lakes basin. *Canadian Journal of Fisheries & Aquatic Sciences* 53 (Suppl. 1):58-66.

Wilcox, D. A. 1995. The role of wetlands as nearshore habitat in Lake Huron, pp. 223-249. In Munawar, M., T. Edsall and J. Leach (eds.), The Lake Huron Ecosystem: Ecology, Fisheries, and Management. SPD Academic, Amsterdam, The Netherlands.

Wilcox, D. A. and J. E. Meeker. 1992. Implications for faunal habitat related to altered macrophyte structure in regulated lakes in northern Minnesota. *Wetlands* 12:192-203.

Wilcox, D. A. and J. E. Meeker. 1995. Wetlands in regulated Great Lakes, pp. 247-249. In LaRoe, E. T., G. S. Farris, C. E. Puckett, P. D. Doran and M. J. Mac (eds.), Our Living Resources: a Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. U.S. DOI, National Biological Service, Washington, DC.

Wilcox, D. A., J. E. Meeker, P. L. Hudson, B. J. Armitage, M. G. Black and D. G. Uzarski. 2002. Hydrologic variability and the application of Index of Biotic Integrity metrics to wetlands: A Great Lakes evaluation. *Wetlands* 22:588-615.

Wilcox, D. A. and T. H. Whillans. 1989. Responses of selected Great Lakes wetlands to water level fluctuations Appendix B, pp. 223-245. In Busch, W. D. N., R. Kavetsky and G. McCullough (eds.), Water Level Criteria for Great Lakes Wetlands. International Joint Commission, Ottawa.

Williams, S. L. and E. D. Grosholz. 2002. Preliminary reports from the *Caulerpa taxifolia* invasion in southern California.

Marine Ecology Progress Series 233:307-310.

Wilson, S. D. and P. A. Keddy. 1985. The shoreline distribution of *Juncus pelocarpus* along a gradient of exposure to waves: An experimental study. *Aquatic Botany* 21:277-284.

Wright, D. I. and W. J. O'Brien. 1984. The development and field test of a tactical model of the planktivorous feeding of white crappie (*Pomoxis annularis*). *Ecological Monographs* 54:65-98.

Wyda, J. C., L. A. Deegan, J. E. Hughes and M. J. Weaver. 2002. The response of fishes to submerged aquatic vegetation complexity in two ecoregions of the mid-Atlantic Bight: Buzzards Bay and Chesapeake Bay. *Estuaries* 25:86-100.

Zalewski, M. and I. G. Cowx. 1990. Factors affecting the efficiency of electric fishing, pp. 89-111. In Cowx, I. G. and P. Lamarque (eds.), Fishing with Electricity. Fishing News Books, Oxford.

Zaret, T. M. 1980. Predation and Freshwater Communities. Yale University Press, New Haven, CT.

Zieman, J. C. 1976. The ecological effects of physical damage from motor boats on turtle grass beds in southern Florida. *Aquatic Botany* 2:127-139.

Zieman, J. C. and R. T. Zieman. 1989. The ecology of seagrass meadows of the west coast of Florida: A community profile, 155 pp. Biological Report 85(7.25), U.S. Fish and Wildlife Service, Washington, D.C.

APPENDIX I: SUBMERGED AQUATIC VEGETATION 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 easily obtaining the original resource. Summaries preceded by the terms '*Author Abstract'* or *'Publisher Introduction*' or similar descriptors were taken directly from their original source. Summaries without such descriptors were written by the authors of the associated chapter.

Batiuk, R. A., P. Bergstrom, W. M. Kemp, E. W. Koch, L. Murray, J. C. Stevenson, R. Bartleson, V. Carter, N. B. Rybicki, J. M. Landwehr, C. L. Gallegos, L. Karrh, M. Naylor, D. J. Wilcox, K. A. Moore, S. Ailstock and M. Teichberg. 2000. Chesapeake Bay submerged aquatic vegetation water quality and habitat-based requirements and restoration targets: A second technical synthesis. United States Environmental Protection Agency for the Chesapeake Bay Program. http://www.chesapeakebay.net/pubs/sav/index.html

Author Summary. The present report provides an integrated approach for defining and testing the suitability of Chesapeake Bay shallow water habitats in terms of the minimum light requirements for SAV survival. It incorporates statistical relationships from monitoring data, field and experimental studies and numerical model computations to produce algorithms that use water quality data for any site to calculate potential light availability at the leaf surface for SAV at any restoration depth. The original technical synthesis defined SAV habitat requirements in terms of five water quality parameters based on field correlations between SAV presence and water quality conditions. In the present approach, these parameters are used to calculate potential light availability at SAV leaves for *any* Chesapeake Bay site. These calculated percent light at the leaf surface values are then compared to minimum light requirements to assess the suitability of a particular site as SAV habitat. Values for the minimum light requirements were derived from algorithm calculations of light at SAV leaves using the 1992 SAV habitat requirements, extensive review of the scientific literature and evaluation of monitoring and field research findings. These calculations account for regionally varying tidal ranges, and they partition total light attenuation into water-column and epiphyte contributions; water-column attenuation is further partitioned into effects of chlorophyll *a*, total suspended solids and dissolved organic matter. This approach is used to predict the presence of suitable water quality conditions for SAV at all monitoring stations around the Bay. These predictions compared well with results of SAV distribution surveys in areas adjacent to water quality monitoring stations in the mesohaline and polyhaline regions, which contain 75 to 80 percent of all recent mapped SAV areas and potential SAV habitat in the Bay and its tidal tributaries.

The approach for assessing SAV habitat conditions described in this report represents a major advance over that presented in 1992. At the same time, areas requiring further research, assessment and understanding have been brought into sharper focus. The key relationships within the algorithm developed for calculating epiphytic contributions to light attenuation can be strengthened and updated with further field and experimental studies. Particular attention needs to be paid to the relationships between epiphyte biomass and nutrient concentrations and between total suspended solids and the total mass of epiphytic material, and to a better understanding of the relationships in lower salinity areas. Detailed field and laboratory studies are needed to develop quantitative, species-specific estimates of minimum light requirements both for the survival of existing SAV beds and for reestablishing SAV into unvegetated sites. Although this report also provides an initial consideration of physical, geological and chemical requirements for SAV habitat, more work is needed to develop integrated quantitative measures of SAV habitat suitability in terms of physical, geological and chemical factors.

Beck, M. W., K. L. Heck, Jr, K. W. Able, D. L. Childers, D. B. Eggleston, B. M. Gillanders, B. Halpern, C. G. Hays, K. Hoshino, T. J. Minello, R. J. Orth, P. F. Sheridan and M. P. Weinstein. 2001. The identification, conservation, and management of estuarine and marine nurseries for fish and invertebrates. *BioScience* 51:633-641.

Author Introduction. Nearshore estuarine and marine ecosystems—e.g., seagrass meadows, marshes, and mangrove forests—serve many important functions in coastal waters. Most notably, they have extremely high primary and secondary productivity and support a great abundance and diversity of fish and invertebrates. Because of their effects on the diversity and productivity of macrofauna, these estuarine and marine ecosystems are often referred to as nurseries in numerous papers, textbooks, and government-sponsored reports. Indeed, the role of these nearshore ecosystems as nurseries is an established ecological concept accepted by scientists, conservation groups, managers, and the public and cited as justification for the protection and conservation of these areas. Nonetheless, the nursery-role concept has rarely been stated clearly, even in papers that purport to test it. This ambiguity hinders the effectiveness of the nursery-role concept as a tool for conservation and management. We seek to redress that ambiguity by briefly tracing the history of the concept, developing a clear hypothesis with testable predictions, and discussing how this work can focus efforts in research, conservation, restoration, and management.

Biebl, R. and C. P. McRoy. 1971. Plasmatic resistance and rate of respiration and photosynthesis of *Zostera marina* at different salinities and temperatures. *Marine Biology* 8: 48-56.

A study was conducted on the *Zostera marina* functions and biological activities in the Izembek Lagoon, Alaska Peninsula. Although the study does not directly address restoration monitoring, the methods presented can be used to measure seagrass response to change in salinity and temperature. Changes in temperature and salinity levels may be due to anthropogenic inputs causing deterioration in seagrass community. The researchers distinguished different morphological forms of *Z. marina* in tide pools and subtidal areas both showed a high level of tolerance for differences in salinity and temperature. Photosynthesis reached maximum levels in normal seawater, decreased to almost zero in distilled water and in water with salinity levels twice that of seawater. Photosynthesis also increased in the tide pool form when temperatures were increased to 35° C. Photosynthesis reached maximum levels in the subtidal form as temperature increased to 30° C. At higher temperatures, photosynthesis in both forms declined. Respiration was minimal in distilled water at 0° C and increased when salinity and temperature also increased.

Bird, K. T., J. Jewett-Smith and S. Fonseca. 1994. Use of in vitro propagated *Ruppia maritima* for seagrass meadow restoration. *Journal of Coastal Research* 10: 732-737.

Author Abstract. The use of *in vitro* propagated *Ruppia maritima* for seagrass meadow restoration was monitored and evaluated in two experiments. Experiment 1 compared two different planting methods for *in vitro* propagated plants. In one method, cultured plants were attached to metal staples that were then inserted into the sediment. Almost all of these transplants disappeared within one month at the four different planting sites. For the other method, *in vitro* propagated plants were first transferred to peat pots and grown in a flowing seawater system for six weeks. These transplants showed 20 to 80% survival. *Ruppia maritima* was still growing in experimental plots after 11 months at three of the four sites. There was an increase in the number of short shoots m^2 and the percent cover. After 23 months, there was decreased cover of *R. maritima* and an increase in *Zostera marina*. In Experiment 2, *R. maritima* was propagated *in vitro* using a modified culture medium. Plants from these cultures were directly rooted *ex vitro* in peat pots during six weeks growth in a flowing seawater system. These planting units were transplanted to three sites. After 12 months, the experimental plots showed significant coverage of *R. maritima* at two sites. The other site was a more exposed location and had no *R. maritima* in the experimental plots from either Experiment 1 or 2, probably due to the severe winter storm of 1993. The increase in shoot numbers and areal coverage in the experimental plots suggests that *R. maritima* can be propagated in vitro and used successfully for habitat restoration.

Bologna, P. A. X. and K. L. Heck. 1999. Macrofaunal associations with seagrass epiphytes. Relative importance of trophic and structural characteristics. *Journal of Experimental Marine Biology and Ecology* 242:21-39.

Attached epiphytes often make important contributions to total primary production in seagrass meadows. Additionally, they may increase the spatial complexity of seagrass habitats. Experiments conducted using artificial seagrass units (ASU) manipulated both epiphytic structure and epiphytic food resources. Previous work suggested that the increase in faunal density associated with epiphytes was related to increases in structure, but our results indicate that the primary impact of epiphytes lies in their trophic role. Data showed that epifaunal density was significantly greater in 22 conditioned ASUs fouled with a live community of epiphytes (12 285 individuals m^{-2}) compared 22 to ASUs with artificially created epiphytic structure (5099 inds. m^{-2}) and to control ASUs (5955 22 inds. m^{-2}). This response to epiphytic trophic resources was significant for most herbivore omnivore taxa, but not necessarily for filter feeding or predatory epifauna. However, densities of two predatory taxa (fish and mud crabs) were significantly greater where epiphytic biomass was higher, which may reflect their response to increased prey abundance. Additionally, ASUs conditioned with live epiphytes had greater taxa richness than other ASUs. Epiphytic structure appeared to play only a limited role in determining the density of most mobile epifauna, but epiphytic structure appeared to be important in augmenting the settlement of bivalves. By using ASUs we were able to control aspects of blade length and shoot density, but the pre-experiment conditioning of treatments fouled with live epiphytes may have played a role in determining absolute differences in macrofaunal density among ASU treatments. Overall, our work suggests that the trophic role of epiphytes can have a dramatic impact on associated epifaunal communities, although future investigations are needed to assess this relationship more fully.

Burgess, C. 1995. Seagrass micropropagation and restoration in North Carolina and Florida, a case study of *Ruppia* (Widgeon grasss). Wetland Plants From Test Tubes, pp. 12-13. North Carolina State Univ., Raleigh, USA. Sea Grant publication UNC-SG-95-08.

Researchers studied the growth of *Ruppia* by evaluating plant health and established root systems within restored areas in North Carolina and Florida. Techniques used in this study should be considered in restoration monitoring. During the growing season, plants were collected from the field and sections were cut into single branch segments with two to five nodes. They were then soaked in fungicide, their surface sterilized with bleach and then submerged in selected antibiotics. A vacuum treatment was used to allow oxidants and antibiotics to filter through the plant's internal spaces. Researchers then added cytokinin to the growth media to stimulate branching and node creation. Each culture was lit with cool white fluorescent lamps in a temperate-controlled room. The plants were then transported from culture tubes or flasks to aerated aquaria to stimulate root formation. The planting units were attached to the mats using plastic-coated hairpins and allowed to root into the mats. Researchers then installed the mats at the site. Cultured *Ruppia* was attached to staples by first transferring the seagrasses into peat pots and then placed in a mariculture system with running seawater. After three to four weeks of growth, the potted *Ruppia* was transported to four different sites. Post-installation monitoring showed that plants were removed by heavy winter storms at one site. At the more protected sites, percent cover of *Ruppia* decreased while *Zostera marina* increased. Additional information on results and methods for monitoring restoration are presented.

Carpenter, S. R. and D. M. Lodge. 1986. Effects of submersed macrophytes on ecosystem processes. *Aquatic Botany* 26:341-370.

Author Abstract. Both natural and managed ecosystems experience large fluctuations in submersed macrophytes biomass. These fluctuations have important consequences for ecosystem processes because of the effects of macrophytes on the physical/chemical environment and littoral biota.

The first part of this paper reviews the effects of submersed macrophytes on the physical environment (light extinction, temperature, hydrodynamics, substrate), chemical environment (oxygen, inorganic and organic carbon, nutrients) and the biota (epiphytes grazers, detritivores, fishes). This extensive literature suggests that variations in macrophytes biomass could have major effects on aquatic ecosystems.

The second part of this paper considers the ecosystem consequence of several common changes in submersed macrophytes: replacement of vascular macrophytes by bryophytes during lake acidification; short-term biomass changes caused by invasion of adventive species, cultural eutrophication or macrophytes management; and changes in littoral grazers. These scenarios illustrate the importance of macrophytes in ecosystems, but raise many questions which cannot be answered at present. Controlled, whole-lake macrophytes experiments are needed to resolve these open questions.

Clark, J. R. and J. M. Macauley. 1990. Comparison of the seagrass *Thalassia testidinum* and its **epiphytes** in the field and in laboratory test systems, pp. 59-68. In Wang, W., J. W.

Gorsuch and W. R. Lower (eds.), Plants for Toxicity Assessment, Ecological Research Service, Environmental Protection Agency. *American Society for Testing and Materials, Philadelphia.*

Author Abstract. *Thalassia testudinum* and associated epiphytes from field plots were compared with plants from laboratory microcosms to determine if laboratory observations reflected responses characteristic of plants in natural systems: Changes in leaf chlorophyll and protein content and rhizome carbohydrate in *Thalassia* and standing crop and chlorophyll content of epiphyte communities were compared for 3 experiments conducted over 6-week intervals at different times of the growing season and for one 12-week laboratory-field comparison. *Thalassia* plants in the laboratory followed similar trends of field plants during the 6-week experiments but the laboratory plants differed significantly from field plants at 12 weeks. Chlorophyll content of epiphyte communities colonizing *Thalassia* leaves was significantly different in the laboratory compared to field samples.

Dennison, W. C., R. J. Orth, K. A. Moore, J. C. Stevenson, V. Carter, S. Kollar, P. W. Bergstrom and R. A. Batiuk. 1993. Assessing water quality with submerged aquatic vegetation. *BioScience* 43:86-94.

This article summarizes the structural characteristics (light availability, nutrient concentration, and other associated measures) required by healthy SAV habitats as they relate to water quality for the Chesapeake Bay. The authors provide a concise summary of the water quality parameters necessary to support SAV and are thus able to determine what levels of water quality and clarity are necessary to support SAV. The amount and health of SAV can then be used as a surrogate measure of water quality. This approach of matching the habitat needs of SAV to water quality characteristics could be exported to other estuaries around the country suffering similar levels of habitat loss and water quality degradation.

Durako, M. J., M. Hall, J. Hall, L. Hefty, J. Bacon and S. Kim. 1996. The status and trends of seagrass communities in Florida Bay. In Seagrass Ecology 1996 Abstracts, Florida Bay Science Conference Abstracts. Partnership with Florida Marine Research Institute (FDEP), St. Petersburg, FL., and Dade County Department of Environmental Resources Management, Miami, FL. http://www.aoml.noaa.gov/flbay/seag96.html.

Researchers assessed variation in macrophyte species distribution and abundance, community structure and population dynamics in relation to the multiple stressors along a northeastern Florida Bay. Four hundred stations in 14 basins were sampled seasonally for seagrass and macroalgal distribution and abundance. Methods are described that can be used by restoration practitioners in monitoring submerged aquatic vegetation restorations.

Analyses performed on seagrass cover/abundance showed significant *Thalassia* loss in western (Rabbit Key Basin, RKB) and southern (Twin Key Basin, TWN) Florida Bay. *Thalassia* cover/abundance values were stable or increased from spring 1995 to spring 1996 in all but one (TWN) of the ten basins sampled. In central-to-northeast basins *Thalassia* abundance was stable or increased. In spring 1995, about 39% of the area sampled had less than 5% of *Thalassia*. In central Florida Bay, *Thalassia* was less abundant (Rankin Lake, RNK and Whipray Basin, WHP) and had the most seagrass die-offs.

Seagrass composition and abundance at two sites in Little Madeira Bay remained unchanged. At Trout Cove, and Long Sound sites, *Thalassia* shoot density decreased from fall 1995 to spring 1996 and dropped below past ranges for each station. *Halodule* density at the Long Sound station increased significantly between Fall 1995 and Spring 1996. *Ruppia* shoot density decreased between Fall 1995 and Spring 1996 at the Highway Creek station. Researchers concluded that increased distribution, abundance, and significance of seagrass recovery may have been due to improved water quality conditions in Florida Bay.

Eleuterius, L. N. 1975. Submergent vegetation for bottom stabilization. *Estuarine Research* 2: 439-456.

Author Abstract. In this study *Thalassia testidinum*, *Cymodocea manatorum,* and *Diplantera wrightii* were transplanted from natural stands to infertile inundated spoiled areas and control areas adjacent to undisturbed seagrass beds. Anchoring devices were developed to hold the transplants in place. Methods used in this study are described in this publication. The results showed that *D. wrightii* had the highest survival, and its growth rate exceeded that of *T. testidinum; C. manatorum* did not survive at all. Based on its distribution, growth tolerance to sediment deposition, therefore *D. wrightii* is considered the best seagrass species for transplant studies. Transplants were unsuccessful on dredged material. Low temperatures and lengthened exposure to low salinity negatively affected seagrass beds and transplants. However, available plant nutrient levels of substrate samples did not vary significantly between vegetated and barren areas. This publication provides information on techniques and monitoring metrics that can be measured in evaluating success.

Eleuterius, L. N. and J. I. Gill. 1981. Long-term observations on seagrass beds and salt marsh established from transplants, pp. 72-86. In R. H. Stovall (ed.), Proceedings of the 8th Annual Conference on Wetlands Restoration and Creation. Hillsborough Community College, Tampa, Florida.

Author Abstract. This report discusses seagrass and saltmarsh transplant projects in Mississippi. The techniques used for this study are described in this article. The projects involved transplanting a wide variety of seagrass and salt marsh species. In seagrass projects, *Halodule beaudettei, Thalassia testudinum* and *Cymodocea manatorum* were transplanted. Approximately 30% of the transplants survived best, and spread rapidly. At these particular test sites the seagrass beds spread only westward, leaving their original planting sites empty as the eastern shoots died. This migration occurred within a few growing seasons and was due to the predominant westward current in the area.

Fisheries and Aquaculture Research. 2000. Oyster Point seagrass monitoring 1995 to 1998. Project leader R. Coles, Fisheries and Aquaculture Research Report, Queensland Government. Department of Primary Industries, 80 Ann St, Brisbane, Queensland Australia. http://www.dpi.qld.gov.au/far/9253.html

Researchers monitored seagrass abundance on both sides of Stony Creek Oyster Point and compared it to the baseline data collected in 1995. Baseline seagrass surveys at Oyster Point were conducted in November 1995 and August 1996, prior to dredging of the main boat access channel. Seagrass monitoring surveys were conducted immediately following dredging and the opening and widening of the marina entrance, and during the dredging of the marina and maintenance dredging of the main boat channel. A survey was conducted in December 1999 to test persistence of the silt layer and its impacts on seagrasses. Abundance (visual estimates) and aerial extent of seagrass habitat in December 1999 were similar to that in 1998. Data collected from field observations, show that biomass of all seagrass species may be similar to previous surveys. In addition, preliminary observations showed that long–term patterns of silt deposition following dredge and excavation activities at Oyster Point were not responsible for large changes in seagrass distribution and abundance.

Fonseca, M. S., W. J. Kenworthy and G. W. Thayer. 1985. Transplanting of the **seagrasses** *Zostera marina* and *Halodule wrightii* for sediment stabilization and habitat development on the east coast of the United States. 64 pp. Technical Report of United States Army Engineers Waterways Experiment Station WES-TR-EL-85-9.

Successful methods for transplanting seagrasses to achieve densities similar to natural, local seagrass populations are described in this report. Researchers used numerous measures and procedures to evaluate, analyze, and carrying out plant growth. The growth of transplants was determined by monitoring the growth rate of shoots, the population, the area covered per planting unit, and the number of planting units remaining. Plant material requirements were estimated by calculating the number of planting units needed for a transplant site. Harvest and storage of plant material included identifying preferred harvest sites, developing a suitable harvest technique, and providing storage for seagrass in transit. Planting units were prepared and carried out. Finally researchers monitored seagrass growth and abundance. Detailed information on these techniques used can be found in this publication.

Fonseca, M. S. 1990. Regional analysis of the creation and restoration of seagrass systems, pp. 179-185. In Kusler, J. A., and M. E. Kentula (eds.), Wetland Creation and Restoration: the Status of the Science. Island Press, Washington, D. C.

This book discusses goals that should be established for seagrass restoration and monitoring. Such goals include development of persistent cover, generation of equivalent acreage or increased acreage, replacement with the identical seagrass species, and restoration of faunal production. The author stated that during monitoring, records should be kept of the number of planting units that survive, the number of shoots, the population growth rate, and area coverage. Additional information for techniques is presented. Researchers suggested that hydrology, substrate, revegetation, reintroduction of fauna, buffers, protective structures, and long term management should be taken into consideration during planning to avoid any detrimental changes from occurring in the ecosystem.

Fonseca, M.S. 1992. Restoring seagrass systems in the United States, pp. 79-110. In Thayer, G. W. (ed.), Restoring The Nation's Marine Environment. Publication UM-SG-TS-92-06. Maryland Sea Grant College, College Park, Maryland

AuthorAbstract. Seagrass restoration has been performed as a defensive or remedial action in conjunction with natural resource damages. In order to protect seagrass habitat, the author suggests that better project goals be established from the outset. Goals may include developing persistent cover, generating equivalent acreage, increasing acreage, replacing the same seagrass species as was injured or removed, and restoring faunal production. See publication for additional information on methods to be use for monitoring and restoration of seagrasses. Site selection is considered a problem in ensuring seagrass restoration success. This paper discusses 8 research needs that are important for improving seagrass restoration science: 1) a definition of functional restoration, 2) a compilation of population growth and coverage rates, 3) the resource role of mixed species plantings, 4) the impact of substituting pioneer for climax species on faunal composition and abundance, 5) culture techniques for propagule development, 6) transplant-optimization techniques such as the use of fertilizer, 7) the importance of maintaining genetic diversity, and (8) resource agencies.

Fonseca, M. S. 1993. A guide to planting seagrasses in the Gulf of Mexico. 27 pp. Texas A&M University Sea Grant College Program. Report No. TAMU-SG-94-601.

This report presents methods used for planting and transplanting seagrass. Methods described include plug, staple, and peat methods. In the plug method, plugs of seagrass are harvested using a core tube. Core tubes remove plugs from the seagrass bed transported them in the tube to planting site. The tube is placed in the sediment while directing seagrass blades into the tube and then capped generating suction that pulls the small plug of seagrass with associated sediment. The bottom is then sealed to avoid losing the plug during transport. The staple method include digging up plants and sediment, shaking sediment from roots and rhizomes and placing the whole plant in flowing seawater tanks until placed in planting units. The plants are then attached to the staples in groups and secured using a paper, coated, metal twist-tie. Finally the staples are placed into the sediment. In the peat pot method, peat pots used were 3 inches on each side. A sod plugger was used to cut plugs from existing beds. The plugs are then placed immediately into peat pots and placed in a floating holding tray descended to the bottom and remains until transported to the planting site. For planting, the sediment is loosened and peat pots are placed in the bottom sediment. Additional information on techniques is also discussed in this manual.

Fonseca, M. S., W. J. Kenworthy, F. X. Courtney and M. O. Hall. 1994. Seagrass planting in the southeastern United States: methods for accelerating habitat development. *Restoration Ecology* 2: 198-212.

Author Abstract. Seagrass transplanting experiments were conducted in Back Sound, Carteret County, North Carolina, and Tampa Bay, Pinellas County, Florida. In Florida, we compared three planting methods (cores, stapled bare root, and peat-pot plugs) for shoot addition rate, coverage, and labor cost (harvest, fabrication, and deployment) using *Halodule wrightii*. Only planting methods and development rates were recorded for *Syringodium filiforme*. Fertilizer additions were made to peat-pot plantings of *H. wrightii* and *Zostera marina* in both North Carolina and Florida. Exclosure cages were tested to attempt to minimize bioturbation of *H. wrightii* and *Z. marina* in both North Carolina and Florida. Recovery from harvesting impacts to existing, natural beds of *S. filiforme* and *H. wrightii* were assessed in Florida. The peat-pot method was about 35% and 63% less expensive in work time than staples and core tubes, respectively. Response to fertilizer additions was masked by inconsistent release properties of the fertilizer, although some indication of positive response to phosphorus fertilizer in sediments with low carbonate content, and nitrogen in general, was detected. Complete loss of peat pots, largely ascribed to bioturbation, occurred in a large planting (Tampa Bay) but not in nearby smaller ones where exclosure cages were used. Cages did not affect planting unit survival in North Carolina but did improve number of shoots per planting unit in one of three experiments. No detrimental effects of cages were noted. Existing natural beds used to harvest transplanting stock in Tampa Bay recovered from excavations as large as 0.5 m in one year. Significant cost savings were found to be possible through methodological improvement, including planting techniques, bioturbation exclusion, and possibly fertilizer additions.

Fonseca, M. S., W. J. Kenworthy and F. X. Courtney. 1996. Development of planted seagrass beds in Tampa Bay, Florida, USA. 1. Plant components. *Marine Ecology Progress Series* 132: 127-139.

Author Abstract. In this study we evaluated the floral attributes of planted seagrass beds as they developed over time. The seagrasses *Halodule wrightii* and *Syringodium filiforme* were planted on 0.5 m centers at several sites within Tampa Bay, Florida, USA. Planting unit (PU) survival, change in aerial shoot density, plant morphometrics and associated macroalgae were monitored over a 3-yr period. These parameters were compared with nearby, natural beds as a reference. Comparisons were not limited to the same species, but included *Thalassia testudinum* in order to address management issues regarding the substitution of one habitat type for another. Despite use of experienced personnel, in some plantings, an average 47% loss of PU was sustained, apparently due to seasonal bioturbation. Depending on the spatial distribution of loss, persistent cover at equivalent densities was still attained within 1.8-yr (for plantings on 0.5 m centers) over portions of some planted sites. Seagrass recovery rate and recommended monitoring times have a positive, linear relationship to spacing of plantings. Although moderately variable, aerial shoot density clearly defined trends in bed development over time. Many plantings exhibited little spread in the first year after planting, and then expanded rapidly in the second year. Seagrass surface area, length or biomass, as well as macroalgal biomass, proved to be weak indicators of system development for most seagrass species. Although substantial PU losses were experienced, the subsequent survival, spread and persistence of seagrasses indicate that large areas of Tampa Bay, which historically had supported seagrass, are now suitable for restoration. For remaining seagrass habitat however, conservation provides a more certain basis for maintaining the resource than attempting to mitigate through planting.

Fonseca, M. S., W. J. Kenworthy and G. W. Thayer. 1982. A low cost transplanting procedure for sediment stabilization and habitat development using eelgrass (*Zostera marina). Wetlands* 2:138-151.

This paper describes procedures for conducting a low cost planting technique for seagrass. Procedures for harvesting and storing plants include identifying preferred harvest sites, developing a harvesting technique and storage guidelines. In order to prepare the planting units, the plants were first collected and the number of shoots per planting unit isolated. Researchers attached the anchor and fasteners with one plant per unit. The planting units were then placed into containers for transport to the planting site. The planting method for eelgrass involved inserting plants into the sediment so that the top of the L-shaped anchor was covered with sediment. Additional information on techniques used for planting eelgrass is described in this report. Requirements for seagrass transplants included establishing the number of units required for a planting and the number of shoots required for planting. Labor requirements must also be taken into consideration. For instance the number of men needed and the amount of hours required for harvesting and preparation of planting units and actual planting. The article provides details on how construction of an efficient time- and man-power schedule can be completed.

Fonseca, M. S., W. J. Kenworthy and G. W. Thayer. 1998. Guidelines for the conservation and restoration of seagrass in the United States and adjacent waters. 222 pp. NOAA Coastal Ocean Program Decision Analysis Series No.12. http://shrimp.ccfhrb.noaa.gov/library/digital.html

Author Abstract. Several criteria have been used for evaluating seagrass planting success. Many habitat functions seem to relate directly to measures of coverage and persistence for structural criteria. Seagrass monitoring should provide for mid-course correction and improve planning of future restoration projects. Structural criteria include planting survival, aerial coverage, and number of shoots. The methods used for planting and transplanting of seagrass included plug methods, staple method and peat pot method. Details of techniques used are described in this publication, and should be used as a guideline in planting and monitoring. Seagrasses should be monitored at least quarterly after the first year and every six months for at least the following four years. In terms of achieving success, a nearby reference site may be used for comparison. An alternative strategy should be used to compare the monitored site with currently published structural values to gauge restoration performance. Cost estimates per hectare of seagrass restoration are presented.

Fonseca, M. S., B. E. Julius and W. J. Kenworthy. 2000. Integrating biology and economics in seagrass restoration: how much is enough and why? *Ecological Engineering* 15:227-237.

Author Abstract. Although success criteria for seagrass restoration have been in place for some time, there has been little consistency regarding how much habitat should be restored for every unit area lost (the replacement ratio). Extant success criteria focus on persistence, area, and habitat quality (shoot density). These metrics, while conservative, remain largely accepted for the seagrass ecosystem. Computation of the replacement ratio using economic tools has recently been integrated with seagrass restoration and is based on the intrinsic recovery rate of the injured seagrass beds themselves as compared with the efficacy of the restoration itself. In this application, field surveys of injured seagrass beds in the Florida Keys National Marine Sanctuary (FKNMS) were conducted over several years and provide the basis for computing the intrinsic recovery rate and thus, the replacement ratio. This computation is performed using the Habitat Equivalency Analysis (HEA) and determines the lost on-site services pertaining to the ecological function of an area as the result of an injury and sets this against the difference between intrinsic recovery and recovery afforded by restoration. Joining empirical field data with economic theory has produced a reasonable and typically conservative means of determining the level of restoration and this has been fully supported in Federal Court rulings. Having clearly defined project goals allows application of the success criteria in a predictable, consistent, reasonable, and fair manner.

Green, E. P. and F. T. Short. 2003. World Atlas of Seagrasses. University of California Press, Berkeley, CA.

Publisher Description. Seagrasses, a group of about sixty species of underwater marine flowering plants, grow in the shallow marine and estuary environments of all the world's continents except Antarctica. The primary food of animals such as manatees, dugongs, green sea turtles, and critical habitat for thousands of other animal and plant species, seagrasses are also considered one of the most important shallow-marine ecosystems for humans since they play an important role in fishery production. Though they are highly valuable ecologically and economically, many seagrass habitats around the world have been completely destroyed or are now in rapid decline. *The World Atlas of Seagrasses* is the first authoritative and comprehensive global synthesis of the distribution and status of this critical marine habitat--which, along with mangroves and coral reefs, has been singled out for particular attention by the United Nations Convention on Biodiversity.

Illustrated throughout with color maps, photographs, tables, and more, and written by a large team of international collaborators, this unique volume covers seagrass ecology, scientific studies to date, current status, changing distributions, threatened areas, and conservation and management efforts for twenty-four regions of the world. As human populations expand and continue to live disproportionately in coastal areas, bringing new threats to seagrass habitat, a comprehensive overview of coastal resources and critical habitats is more important than ever. *The World Atlas of Seagrasses* will stimulate new research, conservation, and management efforts, and will help better focus priorities at the international level for these vitally important coastal ecosystems.

Gulf of Maine Council Habitat Restoration Subcommittee. 2004. Gulf of Maine habitat restoration strategy: Restoring coastal habitat in the Gulf of Maine region, 25 pp., Gulf of Maine Council on the Marine Environment. www.gulfofmaine.org

The Gulf of Maine Restoration Strategy states that habitat restoration is necessary to support aquatic resources in the Gulf of Maine to meet both biological and socioeconomic needs. While restoration projects have already occurred in each of the States or Provinces that share the Gulf of Maine, no formal statement of shared goals or a unified strategy to meet them has been presented. This document lays the groundwork for this by:

- Stating the purpose and scope of regional habitat restoration in the Gulf of Maine
- Identifying habitat types, impacts, and restoration needs, and
- Developing recommendations for enhancing habitat restoration

This report identifies resources of regional significance and promotes habitat restoration that is needed to support the viability of these resources. The strategy presented focuses on four categories of habitats:

(1) Riverine

(2) Intertidal

(3) Subtidal, including nearshore and offshore waters, and

(4) Beaches, sand dunes, and islands

Recommendations provided for the continued success with habitat restoration efforts in the Gulf of Maine include:

- Restore the four coastal marine habitat types identified in this document using a regional strategy to prioritize projects
- Improve our ability to identify habitat restoration sites, focus regional efforts, understand regional trends, and develop effective long-range planning
- Increase development and management capacity in all jurisdictions in the region to make restoration more efficient and effective
- Enhance outreach efforts to federal, state, local governments and the private sector to create a common understanding of the social, economic, and environmental benefits of habitat restoration
- Complete and maintain a database of restoration projects in the region to evaluate progress and ensure accordance with the US National Estuary Restoration Inventory (NERI)
- Refine existing salt marsh monitoring protocols and develop monitoring protocols for other habitats identified in this document

James, W. F., J. W. Barko and M. G. Butler. 2001. Shear stress and sediment resuspension in canopy- and meadow-forming submersed macrophyte communities. 16 pp. U.S. Army Engineer Research and Development Center, Vicksburg, MS. APCRP Technical Notes Collection ERDC TN-APCRP-EA-03. http://www.wes.army.mil/el/aqua/pdf/apcea-03.pdf

This technical note reviewed the impacts that differing plant architecture (canopy vs. meadow) and biomass production have on submerged macrophytes ability to decrease wave-induced shear stress at the sediment surface. Authors found that both growth forms significantly decreased shear stress at high biomass levels (<200 g/m^2). For restoration practitioners interested in monitoring shear stress during restoration activities, a detailed explanation of methods is included.

Kashian, D. R. and T. M. Burton. 2000. A comparison of macroinvertebrates of two Great Lakes coastal wetlands: Testing potential metrics for an Index of Ecological Integrity. *Journal of Great Lakes Research* 26:460-481.

Author Abstract. The macroinvertebrates of two northern Lake Huron wetlands were compared to assess water quality and test potential metrics for an Index of Ecological Integrity (IEI) for Great Lakes coastal wetlands. Macroinvertebrates were collected using sediment coring and dip-net sampling monthly from June through September 1996. One wetland was impacted by domestic wastewater from a lagoon, urban storm-water runoff, and local marina traffic. A nearby wetland with a similar size drainage basin, no wastewater or urban storm-water input or marina traffic served as a reference. Greatest differences in chemistry between sites occurred during lagoon discharge in September. Compared to the reference, the impacted wetland had higher Cl, NH_4-N, NO_3-N, soluble reactive P, conductivity and lower dissolved oxygen levels. There were fewer insects, especially Ephemeroptera and Trichoptera in the impacted wetland than in the reference wetland. A greater proportion of macroinvertebrates in the impacted wetland were Amphipoda, Isopoda, and Naididae. Observed differences in macroinvertebrate communities were used to test 38 metrics, used in indices of biological integrity for streams, to determine their potential as metrics for an index of ecological integrity for Great Lake wetlands. Invertebrate attributes sensitive to water quality changes were identified as candidate metrics if they exhibited low within-site variability and detected differences between wetlands for each sampling period. Candidate metrics included relative abundance of Ephemeroptera, Isopoda, Trichoptera, predators, collector-filterers, and herbivore/detritivore ratio.

Kenworthy, W. J. 1994. Conservation and restoration of the seagrasses of the Gulf of Mexico through a better understanding of their minimum light requirements and factors controlling water transparency, pp. 17-26. In Indicator Development: Seagrass Monitoring and Research in the Gulf of Mexico, Gulf Breeze, Fla., U.S. Environmental Protection Agency, Office of Research and Development, Environmental Research Laboratory.

This paper discusses measurements that should be taken in order to understand and predict seagrass distribution. Water quality and light metrics were used to determine the success and distribution of seagrasses. Detailed information on methods used is presented. Data collected on depth distribution showed that *Halodule wrightii* and *Syringodium filiforme* grew deeper than *Thalassia testidinum.* Mechanisms controlling *T. testidinum* light requirements may include phototoxicity instead of carbon balance. *Halodule wrightii,* however, produced more oxygen at low light levels. Results show that *H. wrightii* can maintain continuous growth at low light levels for longer periods than *T. testidinum.* This shows that seagrass growth in certain light levels and water depths will vary among species. The author states that this prognostic ability is particularly useful for designing management programs for monitoring, protection, and restoration of seagrasses. Other evaluations made and additional information on other parameters investigated for this study are described.

Killgore, K. J., R. P. Morgan II and N. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101-111.

Author Abstract. The distribution and abundance of fishes in submersed aquatic plants of three relative densities (no plants, intermediate plant density, high plant density) were estimated in the tidal Potomac River near Alexandria, Virginia. Fish were sampled with a boat-mounted electroshocker at night in May (when plants were emerging), August (peak plant densities), and November (plant senescence) of 1986. Mean densities of all plants ranged from 9 to 33 g/m^2 (dry-weight basis) in May, and 400 to greater than 1,000 g/m^2 in August and November. *Hydrilla verticillata* was usually the dominant aquatic plant. In May, overall mean fish abundance was highest in areas of high plant density (36 fish/5 min shocking), whereas in August and November fish abundance was highest in areas of intermediate plant densities (100 and 62 fish/5 min electroshocking, respectively). Areas without plants contained a relatively high number of filter-feeding fishes, including Atlantic menhaden *Brevoortia tyrannus* and blueback herring *Alosa aestivalis*. The fish assemblage in the vegetated sites comprised mainly brown bullhead *Ictalurus nebulosus*, banded killifish *Fundulus diaphanus*, pumpkinseed *Lepomis gibbosus*, largemouth bass *Micropterus salmoides*, and yellow perch *Perca flavescens*. The bay anchovy *Anchoa mitchilli*, white perch *Morone americana*, and inland silverside *Menidia beryllina* were distributed throughout all three sites during the study. Fish also were sampled with pop nets in aquatic plants and with seines between shore and the plant beds. More than five times more fish (9.8/m^2) were collected with pop nets in areas with intermediate plant density, where there were several codominant plant species, than in areas with dense hydrilla (1.8 fish/m^2). Shore-zone fish densities estimated with seine hauls were higher in areas adjacent to dense hydrilla beds (9 fish/m^2) than in areas with no plants (1.5/m^2) or near intermediate plant densities (3.3/m^2), but the number of fish species was lowest near hydrilla.

Krieger, K. A. 1992. The ecology of invertebrates in Great Lakes coastal wetlands: current knowledge and research needs. *Journal of Great Lakes Research* 18: 634-650.

Author Abstract. This review summarizes the comparatively sparse information on the community structure, population dynamics, secondary productivity, and trophic relationships of invertebrates in coastal wetlands of the Laurentian Great Lakes. Community structure is discussed in terms of separate but interrelated communities comprising the zooplankton, zoobenthos, epiphytic invertebrates, and neuston. The composition and dynamics of these communities are controlled by a complex set of interacting and continuously changing biotic and abiotic factors. Much additional research is required before a fundamental understanding of invertebrate ecology in Great Lakes coastal wetlands can be achieved. Particular research needs include elucidation of geographic differences in community structure and dynamics within and among wetlands of the same and contrasting types; the influence of micro- and macro-habitat differences and environmental stresses on invertebrate communities; the contribution of invertebrates to energy and materials flow in wetland food webs; the interactions of wetland invertebrates with the adjoining lake biota; the role of invertebrates in nutrient and pollutant transformations and cycling within the wetlands; the impact of changing land used in wetland watersheds and of wetland alteration on the invertebrate communities, and the consequential impacts of these changes on the ecology of the lakes; and the impact on wetland invertebrate communities of predation pressure and competition from exotic species.

Levine, S. N., D. T. Rudnick, J. R. Kelly, R. D. Morton, L. A. Buttel and K. A. Carr. 1990. Pollutant dynamics as influenced by seagrass beds: experiments with tributyltin in *Thalassia* microcosms. *Marine Environmental Research* 30:297-322.

Author Abstract. Seagrass beds are highly productive ecosystems whose leaves and sediments provide considerable surface area for interactions with seawater; thus, they may be foci for the sorption, accumulation, and degradation of pollutants. The fate of the potent biocide tributyltin (TBT) in water that passes through seagrasses and over sediments was studied in marine microcosms containing sediment cores from a subtropical seagrass bed (including *Thalassia testudinum* and associated fauna) and seawater. The TBT was rapidly removed from the water column (half times of 10-20 h), primarily through adsorption onto sediments and seagrass leaves. Accumulation of TBT in sediments and grasses was temporary, however; at harvest, the seagrass microcosms contained just 20-30% of the super(14)C that had been adsorbed or assimilated during dose periods, and half of this label was in degradation products.

Lewis, R. R., III. 1987. The restoration and creation of seagrass meadows in the southeastern United States. pp. 153-174. Proceedings of the Symposium on Subtropical-Tropical Seagrasses of the Southeastern United States.

Author Abstract. The restoration and creation of seagrass meadows is of increasing concern in the southeastern United States, due to large-scale declines in seagrass meadow coverage. Researchers and environmentalists estimate that approximately one-third of the 600,000 ha of seagrass meadows that were present in coastal Florida in the 1940's no longer exist. Associated declines in fisheries harvests have been documented. In Mississippi, 1,970 ha of seagrasses remain, representing a loss of almost two-thirds. Both restoration and creation of meadows have been successful in individual projects at sites up to 6 ha in size, but failures are common. A more analytical approach to successful plantings is encouraged; prior knowledge of water quality and stresses on existing seagrass meadows is essential. Simple transplanting with plugs from existing healthy meadows (particularly *Thalassia testudium* plugs) in not encouraged for large-scale projects. The use of non-destructive sources of material for culture of planting units is documented and recommended. Salvage of seagrasses from areas to be impacted can ensure successful, non-destructive meadow restoration and creation, and is encouraged.

Lores, E. M., E. Pasko, J. M. Patrick, L. Q. Robert, J. Campbell and J. Macauley. 2000. Mapping and monitoring of submerged aquatic vegetation in Escambia-Pensacola Bay System. *Florida Gulf of Mexico Sciences* 18:1-14.

Author Abstract. Recently, the distribution and changes in submerged aquatic vegetation (SAV) in the Escambia-Pensacola Bay System in northeastern Florida were monitored by two techniques. One technique used divers to measure changes in the deepwater margin of beds and provided horizontal growth measurements to the nearest centimeter, the other used a differential global positioning system (DGPS) on a small boat to map the perimeter of SAV beds in shallow water. Current distribution of SAV in Escambia Bay shows that most of the SAV losses that occurred during the 1950s to 1970s have been recovered. In Santa Rosa Sound and Pensacola Bay, SAV showed significant increased growth with horizontal growth rates of some beds averaging more than 50 cm over the past year. In Big Lagoon, however, SAV has declined an average of 10 cm in horizontal coverage along the deepwater edge. Water quality and photosynthetically active radiation light measurements from the Escambia-Pensacola Bay System suggest that increased light availability was associated with the increased seagrass coverage in Santa Rosa Sound and Pensacola Bay, and elevated nutrient concentrations were associated with the seagrass declines in Big Lagoon.

Lundholm, J. T. and S. W. Len. 1999. Regeneration of submerged macrophyte populations in a disturbed Lake Ontario coastal marsh. *Journal of Great Lakes Research* 25:395-400.

Author Abstract. Previous studies in disturbed Great Lakes coastal marshes have determined that seed banks for submerged macrophytes tend to be depauperate if not absent. This was thought to be a major factor that would prevent the regeneration of macrophyte populations under improved conditions, so the transfer of seed or adult plants from healthy wetlands within the same region has been recommended as a restoration strategy. Cootes Paradise is a large, disturbed coastal marsh with a poor seed bank for submerged plants. In this report a large increase in submerged macrophyte population densities following the reduction of carp (*Cyprinus carpio*) densities from approximately 700 kg/ha in 1996 to 50 kg/ha in 1997 is documented. Much of this regeneration occurred in areas devoid of aquatic vegetation in 1996. It was determined that these plants developed from vegetative structures buried in the sediment. It is recommended that detailed surveys of both seed and vegetative propagule banks be undertaken before assessing the likelihood of the recovery of submerged macrophyte communities in disturbed coastal marshes.

McRoy, P. and C. Helffreich. 1977. Culture methods and techniques, pp. 77-81. In McRoy, P., and C. Helffreich (eds.), Seagrass Ecosystems: A Scientific Perspective. Marcel Dekker. Inc., New York, NY.

This paper presents methods used for evaluating seagrasses tolerance to change in light levels under laboratory conditions. Cultures were sustained in outdoor and indoor conditions for a year. Data showed that *Thalassia* survived only seven months and *Halodule* for three and a half months. *Thalassia* present in outdoor tanks survived twelve months but only a few *Halodule* survived. The seawater used in the laboratory studies included synthetic seawater and natural bay water. Seagrass growth in synthetic seawater was less dependent on the source of the medium than salinity, temperature, and light. Additional information on techniques used is presented.

Cultured seagrasses were transplanted into two soils, river sand and sandy loam within the Gulf of Mexico. After five months, *Halophila, Thalassia*, and *Ruppia* had greater survival rates in the sandy loam. *Halodule* had a poor survival in both soil types but *Halophila* flourished in culture containers containing algae. Such data suggests that *Halophilia* can tolerate low light intensity and dense algal growth. A good technique for use in collecting eelgrass based on successful research conducted in the past is also presented.

Muehlstein, L. (draft). Seagrass monitoring protocol. The National Park Service Inventory and Monitoring. http://science.nature.nps.gov/im/monitor/refer.cfm?AutoNumber=3

Author Abstract. The Virgin Islands National Park has been using a SONAR-based underwater position-locating system (AquaMap by Desert Star Systems) for detailed mapping and monitoring of marine habitats. Using this system along with fixed transects has proved to be effective for monitoring seagrass beds. By using this system, complete randomization of sample points within a study site as well as accurate transfer of those points with sub-meter accuracy can be achieved. The advantage to using this method is that it prevents biases of fixed transects and increases the statistical precision for data analyses. Over-sampling a selected seagrass bed and applying the optimization analysis described in Bros and Colwell (1989) determines the optimum sample size. Seagrass species densities are calculated by counts within quadrats. Data is collected at fixed, long-term transects, on seagrass densities, percent cover of seagrasses, and macroalgal community structure. Additional information on methods used for mapping and monitoring seagrass can be obtained from the reference.

Orth, R. J., M. Luckenbach and K. A. Moore. 1994. Seed dispersal in a marine macrophyte: Implications for colonization and **restoration**. *Ecology* 75:1927-1939.

Author Abstract. The authors conducted seed dispersal experiments in the field and laboratory to better describe seed dispersal characteristics in one species, *Zostera marina* L. (eelgrass), the dominant seagrass species in the temperate zone of the United States, Japan, and Europe. Seeds were broadcast by hand into unvegetated 5 m diameter plots at three locations over 3-yr (1989-1991) in the York River, Virginia (Chesapeake Bay). These sites had been previously vegetated but were devoid of any vegetation prior to (since 1972) and during the course of the experiments. Resultant seedling distributions closely matched broadcast patterns, with 80% of all seedlings found within the 5 m diameter plots, despite the fact that geophysical processes would appear sufficient to transport seeds greater distances. Wind records for the 2-mo period between seed broadcasting and germination revealed time-averaged wind speeds in excess of 40 km/h on greater than or equal to 12-d in each of the 3-yr and gale-force winds (72 km/h) in 2 of 3 yr. A three-dimensional hydrographic computer simulation model of the York River provided instantaneous current velocity estimates from which maximum bottom shear velocities (u_*) in the study area were approximated (flood tide: 1.26 cm/s, ebb tide: 1.20 cm/s). These estimates exceeded the critical erosion threshold (u_{*crit}) = 0.7 cm/s) for *Z. marina* seeds determined from laboratory flume experiments. We postulate that small-scale topographic features on the bottom (burrows, pits, mounds, ripples) shield the seeds from the flow. Our results suggest that seeds settle rapidly, dispersing only up to a few meters under the influence of currents and become rapidly incorporated into the sediment. The limited dispersal capabilities of seeds underscore the need to address restoration goals and questions of seagrass ecology in the context of landscape-scale distributional patterns and metapopulation analyses.

Orth, R. J., M. C. Harwell and J. R. Fishman. 1999. A rapid and simple method for transplanting eelgrass using single, unanchored shoots. *Aquatic Botany* 64: 77-85.

Author Abstract. In a large-scale eelgrass (*Zostera marina* L.) restoration program that began in 1996 in Chesapeake Bay, a simple transplant technique was developed where single, unanchored shoots with rhizomes were planted by hand into the sediment at an angle to a depth of between 25 and 50 mm, allowing the more compact area of the sediment above the rhizome to assist in anchoring the plant. This method led to high success, as determined primarily by percent cover and shoot density at four transplant sites in two river systems, where 53,760 shoots were planted into 768 2 x 2 m^2 plots. The estimated total time to plant a single shoot using this method, including collection and sorting of shoots for planting, was approximately 21 s. Survivorship in the first month was high (73%) and compares favorably with methodologies from other published studies. Percent cover increased rapidly from 12.3% to 18.0% over the first eight months to 24.2-38.9% after twenty months. Vegetative growth from a single shoot was rapid, with shoot densities similar to those of nearby, natural beds attained in one year or less (e.g., transplanted areas at eight months: 772 ± 203 to 1234 ± 419 shoots m^{-2}; natural areas: 697 plus or minus 256 shoots m^{-2}). Despite the simplicity of this technique, it is fairly robust and complements the recent development of another simple technique (Davis and Short, 1997 Aquat. Bot. 59, 1-15) with applications for other seagrass species.

Perrow, M. R., J. H. Schutten, J. R. Howes, T. Holzer, F. J. Madgwick and A. J. D. Jowitt. 1997. Interactions between coot (*Fulica atra*) and submerged macrophytes: The role of birds in the restoration process. *Hydrobiologia* 342-343: 241-255.

Author Abstract. Grazing by herbivorous birds is often cited as an important factor in suppressing macrophyte development in shallow lakes undergoing restoration, thus delaying the attainment of the stable clear water state. Development and succession of macrophyte communities and size, diet and grazing pressure of coot (*Fulica atra*) populations upon macrophytes, were monitored over the seasonal cycle at ten shallow lakes of varying nutrient status, in the Norfolk Broads in eastern England. In spring, territorial breeding birds were at relatively low density and included only a small proportion of macrophytes in their diet, resulting in low grazing pressure on macrophytes. In summer, there was a significant relationship between macrophyte cover and bird density, illustrating the importance of macrophytes in the dispersion phase for birds following breeding. Macrophytes comprised the bulk of bird diet where they were available and the consumption of macrophytes was up to 76 fold higher than in spring. However, losses to grazing in both periods were negligible when compared to potential growth rates documented in the literature. Grazing experiments at two biomanipulated lakes confirmed that birds were not responsible for limiting macrophytes during the spring colonization phase or in the summer growth period. During the period of autumnal senescence and over the winter months where some macrophyte species remain available, e.g., as developed individuals or dormant buds, grazing by birds may conceivably have an impact on the development and structure of macrophyte populations in subsequent growing seasons. The relative importance of bird grazing compared to other factors limiting the development of macrophytes in shallow lakes is discussed in the light of other experimental studies.

Phillips, R. C. 1980. Planting methods, pp. 17-20. In Lutz, R. A. (ed.), Planting Guidelines for Seagrasses, Coastal Engineering. United States Army Corps of Engineers, Coastal Engineering Research Center. Technical Aid No. 80-2.

Planting methods for seagrass restoration are presented in this document. The methods described include seeding, planting of eelgrass sprigs, planting plugs, and planting sprigs. Seeding is used primarily for turtle grass because their seeds are larger and not easily away. The seeds are collected from mature fruits or as germinated seedlings that lay on the sediment surface. During the harvest season the fruit is clipped from the stalk and the spongy ovary wall is opened to expose the four to five seeds. Eelgrass sprigs are composed of three to four shoots. Shoal grass sprigs consist of fifteen to twenty shoots on the same rhizome. The sprigs are planted during low currents by excavating a small hole in the substrate, placing the sprigs in the hole, and covering them with sediment. Plugs are acquired by using a cylindrical coring device pushed into the grass bed. The grass plug is then transplanted in a hole, 6 to 8 inches deep. Plugs are recommended for shoal grass transplants. Planting and seagrass sprigs are anchored in areas where currents exceed 1.5 knots and wave currents are influenced by wind or storm. Construction rods and iron mesh painted with vinyl paint can be used as anchoring devices for seagrass plants. Using the rods and iron mesh prevent the plants from being swept away. Techniques are described in detail in this publication. The time in which planting occurs should also be considered because successful growth of seagrass will vary among species.

Phillips, R. C. and P. C. McRoy. 1990. Transplant methods: Seagrass research methods, pp. 51-53. In Phillips, R. C. and P. C. McRoy (eds.), Handbook of Seagrass Biology: An Ecosystem Perspective. Garland STPM Press, New York, NY.

Seagrass transplanting methods that have been successfully used are described in this document. The use of seagrass transplants is an attempt to restore seagrasses and provide structural and functionality to the habitat. Techniques including transplants and anchoring methods are described in detail and should be considering developing planting approaches for seagrass restoration projects. Seagrass transplanting methods include non-anchoring and anchoring methods. The non-anchoring methods include turfs where units of seagrass around 0.1m^2 are dug up and removed from selected sites. The units are then transported to the transplant site and placed or plugged into the sediment. The plug is dug deep enough secure the root. A plastic cylinder is inserted into the sediment around the seed to protect the propagule from erosion. Anchoring methods used involve individual leafy shoots that are fixed using rubber bands to pipes or iron construction rods. Plants can also be fixed to concrete rings and thrown on the bottom. See reference for additional information on techniques used for transplanting.

Sand-Jensen, K. 1975. Biomass net production and growth dynamics in an eelgrass population in Vellerup Vig, Denmark. *Ophelia* 14:185-201.

Author Abstract. Researchers evaluated the biomass of an eelgrass population in Vellerup Vig, Denmark, and seasonal pattern, March to October 1974. Biomass of leaves and flowering turions was significantly greater than initial amount; biomass of rhizomes also increased significantly from March to August. The maximum total biomass was 433 grams dry weight per square meter. The leaf population was determined by a leaf marking technique that made it possible to estimate the rhizome population. Additional information on methods used is described in this publication. Results showed from April 9 – October 16,1974, the leaf production was 856 grams dry weight per square meter. The dominance of leaf production resulted from a higher turnover rate of leaves (1.8% per day) than of rhizomes (0.7% per day). On the average a new leaf was about 56 days. Total radiation seemed to control leaf production. The maximum leaf production rate of 7.9 grams dry weight per square meter per day in mid-June corresponds with maximum radiation. The total production was significantly greater than the net increase of total biomass and more than twice the maximum total biomass. The methods used could be employed in assessing some metrics for submerged aquatics.

Scott, W. A., J. K. Adamson, J. Rollison and T. W. Parr. 2000. Monitoring of aquatic macrophytes for detection of long-term change in river systems. *Environmental Monitoring and Assessment* 73:131-153.

Author Abstract. This paper presents details of the methodology developed by the United Kingdom's Environmental Change Network for the long-term monitoring of macrophytes in rivers and streams. The methodology is based on techniques first proposed by the Standing Committee of Analysts (1987) and later adapted by the National Rivers Authority (NRA) and Environment Agency, but differs in splitting the surveyed 100 m stretch of water into sections to provide an objective measure of the frequency of occurrence of individual species in place of the more subjective estimation of cover. A pilot study of the ECN methodology took place at five sites in 1997. The results of this study, including a few practical difficulties in the application of the methodology, are presented and discussed. For all but one of the sites strong associations were found between the number of species observed and the physical characteristics of the watercourse. The most important characteristics were degree of shading, substrate type, depth and clarity. The frequency of occurrence of individual species within sections of the watercourse was found to be strongly related to the log of the overall estimates of cover. Because the use of sections, rather than a single overall cover estimate, enables variation in the pattern of vegetation over surveyed stretches to be detected and related to watercourse characteristics, the precision with which change can be detected is increased, and the possibility of determining the causes of change is thereby enhanced. Moreover the use of sections allows within-site variation to be calculated and hence the accuracy of estimated changes to be quantified. In general implementation of the ECN methodology was not found to be particularly onerous or difficult. As a result of the pilot study some changes in the ECN methodology have been made, primarily to reduce the workload so that sites can be surveyed comfortably in a single day.

Simons, J. H. E. J., C. Bakker, M. H. I. Schropp, L. H. Jans, F. R. Kok and R. E. Grift. 2001. Man-made secondary channels along the River Rhine (the Netherlands; results of post-project monitoring. *Regulated Rivers: Research and Management* 17:473-491.

Author Abstract. Owing to river regulations in the past and intensive farming, the ecological value of the floodplains of the River Rhine in The Netherlands has decreased dramatically. One way to restore riverine biotopes is to create permanently flowing channels in the floodplain. Along the River Waal, the main branch of the Lower River Rhine, two such secondary channels have been created since 1994. A post-project monitoring program of 5 years was set up, which included hydrological, morphological and ecological parameters. This article focuses on the monitoring of aquatic macrophytes, aquatic macroinvertebrates, fish and wading birds. The results show that man-made, excavated secondary channels function as a biotope for riverine species including the more demanding rheophilic species. The demands for shipping and protection against flooding on the River Waal cause constraints on secondary channels. Despite these constraints there is still enough space for hydromorphological processes to create new habitats in secondary channel 1, near Opijnen. The space for hydromorphological processes is less in secondary channel 2, near Beneden-Leeuwen. The density and the number of (rheophilic) species are for a large part influenced by the water level and frequent inundation caused by the high hydrological connectivity. Man-made secondary channels seem to provide suitable habitat that is currently lacking for a broad range of rheophilic macroinvertebrate and fish species in the Lower River Rhine in The Netherlands. Owing to the lack of suitable habitats for rheophilic macroinvertebrate and fish species before the creation of the secondary channels, the importance of longitudinal and transversal migration could be illustrated by the drift of macroinvertebrates during floods and the seasonal migration of Age-0 and Age-1+ fish species.

Stevenson, J. C. 1988. Comparative ecology of submersed grass beds in freshwater, estuarine, and marine environments. *Limnology and Oceanography* 33: 867-893.

Stevenson's article compares the different types of SAV and the ecological roles they play in their respective environments. It can be a useful first step for those who are knowledgeable about the ecology of one type but not another. While there are 500-700 freshwater and estuarine species worldwide, only 50 species have been recorded in marine settings. This is due in part the physical and chemical stress involved with living in a marine environment. Despite this lack of diversity, marine SAV tends to have higher productivities than freshwater systems, in part due to greater mixing in marine settings. The secondary productivity of each system also differs. Fish, sea urchins, and other grazers make marine SAV a significant portion of their diet. Although ducks have been shown to graze heavily on SAV it is usually at the end of the growing season and few fish species feed on freshwater SAV. The majority of primary production in freshwater systems enters the detrital food web at the end of the growing season. Thus the trophic relationships between freshwater and marine SAV is quite different.

Terrell, J. B. and D. E. Canfield, Jr. 1996. Evaluation of the effects of nutrient removal and the "Storm of the Century" on submersed vegetation in Kings Bay - Crystal River, Florida. *Journal of Lake and Reservoir Management* 12:394-403.

Despite many of the ecological benefits, dense growth of SAV has often been viewed as a nuisance and signal of nutrient enrichment in coastal waters, a sign that something is wrong and needs to be fixed. Such was the case in Cedar Cove of King's Bay on the west coast of Florida. Dense SAV growth was perceived by the general public to be the result of high phosphorus and nitrogen concentrations stemming from a municipal wastewater facility situated on the cove. A grassroots effort was initiated to remove the wastewater effluent from the cove and 'improve water quality'. Hydrologic modeling showed that the main source of water to the cove, however, was naturally nutrient rich, rich enough that the wastewater facility had little to no effect on SAV growth. After the effluent was removed, at great expense, nutrient levels in the cove did decrease but the perceived problem of dense SAV growth was unaffected. Although this project does show that nutrient levels in the water can be successfully mitigated through alternative land use (and thus water quality was improved), the residents of the area did not see the result they had expected (i.e., less SAV growth). The need for all parties to have a clear understanding of the system dynamics and the expected outcomes of restoration projects is crucial to maintain local support for such efforts in the future.

Thayer, G. W., M. S. Fonseca and W. J. Kenworthy. 1982. Restoration and enhancement of seagrass meadows for maintenance of nearshore productivity. *Atlantica. Rio Grande* 5:118-119.

Author Abstract. Studies have been initiated on the use of transplanting as a means to ameliorate the loss of meadows, and to create seagrass habitat on previously unvegetated areas. Whole mature, vegetative shoots are dug from donor sites, washed free of sediments, attached in clumps to anchors and replanted. This technique yields viable meadows within a growing season at a cost comparable to salt marsh planting in man-hours, on an aerial basis. The seagrasses (*Zostera marina* and *Halodure wrightii*) used here exhibit an exponential growth and coverage rate until reaching densities comparable to natural meadows. Faunal recolonization is significantly increased in these areas over unvegetated areas. The number of fauna and taxa per core increased linearly with time and asymptotic when shoot density reached normal levels for that environment.

U.S. NOAA Coastal Services Center. 2001. Guide to the Seagrasses of the United States of America (Including U.S. Territories in the Caribbean), 20 pp., U.S. National Oceanic and Atmospheric Administration, Coastal Services Center, Charlston, SC. http://www.csc.noaa.gov/benthic/cdroms/sav_cd/pdf/overview.pdf

This short report is intended as a primer to introduce the basic concepts of seagrass biology, ecology, and habitat disturbance and loss to the uninitiated. This report is not intended as an exhaustive treatment or catalog of seagrasses, it does provide practitioners with a common vocabulary to explore SAV issues in greater detail.

In addition to this report, other seagrass-related resources are available on a CD-ROM provided by NOAA. The CD-ROM can be requested through contact information on the following webaddress: http://www.csc.noaa.gov/benthic/cdroms/sav_cd/

Weber, D. E., D. A. Flemer and C. M. Bundrick. 1992. Comparison of the effects of drilling fluid on macrobenthic invertebrates associated with seagrass, *Thalassia testidinum*, in the laboratory and field. *Estuarine Coastal Shelf Science* 35: 315-330.

Author Abstract. The structure of a macrobenthic invertebrate community associated with the seagrass, *Thalassia testudinum*, was evaluated under laboratory and field conditions. The research focused on: (1) the effects of pollution stress from a representative drilling fluid used in off-shore oil and gas operations, and (2) a comparison of responses of the seagrass-invertebrate community in the laboratory and field. A series of 15.3 cm diameter cores of the seagrass-invertebrate community was collected from field sites for establishment and sampling of microcosms and in the sampling of field plots over time. Weekly exposures to drilling fluid were conducted in the laboratory microcosms at a mean total suspended matter concentration of 110.7 $mg l^{-1}$ (± 17.7 SD), and in field plots by usage of acrylic exposure chambers at a mean concentration of 132.8 $mg l^{-1}$ (± 33.3 SD). Standing crop of *T. testudinum* was not affected by drilling fluid in the laboratory or field when measured after 6 and 12-week exposure periods. The numbers of macrobenthic invertebrates were suppressed by drilling fluid at both exposure periods in the laboratory, but inhibitory effects were absent in the field. Invertebrate densities in the field were similar among control and treated plots, and were much lower than densities occurring in the laboratory control. In most instances, species richness values were similar in the field and laboratory at the end of each 6 and 12-week period.

Wilcox, D. A. and T. H. Whillans. 1999. Techniques for restoration of disturbed coastal wetlands of the Great Lakes. *Wetlands* 19:835-857.

Author Abstract. A long history of human-induced degradation of Great Lakes wetlands has made restoration a necessity, but the practice of wetland restoration is relatively new, especially in large lake systems. Therefore, we compiled tested methods and developed additional potential methods based on scientific understanding of Great Lakes wetland ecosystems to provide an overview of approaches for restoration. We addressed this challenge by focusing on four general fields of science: hydrology, sedimentology, chemistry, and biology. Hydrologic remediation methods include restoring hydrologic connections between diked and hydrologically altered wetlands and the lakes, restoring water tables lowered by ditching, and restoring natural variation in lake levels of regulated lakes Superior and Ontario. Sedimentological remediation methods include management of sediment input from uplands, removal or proper management of dams on tributary rivers, and restoration of protective barrier beaches and sand spits. Chemical remediation methods include reducing or eliminating inputs of contaminants from point and non-point sources, natural sediment remediation by biodegradation and chemical degradation, and active sediment remediation by removal or by in situ treatment. Biological remediation methods include control of non-target organisms, enhancing populations of target organisms, and enhancing habitat for target organisms. Some of these methods were used in three major restoration projects (Metzger Marsh on Lake Erie and Cootes Paradise and Oshawa Second Marsh on Lake Ontario), which are described as case studies to show practical applications of wetland restoration in the Great Lakes. Successful restoration techniques that do not require continued manipulation must be founded in the basic tenets of ecology and should mimic natural processes. Success is demonstrated by the sustainability, productivity, nutrient-retention ability, invasibility, and biotic interactions within a restored wetland.

Wood, N. and P. Lavery. 2000. Monitoring seagrass ecosystem health - the role of perception in defining health and indicators. *Ecosystem Health* 6: 134-148.

Author Abstract. Thirty-four seagrass researchers/managers were asked to identify seagrass sites in Cockburn Sound, Western Australia, which they perceived to be healthy or unhealthy, and indicate the basis for these perceptions. The average respondent based their perception on three variables, ranging from ecosystem features to plant attributes. Four variables were considered very important in developing perceptions: canopy cover, shoot density, epiphyte biomass, and the proportion of calcareous epiphytes. Three sites perceived to be healthy and three perceived to be unhealthy were then compared to determine if features indicated as important in developing perceptions about health differed between the sites. None of the four variables considered important by respondents differed statistically between healthy and unhealthy sites in winter, but shoot length and above ground biomass were different. In summer, two of the important variables (canopy cover and shoot density) differed, along with shoot height, productivity, and leaf area index. Despite their perceived importance, epiphyte features were not different between perceived healthy and unhealthy sites. The study suggests that shoot density, canopy cover, shoot height, aboveground biomass, productivity, and leaf area index of *Posidonia angustifolia* ecosystems differ statistically between sites perceived to be healthy and unhealthy. However, the usefulness of these variables as indicators of seagrass health varies seasonally. Health was clearly a respondent-dependent concept. The basis of perceptions about health among a group of expert scientists did not correspond strongly to measurable differences between sites. The unwarranted importance placed on epiphytes may be due to previous studies that have reinforced their importance. These observations highlight the role of personal perspective and scientific preconditioning in forming concepts of health, and raise the question of the role that experts should be playing in formulating those concepts.

APPENDIX II: SUBMERGED AQUATIC VEGETATION 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. 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.

Adamus, P. R., L. T. Stockwell, E. J. Clairain, Jr., M. E. Morrow, L. P. Rozas and R. D. Smith. 1991. Wetland evaluation technique. United States Army Corps of Engineers, Waterways Experiment Station. Technical Report WRP-DE-2.

The Wetland Evaluation Technique (WET) provides information on predictors of wetland functions. The target audience for this manual includes persons such as community groups, NGO's, and anyone who has no contact on a regular basis with technical experts. The manual is divided into two volumes. Information presented in volume one includes conceptual fundamentals for WET, wetland functions in relation to their processes and interactions with other functions, a review of technical literature on each function, the predictors used for determining the probability ratings for wetland functions, and the concept of wetland social significance as used in WET. Volume two of the manual outlines steps required to put into practice the WET method, discusses its application and limitations in detail, and provides documentation for a computer program designed to assist data analysis in WET. Detailed information on methods and procedures described here can be obtained from the manual.

Adamus, P. and K. Brandt. 2003. Impacts on quality of inland wetlands of the United States: A survey of indicators, techniques, and applications of community level biomonitoring data. U.S. Environmental Protection Agency. http://www.epa.gov/owow/wetlands/wqual/introweb.html

This on-line resource is based on the now out of print Report #EPA/600/3-90/073 prepared for the U.S. EPA Wetland Research Program. It is currently being updated. Although it is intended for inland wetlands, many of the resources cited and information provided is applicable to coastal freshwater wetlands. The report describes in detail many of the interactions and possible effects of eutrophication, organic loading, contaminant toxicity, acidification, salinization, sedimentation, turbidity/shade, vegetation removal, thermal alteration, dehydration, inundation, and fragmentation of habitat on wetland biological communities. The effect of these stressors on microbes, algae, vascular plants, invertebrates, fish, amphibians, reptiles, birds, mammals, and selected biological processes is presented wherever information is available. Extensive lists of cited literature can also be used to supplement presented information.

This resource was originally designed for use in developing biological criteria for use in wetland assessment, protection, and management as well as to help identify degraded sites for potential restoration. The information presented can also be used to develop parameters to monitor the progress of restoration efforts, before and after implementation. By linking many of the structural components that help make up wetland habitats with functional components (in this case biota) the information presented can be used to help restoration practitioners select the appropriate structural and functional parameters to monitor as they relate to project goals.

American Public Health Association. 1998. Standard Methods for Examination of Water and Wastewater. 20th ed. American Public Health Association, Washington, D.C.

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

Batzer, D. P., A. S. Shurtleff and R. B. Rader. 2001. Sampling invertebrates in wetlands, pp. 339-354. In Rader, R. B., D. P. Batzer and S. A. Wissinger (eds.), Bioassessment and Management of North American Freshwater Wetlands. John Wiley and Sons, New York.

Author Abstract. Difficulties in sampling have long hindered research on wetland macroinvertebrates. With the increasing interest in using macroinvertebrate populations to monitor the environmental health of wetlands, sampling of these organisms has become an important research focus. For this chapter we summarized sorting and subsampling procedures and queried many of the prominent researchers who study freshwater wetland macroinvertebrates about their preferences in samplers. For each device we provide a synopsis of their comments, both pro and con, and provide direction on how to use each sampler. Based on the results of this survey as well as published studies that contrast sampler efficacies, we conclude that the sweep net should probably become the sampler of choice for most bioassessment efforts that use wetland macroinvertebrates. We also recommend that most programs sort in the laboratory using either a selective or random technique (depending on the level of taxonomic expertise) and a fixed count of 100 to 300 individuals.

Bergstrom, P. 2003. Chesapeake Bay submerged aquatic vegetation (SAV) ground survey directions. June 10. 10 pp. National Oceanic and Atmospheric Administration. http://noaa.chesapeakebay.net/sav/SAVHunt0602.doc.

Author Introduction. Ground surveys of SAV in the tidal waters of Chesapeake Bay have four main purposes:

(1) "Ground truthing" to verify that beds mapped in the SAV Aerial Survey conducted by Virginia Institute of Marine Science (VIMS) are in fact SAV

(2) To identify and map the SAV species in those mapped beds

(3) To supplement the SAV aerial survey by locating additional SAV beds that are too small to be seen from the air, or were not visible when the photo was taken that year; and

(4) More detailed ground surveys done for research or for permitting such activities as dredging and dock construction.

These directions are designed to be used for the first three purposes, which are addressed by the volunteer "SAV Hunt" coordinated by the Chesapeake Bay Foundation and the US Fish & Wildlife Service. They can be used as the starting point for a detailed survey of the fourth type, but do not give complete instructions for detailed surveys. They do not apply to SAV in non-tidal waters, where more species are present, and different survey methods are needed.

These directions recommend the planning needed, the best types of boats and tools to use, the best times and places to look for SAV, and how to record the data. There is no one "right" way to hunt for SAV, but following these directions will reduce the chance of recording "false negatives", which means concluding an area has no SAV when in fact some was present. "False positives" are always possible if other types of plants in the water are mis-identified as SAV. How to do SAV identification is outside of the scope of this document, and requires a field guide or key.

Cheruvelil, K. S., P. A. Soranno and R. D. Serbin. 2000. Macroinvertebrates associated with submerged macrophytes: Sample size and power to detect effects. *Hydrobiologia* 441:133–139.

Author Abstract. When planning and conducting ecological experiments, it is important to consider how many samples are necessary to detect differences among treatments with acceptably high statistical power. An analysis of statistical power is especially important when studying epiphytic macroinvertebrate colonization of submerged plants because they exhibit large plant-to-plant variability. Despite this variability, many studies have suggested that epiphytic macroinvertebrates preferentially colonize plants based on plant architecture type (broad versus dissected leaves). In this study, we calculated the power and number of samples necessary to detect differences in epiphytic macroinvertebrate abundance (numbers and biomass) among five species and two architecture types of macrophytes in a lake in MI, U.S.A. Using power analysis, we found that we had very high power to detect the differences present between macroinvertebrate abundance by architecture type and by macrophyte species (power = 1.000 and 0.994; effect sizes = 0.872 and 0.646, respectively. However, to detect very small differences between the two architecture types and the five plant species, we determined that many more samples were necessary to achieve similar statistical power (effect size = 0.1–0.3, number of samples = 60–527 and 36–310, respectively; power = 0.9). Our results suggest that macroinvertebrate abundance does in fact vary predictably with plant architecture. Dissected-leaf plants harbored higher abundances of macroinvertebrates than broad-leaf plants (ANOVA, density $p = 0.001$, biomass $p < 0.001$). This knowledge should allow us to better design future studies of epiphytic macroinvertebrates.

Cook Inlet Keeper. 1998. Volunteer training manual: Citizens environmental monitoring program. U.S. Environmental Protection Agency, Region 10, Homer, AK. http://www.inletkeeper.org/training.htm

This manual provides Cook Inlet Keeper volunteers with information needed to monitor water quality in the Cook Inlet watershed. It also provides guidelines for monitoring procedures that are currently included in the Keeper's

Citizens' Environmental Monitoring Program (CEMP). Outlined in this document are safety and access issues; a monitoring overview that discusses water quality test methods, test parameters and a proposed sampling schedule; monitoring procedures including a field procedure checklist, field observations, collecting the samples, testing procedures, sample custody and completing data sheets; equipment care and waste disposal; data management and reporting; and quality control. Additional information for methods and procedures used can be obtained from this manual.

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

The UK Marine Science Project developed this handbook to provide guidelines for recording, monitoring, and reporting characteristics and conditions of marine habitats. This manual addresses the fundamentals and procedures for monitoring different parameters in marine habitats, management tools, and benefits and costs for developing a monitoring project. Topics include the establishment of marine monitoring programs highlighting what needs to be measured and methods to use; guidance for developing a monitoring program; selection of proper monitoring techniques to attain precision and accuracy; and procedural guidelines for monitoring specific marine habitats. Detailed information on the tools needed for monitoring marine habitats are also described.

Dromgoole, F. I. and J. M. A. Brown. 1976. Quantitative grab sampler for dense beds of aquatic macrophytes. *New Zealand Journal of Marine and Freshwater Research* 10:109-118.

Author Abstract. The construction and operation of a simple mechanical grab, suitable for sampling dense beds of aquatic macrophytes, is described. The technique has several advantages over the diver-quadrat method. Both methods have been used in vegetation surveys of the Rotorua lakes where plant densities attain the maximum recorded for freshwater lakes. The results indicate marked variations in weed density over short distances, and thus both methods require a large number of samples for an accurate determination of biomass.

Ferguson, R. L., L. L. Wood and D. B. Graham. 1993. Monitoring spatial change in seagrass habitat with aerial photography. *Photogrammetric Engineering and Remote Sensing* 59:1033-1038.

Author Abstract. Photographs, taken during aerial surveys in 1985 and 1988, of seagrass habitat were interpreted, transferred to geo-referenced base maps and used to estimate spatial changes in bottom coverage. This paper spends a good deal of time carefully reviewing the criteria of acceptable conditions (e.g., sun angle, sea surface conditions, water clarity, etc) during which accurate aerial photographs can be taken of submerged aquatic vegetation. A particularly useful discussion is included concerning the geo-referencing of seagrass beds to the shoreline, and the need for adequate geodetic information. In addition, a thorough discussion details the steps used in transferring and geo-referencing the photographs to base maps. A helpful analysis of the size, shape, and location of polygons (representing seagrass beds) between years determined that habitat loss was localized to specific areas and not experienced throughout the system. Field verification was done to identify the seagrass coverages, determine the causes for habitat loss, and confirm the accuracy of this procedure.

Gertz, S. M. 1984. Biostatistical aspects of macrophyton sampling, pp. 28-35. ASTM Special Technical Publication 1984, ASTM, Philadelphia.

Author Abstract. Problems of sampling macrophytes are related to the types of communities under consideration and the goals of a particular study. The communities may range from completely submersed beds of large algae, mosses, pteridophytes, or angiosperms to rooted plants with floating leaves or floating plants with emergent leaves to wetland areas. The goals of a study may be community description or impact analysis. Because of this community goal diversity a quantitative investigation often requires a rigorous statistical design to determine the best sampling design. Of the various sampling designs available there are two general techniques; plot or quadrat methods and plotless methods. Plot or quadrat methods are area methods of sampling communities where the plot may be rectangular, square, or circular, and all individuals in the plot are sampled. Plotless methods usually involve a more random approach of sampling; for example, a compass line is laid out through the community and samples are taken according to some fixed rule. It is the purpose of this paper to review these various sampling methodologies and to evaluate their efficacy, in a statistical sense, in view of the goals of a specific study.

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

The document describes four levels of investigative intensity or sampling tiers. These tiers are suggested as one possible approach to organizing data gathering efforts and investigation needed to be able to establish biocriteria in a scientifically defensible manner. Other approaches using variations of these tiers may be appropriate depending on program objectives. Tier 0 is a preliminary review of existing literature and data available for the estuary or coastal water of concern. It provides candidate reference sites for the development of a reference condition; Tier I is a one-time site visit with preliminary data gathering to refine the information in Tier 0 and establish candidate biocriteria; Tier II repeats and builds on measurements initiated in Tier I and establishes the reference condition data which is combined with the historical record, possible models or other extrapolations, and a consensus of regional expert opinion to establish and employ the biocriteria for management decision making; Tier III is the diagnostic investigation requiring the most sampling events and most extensive parameters to help establish management efforts for those waters which do not meet the biocriteria.

Biocriteria can be used to help support and protect designated uses of water resources; expand and improve water quality standards; detect problems other water quality measurements may miss or underestimate; help water resource managers set priorities for management planning and, assess the relative success or failure of management projects. Biocriteria do not supersede or replace physical or chemical criteria for water resource decision making and management. In fact, biocriteria augment these established measures so USEPA and the States and Tribes are better informed about the quality of our nations extensive and coastal water resources. The bioassessment/biocriteria process is a particularly cost effective screening tool to evaluate over all water quality and determine water resource status and trends.

An abbreviated table of contents for this document includes:

Goldsborough, G. 2001. Sampling algae in wetlands, pp. 263-295. In Rader, R. B., D. P Batzer and S. A. Wissinger (eds.) Bioassessment and Management of North American Freshwater Wetlands. John Wiley and Sons, New York.

Author Abstract. Algae are often neglected in wetland monitoring programs, but their contributions as food resources for herbivores and regulators of the physical and chemical environment can be significant. In this chapter, I introduce terminology pertaining to planktonic and benthic algal assemblages in wetlands. Some common methods for algal sampling and analysis, and their respective advantages and disadvantages are described. Also discussed are issues affecting the expression and comparability of data from different sites and studies.

Granger, S., M. Traber, S. W. Nixon and R. Keyes. 2002. A practical guide for the use of seeds in eelgrass (*Zostera marina* L.) restoration. Part I. Collection, processing, and storage. 20 pp. Rhode Island Sea Grant, Narragansett, RI. http://nsgl.gso.uri.edu/riu/riuh02001.pdf

Partial Author Introduction. Transplanting mature plants has failed to keep pace with the loss of eelgrass habitat. Consequently, there has been growing interest in the use of *Zostera marina* L. seeds as an alternative method of eelgrass habitat restoration (20). Sexual reproduction through flowering, cross or self pollination, and seed production has been shown to be an effective means by which *Zostera* colonizes new areas, fills in gaps that may form within a meadow, and increases genetic diversity within existing beds (19; 22). While there are many good reasons to believe that the use of seeds is an ecologically and economically attractive alternative to mature shoot transplants, the approach is still experimental. This guide has been prepared in an effort to encourage additional field trials and to assist those who may wish to help develop this very promising method. This guide describes the field and aquarium techniques for harvesting, preparing, and storing large quantities of viable eelgrass seed. A subsequent booklet will describe the methods used for planting the seeds in the field and offer preliminary cost comparisons between whole plant and seed-based restorations. Seeds can also be used to raise seedlings in aquaria for later field planting. Before designing a field program, however, keep in mind that some states have laws protecting submerged aquatic vegetation and a permit may be required for harvesting flowering stalks. It is always prudent to contact the relevant state and federal environmental and coastal management agencies to get the most up-to-date information.

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

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

Hatcher, D., J. Eaton, M. Gibson and R. Leah. 1999. Methodologies for surveying plant communities in artificial channels. *Hydrobiologia* 415:87-91.

Author Abstract. The gathering of quantitative information on aquatic macrophyte communities in artificial drainage and navigation channels presents a number of methodological and analytical problems. These include subjectivity of plant abundance estimation, the conflict between standardization and adaptation of methods to specific purposes, and the concepts of randomness and homogeneity in linear surveying. As a result, much of the currently available information is highly subjective and difficult to use in any comparative way, either temporally or spatially. More standardized procedures should be developed which minimizes these shortcomings and permit later re-use of data in comparative studies.

Holst, L., R. Rozsa, L. Benoit, S. Jacobson and C. Rilling. 2003. Long Island Sound habitat restoration initiative: Technical support for coastal habitat restoration. EPA Long Island Sound Office, Stamford, CT. http://www.longislandsoundstudy.net/habitat/

Partial Author Introduction. This document contains a series of reports produced through the Habitat Restoration Work Group of the Long Island Sound Study (LISS). It is designed to provide basic technical information about the subject habitat and its restoration for persons interested in planning and pursuing a restoration project. Topics covered include ecological descriptions of the plant and animal communities associated with the habitat, the natural history and effects of human influence on the habitat, and the state of the science in restoring the habitat. Included at the end of each section is a list of the literature cited. The reader is strongly urged to investigate these source materials further to achieve a fuller understanding of the ecology and issues related to the subject habitat. The reader is also encouraged to contact the state and federal agency representatives of the Habitat Restoration Work Group for technical advice.

The habitats covered to date include: tidal wetlands, freshwater wetlands, submerged aquatic vegetation, coastal grasslands, coastal barriers, beaches, and dunes.

Killgore, K. J., R. P. Morgan II and N. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101-111.

Author Abstract. The distribution and abundance of fishes in submersed aquatic plants of three relative densities (no plants, intermediate plant density, high plant density) were estimated in the tidal Potomac River near Alexandria, Virginia. Fish were sampled with a boat-mounted electroshocker at night in May (when plants were emerging), August (peak plant densities), and November (plant senescence) of 1986. Mean densities of all plants ranged from 9 to 33 g/m^2 (dry-weight basis) in May, and 400 to greater than 1,000 g/m^2 in August and November. *Hydrilla verticillata* was usually the dominant aquatic plant. In May, overall mean fish abundance was highest in areas of high plant density (36 fish/5 min shocking), whereas in August and November fish abundance was highest in areas of intermediate plant densities (100 and 62 fish/5 min electroshocking, respectively). Areas without plants contained a relatively high number of filter-feeding fishes, including Atlantic menhaden (*Brevoortia tyrannus*) and blueback herring (*Alosa aestivalis*). The fish assemblage in the vegetated sites comprised mainly brown bullhead (*Ictalurus nebulosus*), banded killifish (*Fundulus diaphanous*), pumpkinseed *Lepomis gibbosus*), largemouth bass (*Micropterus salmoides*), and yellow perch (*Perca flavescens*). The bay anchovy (*Anchoa mitchilli*), white perch (*Morone Americana*), and inland silverside (*Menidia beryllina*) were distributed throughout all three sites during the study. Fish also were sampled with pop nets in aquatic plants and with seines between shore and the plant beds. More than five times more fish (9.8/m^2) were collected with pop nets in areas with intermediate plant density, where there were several codominant plant species, than in areas with dense hydrilla (1.8 fish/m^2). Shore-zone fish densities estimated with seine hauls were higher in areas adjacent to dense hydrilla beds (9 fish/m^2) than in areas with no plants (1.5/m^2) or near intermediate plant densities (3.3/m^2), but the number of fish species was lowest near hydrilla.

Kornijów, R. 1998. Quantitative sampler for collecting invertebrates associated with submersed and floating-leaved macrophytes. *Aquatic Ecology* 32:241-244.

Author Abstract. A new hand-operated sampler was developed consisting of a perspex cylinder (thickness 0.5 cm, length 32 cm, diameter 13 cm) cut in half lengthwise. The valves are joined together by means of a piano hinge for opening and closing of the sampler. In each of the sites there are openings covered with a net of 0.18×0.18 mm mesh. The external free edges of the halves are covered with weather stripping. The apparatus allows sampling of epiphytic fauna, or animals swimming around various macrophyte structures, including those trailing on the bottom, and those with floating leaves.

Lougheed, V. L. and P. Chow-Fraser. 2002. Development and use of a zooplankton index of wetland quality in the Laurentian Great Lakes basin. *Ecological Applications* 12:474-486.

Author Abstract. Recent interest in biological monitoring as an ecosystem assessment tool has stimulated the development of a number of biotic indices designed to aid in the evaluation of ecosystem integrity however, zooplankton have rarely been included in biomonitoring schemes. We developed a wetland zooplankton index (WZI) based on water quality and zooplankton associations with aquatic vegetation (emergent, submergent, and floating-leaf) that could be used to assess wetland quality, in particular in marshes of tile Laurentian Great Lakes basin.

Seventy coastal and inland marshes were sampled during 1995-2000. These ranged from pristine, macrophyte-dominated systems, to highly degraded systems containing only a fringe of emergent vegetation. The index was developed based on the results of a partial canonical correspondence analysis (PCCA), which indicated that plant-associated taxa such as chydorid and macrothricid cladocerans were common in high-quality wetlands while more open-water, pollution-tolerant taxa (e.g., *Brachionus, Moina*) dominated degraded wetlands. The WZI was found to be more useful than indices of diversity (H', species richness) and measures of community structure (mean cladoceran size, total abundance) for indicating wetland quality. Furthermore, an independent test of the WZI in a coastal wetland of tile Great Lakes, Cootes Paradise Marsh, correctly detected moderate improvements in water quality following carp exclusion. Since wetlands used in this study covered a wide environmental and geographic range, the index should be broadly applicable to wetlands in the Laurentian Great Lakes basin, while further research is required to confirm its suitability in other regions and other vegetated habitats.

Madsen, J. D. 2000. Advantages and disadvantages of aquatic plant management techniques. 31 pp. ERDC/EL MO-00-1, U.S. Army Engineer Research and Development Center, Vicksburg, MS.

In areas were exotic or nuisance plant and animal species have come to dominate an area, it may be desirable to remove these organisms and try to establish populations of native species. Madsen reviews a variety of techniques that have been using primarily in lakes but could be adapted to coastal projects as well. There are advantages and disadvantages to each of the techniques presented, the final decision for which method to use will depend on the characteristics of the site and the amount of time and effort individuals are willing to commit to the process. Biological, chemical, mechanical, and physical means to control SAV are each described. Biological controls include the use of grass carp (*Ctenopharyngodon idella*), use of insects, pathogens, and introduction of native plants to compete with invasives. The chapter on chemical techniques includes an introduction to the herbicides currently in use in the United States and methods to apply them. Mechanical techniques such as hand cutting/pulling, cutting, harvesting, diver operations, and rotovating are discussed. A variety of physical techniques including dredging, drawdown, benthic barriers, shading, and nutrient control are also described. Madsen discusses the implications of taking no action as a management strategy as well.

Marshall, T. R. and P. F. Lee. 1994. An inexpensive and lightweight sampler for the rapid collection of aquatic macrophytes. *Journal of Aquatic Plant Management* 32:77.

Author Abstract. The quantitative sampling of aquatic macrophytes demands that all plants be sampled along a series of line transects, or within a large number of randomly-chosen quadrats. Scuba divers are frequently employed for this purpose, and offer the advantage of precise removal (by hand) of all plants within a sampling frame, regardless of substrate type and water depth. Their effectiveness is reduced in turbid waters, though, and even under optimal conditions this is an exceedingly time-consuming process. As an alternative to divers, remote sampling devices, such as corers, scoops, and dredges, can be employed from small boats to speed the collection process. Problems have been documented with these samplers, however, including small sample areas, the wrongful inclusion and exclusion of plants at the edges, and their inability to operate satisfactorily on hard lake bottoms. Several customized macrophyte samplers have been developed to overcome these problems, but these are generally massive and complicated devices which require permanent platforms with booms, winches, or pumps. None of these methods or devices were suitable for a survey of aquatic plants in northwestern Ontario, due to the number of lakes involved and the fact that many are without road access. This prompted the development of a new sampling device, designed to meet the following criteria: 1) allow the retrieval of rooted macrophytes from a known area of substrate without the need of a diver's assistance; 2) be rapidly deployed by a single operator; 3) be lightweight and easily transported from site to site; 4) be inexpensive to manufacture; and 5) function at both shallow and deep water sites, in clear or turbid water. This paper describes the design and operation of this sampler, and includes some observations on its use in these lakes.

McCauley, V. J. E. 1975. Two new quantitative samplers for aquatic phytomacrofauna. *Hydrobiologia* 47:81-89.

Author Abstract. A description and drawings are given for 2 new samplers for quantitative studies on invertebrates associated with aquatic macrophytes. One was designed for sampling rushes and bullrushes, and the other for submerged and/or floating vegetation.

McCobb, T. D. and P. K. Weiskel. 2002. Long-term hydrologic monitoring protocol for coastal ecosystems, Protocol. 93 pp. 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 groundwater and pond levels, and rating curves between stream stage and discharge for stream flow, 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 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.

Miller, T., C. Bertolotto, J. Martin and L. Storm. 1996. Monitoring wetlands: A manual for training volunteers. Reports available by contacting: Adopt-a-Beach, P.O. Box 21486, Seattle, WA 98111-3486. Contact information: Phone # (206) 624-6013 and Fax # (206) 682-0722.

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

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

Molano-Flores, B. 2002. Critical trends assessment program: Monitoring protocols. 39 pp. Illinois Natural History Survey, Office of the Chief Technical Report 2002-2, Champaign, IL. http://ctap.inhs.uiuc.edu/mp/pdf/mp.htm

The Critical Trends Assessment Program (CTAP) monitors the conditions of forests, grasslands, wetlands and streams throughout Illinois. CTAP also assesses current and future trends in ecological conditions for state, regional and site-specific basis. The CTAP document presents standardized monitoring protocols for the habitat types previously mentioned. Wetland habitat criteria as well as wetland sampling protocols are discussed in this document. Highlighted in this section are methods used to monitor ecological changes occurring in wetlands. These methods include establishing study plots, GPS data, general site characteristics, slope and aspects, ground cover and woody vegetation measurements, big plot and collection of voucher specimens.

Each method used and parameters measured provide data on the structural and functional characteristic of the habitat as well as the habitat's condition.

Morgan, R. P., K. J. Killgore and N. H. Douglas. 1988. Modified popnet design for collecting fishes in varying depths of submersed aquatic vegetation. *Journal of Freshwater Ecology*. 4:533-539.

Author Abstract. Recent popnet development for the analysis of fish distribution and abundance in submersed aquatic vegetation (SAV) has focused on its utilization of popnets in shallow estuarine environments. A number of modifications have been made to the popnet and in seining techniques in order to deploy these nets in areas with SAV great than 2 m deep. A description of the modified net design and the procedure used in setting the popnets is presented. The coefficient of variation for fish density (per 10 sq. m) ranged from a low of 9.4% (2 replicates) to a high of 80.0% (3 replicates) depending on the species of SAV and the time of year.

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

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

Muscha, M. J., K. D. Zimmer, M. G. Butler and M. A. Hanson. 2001. A comparison of horizontally and vertically deployed aquatic invertebrate activity traps. *Wetlands*. 21:301-307.

Author Abstract. Activity traps are commonly used to develop abundance indices of aquatic invertebrates and may be deployed with either the funnel parallel to the water surface (horizontal position) or facing down (vertical position). We compared the relative performance of these two positions in terms of numbers of invertebrates captured, species richness of samples, detection rates of specific taxa, and community-level characterizations. Estimates of zooplankton abundance were also compared to quantitative estimates obtained using a water-column sampler. We used a matched pairs design where 10 pairs of traps (one horizontal, one vertical) were deployed in each of 4 prairie wetlands on 5 dates in 1999. Vertical traps had higher detection rates and captured greater numbers of adult and larval Coleoptera, Hemiptera, Chaoboridae, Hydracarina, Cladocera, and Copepoda and also produced samples with greater species richness. Horizontal traps captured greater numbers of Amphipoda and Ostracoda and had higher detection rates for these taxa. Estimates of zooplankton abundance with vertical traps also correlated better with quantitative estimates and indicated greater differences between wetlands than horizontal traps. Both traps showed similar relationships among wetlands and changes through time at the community level, but vertical traps were more sensitive to temporal change. Our results indicate that vertical traps outperform horizontal traps and are preferable for obtaining indices of invertebrates.

National Park Service Inventory and Monitoring. Guidance for designing an integrated monitoring program. http://science.nature.nps.gov/im/monitor/vsmTG.htm#Introduction

The goal of the National Park Service (NPS) program is to monitor the status and trend of the park's habitat structure and function as well as its condition. Monitoring tracks management and restoration efforts, detects early warning signs of threats to the habitat, and provides fundamentals needed to understand and identify changes occurring in the habitat. NPS provides information on developing a scientifically sound monitoring program. Information needed to develop a monitoring plan include establishing and stating clearly the project goals and objectives; monitoring objectives must be effective, realistic, specific, unambiguous, and measurable; providing a process for developing conceptual models of relevant ecosystems; steps on how to prioritize and select indicators to be monitored; sampling designs to consider; how protocols will be developed; and data management and analysis. Additional information on guidelines for developing monitoring protocols is described in this report. Links are also provided to download individual reports that offer more detail.

Norris, J. G., S. W. Echeverria, J. R. Skalski and R. C. Zimmerman. 2001. Eelgrass monitoring in Puget Sound: Methods and preliminary results of the submerged vegetation monitoring project. http://www.psat.wa.gov/Publications/01_proceedings/sessions/poster/h_norris.pdf

Author Abstract. Eelgrass *(Zostera marina)* is an important nearshore resource. In order to monitor changes in the abundance and distribution of this habitat type, the Nearshore Habitat component of the Puget Sound Ambient Monitoring Program initiated a Submerged Vegetation Monitoring Project. We are using a rotational random sampling plan with partial replacement. One fifth of the selected sample units are replaced each year, and once chosen, the unit is sampled for five consecutive years. We designated two types of sample units, 1,000 m sections of shoreline (potential 'fringe' eelgrass habitat) and eelgrass 'flats' (eelgrass beds wider than 1000 m). In summer 2000, we sampled 68 stations throughout Puget Sound including the Straits of Juan de Fuca. At each station we used underwater videography on a line transect to estimate eelgrass abundance, patchiness index, and average maximum and minimum depths. At 28 sites, we collected whole plant samples using a van Veen benthic grab to estimate shoot density, leaf area index, and shoot/root ratio. Data on the physical properties of the water column (temperature, salinity, dissolved oxygen, pH, turbidity, photosynthetically active radiation, and backscatter) at each site can be linked to other data on stressors. The results show sound-wide patterns in overall abundance, density, subtidal extent and variability in eelgrass morphology.

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

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

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.

Pacific Estuarine Research Laboratory. 1990. A manual for assessing restored and natural coastal wetlands with examples from Southern California. La Jolla, California. California Sea Grant Report -T-CSGCP-021. http://www.tijuanaestuary.com/nat_res.asp

This manual provides information for assessing the structure and functions of coastal wetlands. The main purpose of this document is to standardize methods of assessing restored, enhanced or constructed wetlands in order to maintain biodiversity emphasizing salt marshes and tidal creeks. The document provides strategies for wetland construction, restoration, and enhancement that include stating the rationale for functional assessment, objectives of assessment, criteria, and reference wetlands and reference data sets. Sampling methods and comparative data collected from natural wetlands include hydrologic functions, water quality, soil substrate quality, and nutrient dynamics, vegetation composition and growth, and fauna presence and abundance. Additional information on methods used for coastal wetlands are described.

Phillips, R. C. 1980. Planting methods, pp. 17-20. In Lutz, R. A. (ed.), Planting guidelines for seagrasses, coastal engineering. United States Army Corps of Engineers, Coastal Engineering Research Center. Technical Aid No. 80-2.

Planting methods for seagrass restoration are presented in this document. The methods described include seeding, planting of eelgrass sprigs, planting plugs, and planting sprigs. Seeding is used primarily for turtle grass because their seeds are larger and not easily swept away. The seeds are collected from mature fruits or as germinated seedlings that lay on the sediment surface. During the harvest season the fruit is clipped from the stalk and the spongy ovary wall is opened to expose the four to five seeds. Eelgrass sprigs are composed of three to four shoots. Shoal grass sprigs consist of fifteen to twenty shoots on the same rhizome. The sprigs are planted during low currents by excavating a small hole in the substrate, placing the sprigs in the hole, and covering them with sediment. Plugs are acquired by using a cylindrical coring device pushed into the grass bed. The grass plug is then transplanted in a hole, 6 to 8 inches deep. Plugs are recommended for shoal grass transplants. Planting and seagrass sprigs are anchored in areas where currents exceed 1.5 knots and wave currents are influenced by wind or storm. Construction rods and iron mesh painted with vinyl paint can be used as anchoring devices for seagrass plants. Using the rods and iron mesh prevent the plants from being swept away. Techniques are described in detail in this publication. The time in which planting occurs should also be considered because successful growth of seagrass will vary among species.

Poppe, L. J., A. H. Eliason, J. J. Fredericks, R. R. Rendigs, D. Blackwood and C. F. Polloni. 2003. Grain-size analysis of marine sediments: methodology and data processing. 58 pp. In USGS East-coast Sediment Analysis: Procedures, Databases, and Georeferenced Displays. US Geological Survey Open-File Report 00-358. http://pubs.usgs.gov/of/of00-358/text/chapter1.htm

Partial Author Introduction. The purpose of this chapter is to describe some of the laboratory methods, equipment, computer hardware, and data-acquisition and data-processing software employed in the sedimentation laboratory at the Woods Hole Field Center of the Coastal and Marine Geology Program of the U.S. Geological Survey. The recommendations and laboratory procedures given below are detailed, but are by no means complete. Serious users are strongly encouraged to consult the original references and product manuals.

Raposa, K. B. and C. T. Roman. 2001. Monitoring nekton in shallow estuarine habitats, Protocol, Long-term Coastal Ecosystem Monitoring Program. 39 pp. Cape Cod National Seashore, Wellfleet, MA. http://science.nature.nps.gov/im/monitor/protocols/caco_nekton.pdf

Author Abstract. Long term monitoring of estuarine nekton has many practical and ecological benefits but efforts are hampered by a lack of standardized sampling procedures. This study develops a protocol for monitoring nekton in shallow (<1m) estuarine habitats for use in the Long Term Coastal Monitoring Program at Cape Cod National Seashore. Sampling in seagrass and salt marsh habitats is emphasized due to the susceptibility of each habitat to anthropogenic stress and to the abundant and rich nekton assemblages that each habitat supports. Extensive sampling with quantitative enclosure traps that estimate nekton density is suggested. These gears have a high capture efficiency in most habitats and are small enough (typically 1 m^2) to permit sampling in specific microhabitats. Other aspects of nekton monitoring are discussed, including seasonal sampling considerations, sample allocation, station selection, sample size estimation, parameter selection, and associated environmental data sampling. Developing and initiating long term nekton monitoring programs will help track natural and human-induced changes in estuarine nekton over time and advance our understanding of the interactions between nekton and the dynamic estuarine environments.

Rey, J. R., R. A. Crossman, T. R. Kain, F. E. Vose and M. S. Peterson. 1987. Sampling zooplankton in shallow marsh and estuarine habitats: Gear description and field tests. *Estuaries* 10:61-67.

Author Abstract. Pump and net samplers for collecting zooplankton from very shallow marsh and estuarine habitats are described. Their use is illustrated with data obtained in salt marshes along the Indian River lagoon in east central Florida. In general, both pump and net samplers were found to be satisfactory for sampling zooplankton in these areas. Larger sample volumes were obtained with gear utilizing 202 *u* mesh sizes than with gear using 63 u mesh because the latter became clogged very quickly. Quantitative and qualitative similarity between samples collected with different gear was moderate to low. Comparison of the kinds and densities of taxa captured with the various gear indicate that a combination of techniques may be needed to ensure a proper description of the plankton communities of the area.

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

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

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

Richardson, C. J. and J. Vymazal. 2001. Sampling macrophytes in wetlands, pp. 297-336. In Rader, R. B, D. P Batzer and S. A. Wissinger (eds.) Bioassessment and Management of North American Freshwater Wetlands. John Wiley and Sons, New York.

Author Abstract. The use of macrophytes as biomonitors in wetland ecosystems are presented in terms of assessment of plant population and community responses to disturbance or anthropogenic inputs. The life forms of macrophytes are reviewed and the sampling procedures for estimating changes in population size as well as community structure are presented for herbaceous plants, shrubs, and trees. The methods and formulas for determining abundance and cover as well as frequency, density and dominance are given for plant biomass and productivity measurements. We also outline procedures for establishing macrophytes growth rates and nutrient status in wetland plants. Procedures for determining both above- and belowground biomass, nitrogen and phosphorous as well as ash-free dry matter are present along with representative data for typical wetland species. In this chapter, we provide a comprehensive plan for sampling and monitoring of plant populations and communities in wetlands.

Shafer, D. J. and D. J. Yozzo. 1998. National guidebook for application of hydrogeomorphic assessment of tidal fringe wetlands. 69 pp. U.S. Army Engineer, Waterways Experiment Station, Vicksburg, Mississippi. Technical Report WRP-DE-16. http://www.wes.army.mil/el/wetlands/pdfs/wrpde16.pdf

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

The Tidal Wetland HGM Approach Application Phase involves determining the wetland assessment area (WAA) and the indirect wetland assessment area (IWAA) and, determining wetland type. The boundaries of the area and the type of tidal wetland to be assessed are identified. The WAA is the wetland area impacted by a proposed project. The WAA defines specific boundaries where many of the model variables are ascertained and directly contributes to calculations for other variables (e.g. maximum aquatic and upland edge). Methods for determining WAA are discussed in detail in the procedural manual of the HGM Approach. The IWAA is any adjacent portions of hydrologic unit that may not be affected by the project directly but indirectly affected through hydrologic flow alterations. Wetland types are determined by comparing the hydroperiod, salinity regime, and vegetation community structure with those described in the wetland type profiles for each region. Plant communities react to change in the environment (e.g., salinity and hydrologic alterations) so are considered good indicators of a wetland type. Descriptions of the vegetation present, salinity levels, and hydrological conditions for each wetland type are presented in each regional wetland type profile. To determine the salinity regime of an area, one can refer to available references on salinity and or wetland distribution. Data collected on average salinity or the range of salinity helps to sort each site into one of the four categories of the Cowardin system.

Shafer, D. J., B. Herczeg, D. W. Moulton, A. Sipocz, K. Jaynes, L. P. Rozas, C. P. Onuf and W. Miller. 2002. Regional guidebook for applying the hydrogeomorphic approach to assessing wetland functions of northwest Gulf of Mexico tidal fringe wetlands. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. Technical Report ERDC/EL TR-02-5.

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

Short, F.T., L. J. McKenzie, R. G. Coles and J. L. Gaeckle. 2004. SeagrassNet Manual for Scientific Monitoring of Seagrass Habitat – Western Pacific Edition. 71 pp. University of New Hampshire, USA; QDPI, Northern Fisheries Centre, Australia. http://www.seagrassnet.org/SeaNetMan.PDF

This manual discusses the importance of monitoring seagrasses, the process and methods used for monitoring, and parameters commonly measured in seagrass habitats. The monitoring process discussed in the manual include why monitoring should be performed for seagrass habitats and how changes in seagrass affects fisheries in this habitat and how to measure changes in seagrass meadows (e.g., the use of mapping and selecting parameters that should be measured). The monitoring methods include gathering background information of the selection restoration monitoring site, designing a sketch map for field studies and material that should be used (e.g. GPS, aerial photographs, temporary markers, etc.), and informing the community of the monitoring activity conducted in the area, seagrass establishment and transect marking, seagrass station measures (light, temperature, salinity and tidal range), quadrat measures and laboratory procedures, and cross transects measures. The highlighted points mentioned here are discussed in detail in the manual.

Smart, R. M. and G. O. Dick. 1999. Propagation and establishment of aquatic plants: A handbook for ecosystem restoration projects. Technical Report A-99-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. http://www.wes.army.mil/el/elpubs/pdf/tra99-4.pdf

Smart and Dick have prepared an excellent document to help guide practitioners through the many steps necessary to grow and transplant aquatic plants for restoration or mitigation purposes. The first step in the process is the establishment of pioneer colonies on site. These are small groups of a variety of plant species, grown in wire cages to protect them from herbivores. Pioneer colonies should be scattered throughout the area to be restored. Through monitoring, it can be determined which plant species perform best under existing site conditions. These species then can be grown for the restoration project[1]. The authors explain why it is advisable to grow one's own plants, what the physical and chemical requirements of different aquatic plants types are, and how to prepare and build off-site and in-place facilities. They include a chapter on how to implement the planting project containing information on proper site selection, planting depth, species selection, and timing of planting projects. The authors also include a variety of methods for protecting plantings from herbivores, a critical part of successful planting projects.

[1]Note: Growing one's own plants for restoration projects can be a cost effective means for supplying propagules for a restoration project. However, it requires that the hydrodynamics of the area in question are relatively predicable from one year to the next. Coastal wetlands of the Great Lakes for example are subject to water level fluctuations of the lakes that can drastically alter available habitat type. Unless water level fluctuations can be controlled or reliably predicted from year to year, the expense of growing your own plants may not be worthwhile.

Spencer, D. F. and L. C. Whitehand. 1993. Experimental design and analysis in field studies of aquatic vegetation. *Lake and Reservoir Management* 7:165-174.

Author Abstract. Field experiments may be useful for researchers and managers concerned with aquatic plants. Since experimental design and statistical analysis are closely related, this paper discusses statistical and practical considerations for conducting and evaluating field experiments with aquatic plants. Special emphasis is given to the analysis of variance, assumptions required for its use, and concepts related to it (e.g., statistical power, means comparison procedures, treatment structure, pseudoreplication, etc.). The paper concludes with a brief introduction to papers in the literature which illustrate the use of field experiments for studying aquatic plants.

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. Although 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 aerial photo 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.

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

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

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

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

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

This document provides guidance on the design, implementation, and evaluation of the required monitoring programs. It also identifies steps to be taken when developing and implementing estuarine monitoring programs and provides technical basis for discussions on the development of monitoring program objectives, the selection of monitoring program components, and the allocation of sampling effort. Some of the criteria listed for developing a monitoring program and described in this document include monitoring program objectives, performance criteria, establish testable hypotheses, selection of statistical methods, alternative sampling designs, use of existing monitoring programs, and evaluate monitoring program performance. Additional information on guidelines for developing a monitoring program is described.

U.S. EPA. 1993. Volunteer estuary monitoring: A methods manual. 383 pp. EPA 842-B-93-004, U.S. Environmental Protection Agency, Office of Water, Washington, D.C. http://www.epa.gov/owow/estuaries/monitor/.

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

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

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

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

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

U.S. EPA. 2002. Assessing and monitoring floatable debris. 49 pp. EPA-842-B-02-002, Oceans and Coastal Protection Division, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/owow/oceans/debris/floatingdebris/pdf.html

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

U.S. EPA. 2002. Guidance for quality assurance project plans. 130 pp. EPA QA/G-5, U. S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/swerust1/cat/epaqag5.pdf

Author Abstract. 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 describes the target audience and the importance of systematic sampling. A second chapter describes all of the pieces of a QAPP, focusing on environmental data collection and analysis. The third chapter describes methods for developing QAPPs for projects that use previously collected data.

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

U.S. EPA. 2002. Methods for evaluating wetland condition: Introduction to wetland biological assessment. 42 pp. Office of Water, U.S. Environmental Protection

Agency, Washington, D.C. EPA-822-R-02-014. http://www.epa.gov/ost/standards or http://www.epa.gov/waterscience/criteria/wetlands/

Author Abstract. In 1999, the U.S. Environmental Protection Agency (EPA) began work on this series of reports entitled *Methods for Evaluating Wetland Condition*. The purpose of these reports is to help States and Tribes develop methods to evaluate (1) the overall ecological condition of wetlands using biological assessments and (2) nutrient enrichment of wetlands, which is one of the primary stressors damaging wetlands in many parts of the country. This information is intended to serve as a starting point for States and Tribes to eventually establish biological and nutrient water quality criteria specifically refined for wetland waterbodies. This purpose was to be accomplished by providing a series of "state of the science" modules concerning wetland bioassessment as well as the nutrient enrichment of wetlands. The individual module format was used instead of one large publication to facilitate the addition of other reports as wetland science progresses and wetlands are further incorporated into water quality programs. Also, this modular approach allows EPA to revise reports without having to reprint them all. A list of the inaugural set of 20 modules can be found at the end of this section.

This series of reports is the product of a collaborative effort between EPA's Health and Ecological Criteria Division of the Office of Science and Technology (OST) and the Wetlands Division of the Office of Wetlands, Oceans and Watersheds (OWOW). The reports were initiated with the support and oversight of Thomas J. Danielson (OWOW), Amanda K. Parker and Susan K. Jackson (OST), and seen to completion by Douglas G. Hoskins (OWOW) and Ifeyinwa F. Davis (OST). EPA relied heavily on the input, recommendations, and energy of three panels of experts, which unfortunately have too many members to list individually: Biological Assessment of Wetlands Workgroup, New England Biological Assessment of Wetlands Workgroup, Wetlands Nutrient Criteria Workgroup.

More information about biological and nutrient criteria is available at the following EPA website: http://www.epa.gov/waterscience/criteria/wetlands/

More information about wetland biological assessments is available at the following EPA websites: http://www.epa.gov/owow/wetlands/bawwg and http://www.epa.gov/waterscience/criteria/wetlands/

U.S. EPA. 2002. Methods for evaluating wetland condition: Study design for monitoring wetlands. 21 pp. EPA-822-R-02-015, Office of Water, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/ost/standards or http://www.epa.gov/waterscience/criteria/wetlands/

Author Abstract. State and Tribal monitoring programs should be designed to assess wetland condition with statistical rigor while maximizing available management resources. The three study designs described in this module—stratified random sampling, targeted/tiered approach, and before/after, control/impact (BACI)—allow for collection of a significant amount of information for statistical analyses with relatively minimal effort. The sampling design selected for a monitoring program will depend on the management question being asked. Sampling efforts should be designed to collect information that will answer management questions in a way that will allow robust statistical analysis. In addition, site selection, characterization of reference sites or systems, and identification of appropriate index periods are all of particular concern when selecting an appropriate sampling design. Careful selection of sampling design will allow the best use of financial resources and will result in the collection of high quality data for evaluation of the wetland resources of a State or Tribe. Examples of different sampling designs currently in use for State and Tribal wetland monitoring are described in the Case Study (Bioassessment) module and on http://www.epa.gov/owow/wetlands/bawwg/case.html.

U.S. EPA. 2002. Methods for evaluating wetland condition: Developing an **invertebrate** index of biological integrity for wetlands. 45 pp. EPA-822-R-02-019, Office of Water, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/ost/standards or http://www.epa.gov/waterscience/criteria/wetlands/

Author Abstract. The invertebrate module gives guidance for developing an aquatic invertebrate Index of Biological Integrity (IBI) for assessing the condition of wetlands. In the module, details on each phase of developing the IBI are given. First, in the planning stage, invertebrate attributes are selected, the wetland study sites are chosen, and decisions are made about which stratum of the wetland to sample and what is the optimal sampling period or periods. Then, field-sampling methods are chosen. The module describes field methods used in several States, and gives recommendations. Laboratory sampling procedures are reviewed and discussed, such as whether and how to subsample, and what taxonomic level to choose for identifications of the invertebrates. Specific categories of attributes, such as taxa richness, tolerance, feeding function, and individual health are discussed, with examples. Appendices to the invertebrate module give details about the advantages and disadvantages of using invertebrates, of the different attributes, of various field sampling methods, and of lab processing procedures as used by several State and Federal agencies. The module and appendices give a detailed example of one State's process for developing an invertebrate IBI, with a table of metrics with scoring ranges, and a table of scores of individual metrics for 27 wetlands. A glossary of terms is provided as well as sampling methods.

U.S. EPA. 2002. Methods for evaluating wetland condition: biological assessment methods for **birds**. 22 pp. EPA-822-R-02-023, Office of Water, U.S. Environmental Protection Agency, Washington, D.C. http://www.epa.gov/ost/standards or http://www.epa.gov/waterscience/criteria/wetlands/

Author Abstract. Birds potentially detect aspects of wetland landscape condition that are not detected by the other groups commonly used as indicators. Moreover, birds are of high interest to a broad sector of the public. When using birds as indicators, one must pay particular attention to issues of spatial scale. This requires an understanding of home range sizes of the bird species being surveyed. The development of wetland and riparian bird indices of biological integrity is still in its infancy, but holds considerable promise.

Methodologies for sampling birds in coastal habitats are also presented.

U.S. NOAA Coastal Services Center. 2001. Guidance for benthic habitat mapping: an aerial photographic approach by Mark Finkbeiner, Bill Stevenson. and Renee Seaman. 75 pp. U.S. National Oceanic and Atmospheric Administration. Coastal Services Center, Charlston, SC. http://www.csc.noaa.gov/benthic/cdroms/sav_cd/pdf/bhmguide.pdf

Author Introduction. The goal of this document is to provide technical guidance to data developers working to produce digital spatial data on benthic habitat. Using these methods, developers will be able to produce consistent benthic data suitable for regional comparison and application to various coastal management issues. All mapping efforts are designed to answer specific questions about the environment and meet objectives specific to a given project. The techniques used in generating a map determine its utility for meeting those objectives. The methods described in this document are designed to meet the following general objectives:

- Produce digital baseline data on the spatial extent and characteristics of benthic habitats
- Produce synoptic data over estuary-sized study areas
- Provide data that optimize the efficiency of further in-situ sampling
- Provide data at a resolution that can contribute to environmental permitting processes (such as Clean Water Act Section 404 fill determinations)
- Produce data that support change detection over extensive areas

The technical recommendations are designed to allow some flexibility in the choices of classification scheme, remote sensor data source, analysis procedures, and other key elements that vary regionally; however, all have been applied in various regions of the country and should be usable with minor modifications in the majority of geographic settings.

The primary audience of this document is the spatial data analyst tasked with developing baseline benthic habitat data. The methods that follow rely strongly on aerial photointerpretation and photogrammetry. Effective implementation of these technologies requires a specialized set of skills and experience. Project analysts ideally should have a background in remote sensing and photogrammetry. A familiarity with the physical and biological components of the study area is also very important and a working knowledge of geographic information system (GIS) technology is essential to producing the digital data and conducting further spatial analysis of the results. A secondary audience is the coastal resource manager. Managers can use the major components of this document as guidance for preparing technical statements for grants or contracts, and for project planning. One element that is usually of particular interest to managers is the expected cost of a mapping project. The actual cost of a project is determined by many project variables and objectives. Therefore, specific information on costs is not provided in this document. Cost information is best obtained on a project-by-project basis in consultation with commercial data and service providers and other professionals working in the field.

In addition to this report, other seagrass-related resources are available on a CD-ROM provided by NOAA. The CD-ROM can be requested through contact information on the following webaddress: http://www.csc.noaa.gov/benthic/cdroms/sav_cd/

U.S. NOAA Coastal Services Center. 2001. Guide to the seagrasses of the United States of America (including U.S. Territories in the Caribbean). 22 pp. U.S. National Oceanic and Atmospheric Administration, Coastal Services Center, Charlston, SC. http://www.csc.noaa.gov/benthic/cdroms/sav_cd/pdf/guide.pdf

This seagrass field guide will help practitioners identify species that live, or that have historically existed, in their coastal waters. This handy, full-color guide contains photographs and identification information on individual species, their habitat preferences, and distribution maps for seagrasses of the United States and its Caribbean territories.

In addition to this report, other seagrass-related resources are available on a CD-ROM provided by NOAA. The CD-ROM can be requested through contact information on the following webaddress: http://www.csc.noaa.gov/benthic/cdroms/sav_cd/

Wenner, E. L. and M. Geist. 2001. The national estuarine research reserves program to monitor and preserve estuarine waters. *Coastal Management* 29:1-17.

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

Zedler, J. B. 2001. Handbook for restoring tidal wetlands. CRC Press, Boca Raton.

This handbook provides a collection of case studies and guidelines to assist tidal restoration management. Zedler describes the conceptual planning for coastal wetlands restoration, strategies for management of hydrology and soils, the restoration of vegetation and assemblages of fishes and invertebrates, and the process of evaluating, monitoring, and sustaining restored wetlands. She also highlights parameters that should be monitored and techniques that can be used during restoration. Parameters addressed include hydrology and topography, water quality, soils, substrate qualities, nutrient dynamics, elevation, species abundance and diversity (vegetation, invertebrates and fishes). Technology used to monitor certain parameters includes Global Positioning Systems (GPS) and Geographic Information Systems (GIS). Additional information on parameters monitored and techniques used are also described.

APPENDIX III: LIST OF SUBMERGED AQUATIC VEGETATION 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

http://www.aswm.org/lwp/nys/glossary.htm

http://water.usgs.gov/nwsum/WSP2425/glossary.html

http://water.usgs.gov/wicp/acwi/monitoring/glossary.html

http://www.webster.com