CHAPTER 1: INTRODUCTION TO VOLUME TWO

INTRODUCTION

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

- Outdoor recreation and tourism
- Education
- Traditional use and subsistence lifestyles
- Healthy fishing communities, and
- Obtaining other marketable goods

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

WHAT IS RESTORATION MONITORING?

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

For this manual, restoration monitoring is defined as follows:

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

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

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

- Will active or passive capture techniques be used (e.g., beach seines vs. fyke nets)?
- Where and when will samples be taken?
- Who will conduct the sampling?
- What level of identification will be required?
- What structural characteristics such as water level fluctuation or water chemistry will also be monitored and how?
- Who is responsible for housing and analyzing the data?
- How will results of the monitoring be disseminated?

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

Monitoring is an essential component of all restoration efforts. Without effective monitoring, restoration projects are exposed to several risks. For example, it may not be possible to obtain early warnings indicating that a restoration project is not on track. Without sound scientific monitoring, it is difficult to gauge how well a restoration site is functioning ecologically both before and after implementation. Monitoring is necessary to assess whether specific project goals and objectives (both ecological and human dimensions) are being met, and to determine what measures might need to be taken to better achieve those goals. In addition, the lack of monitoring may lead to poor project coordination and decreased efficiency.

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

CONTEXT AND ORGANIZATION OF INFORMATION

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

To accomplish this task, NOAA has provided guidance to the public in two volumes. The first, *Science-Based Restoration Monitoring of Coastal Habitats, Volume One: A Framework* *for Monitoring Plans Under the Estuaries and Clean Waters Act of 2000 (Public Law 160-457)* was released in 2003. It outlines the steps necessary to develop a monitoring plan for any coastal habitat restoration project. *Volume One* briefly describes each of the habitats covered and provides three matrices to help practitioners choose which habitat characteristics may be most appropriate to monitor for their project. Experienced restoration practitioners, biologists, and ecologists as well as those new to coastal habitat restoration and ecology can benefit from the step-by-step approach to designing a monitoring plan outlined in *Volume One*.

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

- Detailed information on the structural and functional characteristics of each habitat that may be of use in restoration monitoring
- Annotated bibliographies, by habitat, of restoration-related literature and technical methods manuals, and
- A chapter discussing many of the human dimensions aspects of restoration monitoring

The second section, Context for Restoration includes:

- A review of methods to select reference conditions
- A sample list of costs associated with restoration and restoration monitoring
- An overview of an online, searchable database of coastal monitoring projects from around the United States, and
- A review of federal legislation that supports restoration and restoration monitoring

The Audience

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

The information presented in *Volume Two* is not intended as a 'how to' or methods manual: many of these are already available on a regional or habitat-specific basis. *Volume Two* does not provide detailed procedures that practitioners can directly use in the field to monitor habitat characteristics. The tremendous diversity of coastal habitats across the United States, the types and levels of impact to them, the differing scales of restoration activities, and variety of techniques used in restoration and restoration monitoring prevent the development of universal protocols. Thus, the authors have taken the approach of explaining *what one can measure during restoration monitoring, why it is important*, and *what information it provides* about the progress of the restoration effort. The authors of each chapter also believe that monitoring plans must be derived from the goals of the restoration project itself. Thus, each monitoring effort has the potential to be unique. The authors suggest, however, that restoration practitioners seek out the advice of regional experts, share data, and use similar data collection techniques with others in their area to increase the knowledge and understanding of their local and regional habitats. The online database of monitoring projects described in Chapter 17 is intended to facilitate this exchange of information.

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

MONITORING PROGRESS TOWARDS GOALS

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

THE HABITAT CHAPTERS

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

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

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

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

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

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

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

Organization of Information

Each of the habitat chapters is structured as follows:

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

Three appendices are also provided for each habitat chapter. In the online form of *Volume Two,* these appendices download with the rest of the habitat chapter text. In the printed versions of *Volume Two*, each chapter's appendices are provided on a searchable CD-ROM located inside the back cover. Each appendix is organized as follows:

Appendix I - An Annotated Bibliography
a. Overview of case studies of restoration monitoring and general ecological studies pertinent to restoration monitoring
b. Entries are alphabetized by author

Parameters to Monitor the Structural Characteristics of SAV (excerpt)

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

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

Parameters to Monitor the Functional Characteristics of SAV (excerpt)

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

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

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

Appendix II - Review of Technical and Methods Manuals

These include reviews of:

a. Restoration manuals
b. Volunteer monitoring protocols
c. Lab methods
d. Identification keys, and
e. Sampling methods manuals

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

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

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

- The material presented in *Volume One*
- Resources provided in the appendices
- The advice of regional habitat experts, and
- Research on the local habitat to be restored

WHAT ARE THE HABITATS?

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

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

Habitat Decision Tree

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

THE HUMAN DIMENSIONS CHAPTER

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

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

1) Human dimensions goals and objectives of a project
2) Measurable parameters that can be monitored to determine if those goals are being met, and
3) Social science research methods, techniques, and data sources available for monitoring these parameters

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

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

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CHAPTER 6: RESTORATION MONITORING OF ROCKY HABITATS

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INTRODUCTION

Rocky habitats are found in freshwater, estuarine, and marine systems. In estuarine and marine systems, they include rocky shorelines, rock bottoms, and the substratum in kelp and other macroalgal habitats as defined and discussed in *Volume One* of the "*Science-Based Restoration Monitoring of Coastal Habitats*" document. Rocks in these habitats can vary from expanses of solid bedrock to large boulders to cobbles greater than seven centimeters in diameter, and often contain mixtures of these rock sizes. Habitats composed mostly of particles smaller than seven centimeters support very diverse communities, are affected by different environmental factors, and therefore, are best monitored using approaches and techniques for soft bottom habitats. Rocky habitats occur at all depths in the ocean, but because of accessibility and cost issues, it is unlikely, at least in the near future, that restoration or recovery after anthropogenic disturbance will be commonly monitored at depths greater than 30 meters. These habitats found at depths greater than 30 meters can be very important in freshwater systems, and are a critical component of restoring stream habitat for salmon and other fish (Koski 1992). In this document, in-stream monitoring and deeper rocky habitats will not be discussed, although many of the monitoring approaches for marine rocky habitats are applicable.

Figure 1. Big Sur rocky coastline towards Point Sur, California. Photo courtesy of Captain Albert E. Theberge, NOAA Corps. Publication of NOAA Central Library. http://www.photolib.noaa.gov/coastline/line3023.htm

Rocky habitats (see rocky shoreline, Figure 1) are generally high-energy habitats exposed to frequent wave action or strong currents (Lewis 1964; Stephenson and Stephenson 1972; Cowardin et al. 1979; Raffaelli and Hawkins 1996; Menge and Branch 2000). The rocky substrate provides a place of attachment and growth for sessile invertebrates and seaweeds which would otherwise be swept away or buried. In turn, the invertebrates and seaweeds provide sub-habitats and food for numerous other invertebrates, algae, and fishes. Vertical zonation of organisms is a consistent feature of rocky habitats, and is especially evident on intertidal shores subjected to steep gradients of tidal exposure and wave action (Stephenson and Stephenson 1972; Cowardin et al. 1979; Archambault and Bourget 1996; Menge and Branch 2000).

Rocky habitat types are inhabited by highly diverse assemblages of organisms from a variety of taxonomic groups (Figure 2). Organisms range from primary producers such as macroalgae to consumers such as fish, birds, seals, and sea otters (Lewis 1964; Cowardin et al. 1979; Menge and Branch 2000). For example, macroalgae on rocky shores in the high intertidal zone in central California harbor over 90 species of invertebrates (Glynn 1965). Rocky habitats can

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[2] 4001 N. Wilson Way, Stockton, CA 95205.
[3] 8272 Moss Landing Road, Moss Landing, CA 95039.

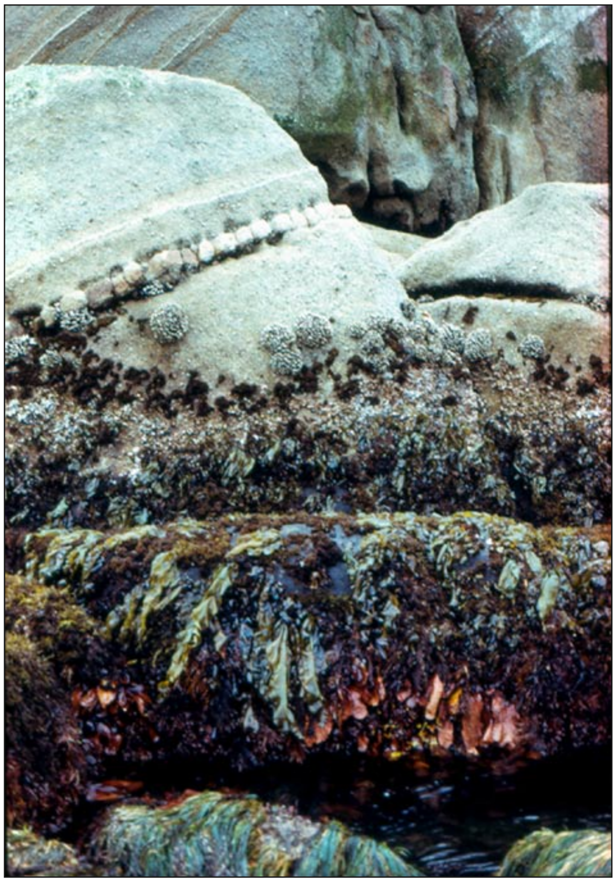

Figure 2. Semi-exposed rocky shore at low tide in central California. Note the considerable diversity and complex structure, with conspicuous organisms in zones from clumps of goose barnacles in the high intertidal zone to surf grass in the low tide. Photo courtesy of Michael Foster, Moss Landing Marine Laboratories, California.

support numerous filter feeding organisms such as mussels, barnacles, and oysters that contribute to habitat and water quality. Animals such as juvenile fishes, crustaceans, and polychaetes may also seek refuge within the matrices of rocky substrates and their attached organisms to prevent being swept away by strong currents and avoid predators. Additional descriptions of the natural history of rocky habitats are in *Volume One* of the "Science-Based Restoration Monitoring of Coastal Habitats" document.

Not only do these habitats play an important ecological role, but they also have very high economic value. Rocky habitats contribute to the economy by providing breeding, feeding, nursery, and adult habitat for commercially and recreationally fished species, including invertebrates such as abalone and lobster, and seaweeds that are harvested for food and chemicals. Rocky habitats also have increasingly important economic value as recreational resources for shore visitors, divers, boaters, and kayakers attracted to their diversity and aesthetic values. Finally, these habitats have high scientific value. Because of their accessibility, diversity, and structure, rocky habitats have been primary research sites for studies of land-sea interactions; morphological, physiological, and life history adaptations; as well as ecological interactions. Information from such studies has been critical to understanding the role of competition, predation, and physical gradients in structuring communities as well as assessing the causes of variation in biodiversity and the effects of this variation on community dynamics.

HUMAN IMPACTS TO ROCKY HABITATS

Various natural and human disturbances impact rocky habitats. Human impacts that may disrupt the natural ecological communities include:

- Agricultural and chemical runoff
- Sewage discharges
- Oil spills
- Heat from coastal power plant discharges
- Construction (i.e. increase sedimentation from coastal development), and
- Recreational activities (e.g., fishing and human trampling

Despite their ecological, economic, and aesthetic importance, impacted rocky habitats are rarely considered for restoration because they are usually spatially small or patchy, many of the organisms have the ability to disperse long distances via adult movement and dispersal of planktonic larvae and spores, and the rocks are rarely destroyed. Thus, recovery often readily occurs via natural processes once the impact is removed. This may be true even if the chemical impact remains in the environment for some time after the source has been eliminated. Some researchers suggest that removing residual oil from rocky shores after an oil spill may delay recovery more than if the oil was left to degrade naturally (DeVogelaere and Foster 1994). Recovery times from natural and human-induced disturbances are often on the order of one to ten years (Foster et al. 1988; Hawkins and Southward 1992; Schiel and Foster 1992; Foster et al. 2003). In most cases, the decision to restore or not to restore depends on whether researchers want to try and increase the rate of natural recovery. Increasing the rate of natural recovery has not been attempted in rocky habitats except in the context of trying to increase populations depleted by overfishing, or to speed the recovery of some algal populations and habitats (Schiel and Foster 1992; Walder and Foster 2000). There is little evidence that the former goal has ever worked well, and the latter is still experimental.

Cases where human impacts to rocky habitats have occurred and the results of these impacts include pollution and physical damage.

Pollution

Oil spills are considered a major threat to plant and animal communities of rocky habitats (Figure 3). A well-known oil spill event which affected marine life along the coast of Prince William Sound, Alaska is the *Exxon Valdez* oil spill (Andres 1998; Jewett et al. 2001). Following this spill event, the growth and survival of important economic fish species (e.g., juvenile

Figure 3. Oil-covered rocks on the shoreline of San Juan, Puerto Rico. Photo courtesy of Morris Berman. NOAA Office of Response and Restoration (ORR) photo gallery. http://photos.orr.noaa.gov//Photos/PCD4446/IMG0088.JPG.

Figure 4. Cleanup workers use vacuums to remove oil from rocky shores of San Juan, Puerto Rico. Photo courtesy of Morris Berman. NOAA Office of Response and Restoration (ORR) photo gallery.

salmon) were reduced significantly (Willette 1996), which in turn caused a decline in the fisheries industry.

Chemical dispersants used to remove oil may leave traces of chemicals in the environment that can cause additional harm to organisms occupying these habitats. Mechanical cleaning of oil may also disturb the physical structure of the environment (Figure 4) (Foster et al. 1988). Oil spill impacts vary significantly in amount, chemical composition, and degree of weathering before reaching the shore (Foster et al. 1988). Ongoing research in central California using completely cleared plots as indicators of recovery from oil spills showed that recovery can occur within a year in the upper intertidal zone, but in the mid intertidal zone where mussel beds exist, the recovery may take more than ten years (MMS 1992). Recovery rates may also be influenced by damage intensity and cleanup efforts (DeVogelaere 1991; DeVogelaere and Foster 1994).

Pollutants associated with stormwater runoff, sewage, and other point source discharges can also cause direct degradation to rocky habitat communities as a result of toxicity (Littler and Murray 1975). Excessive sedimentation and turbidity can negatively impact the growth of algae by smothering the algae or reducing light needed for photosynthesis (Devinny and Volse 1978). Pollutants discharged along rocky habitats may also affect the growth and survival of juvenile fish and crustaceans, particularly those species closest to the loading source (Smith et al. 1999; Guidetti et al. 2003).

Physical Damage

Various factors such as ship groundings and bottom fishing practices can physically damage rocky habitats. Bottom fishing activities, for example, may cause permanent habitat changes when rock substrata used as a place of attachment for sessile organisms is damaged or destroyed (Kaiser 1998). Trawling and dredging are two common fishing activities that can damage rocky habitats and disrupt animal communities. Bottom trawlers have wide nets consisting of extremely heavy rollers, chains, and doors that are dragged across rocky bottom habitats. Dredges contain rake structures at the end of their frames that also drag and scrape along the bottom (Freese et al. 1999; NAS 2002). As a result of rocky habitat destruction, the abundance of sessile organisms is reduced and mobile organisms (e.g., juvenile fish and shellfish) may migrate to areas that can provide adequate shelter. The removal of sessile epifauna through harvesting may also negatively alter habitat topography. In some cases, species that contribute to the topographic relief of rocky habitats tend to experience slow growth and require several years to recolonize.

RESTORATION EFFORTS

Restoration may be attempted in areas impacted by ship groundings that can destroy the rock or by sediment discharge that may bury the rocky substratum in calm water portions of an estuary. Restoration of ship grounding impacts may include replacing the destroyed rock, although in many wave-exposed coastal areas, it would be extremely expensive to transport and anchor rocks large enough to remain in place. Restoration of rocks that have been buried by human activity may include suction dredging to remove the deposited material. Guidance on restoration for sediment discharge may be provided by projects that have created rocky habitat to compensate or mitigate for a human impact. For example, an artificial reef was created to replace habitat loss due to a power plant discharging heated, turbid water into a kelp forest (Reed and Schroeter 2004)[4]. Mitigation projects for rocky bottom impacts are, however, still in the experimental stage and are likely to be very site-specific. Such projects require the creation of rocky habitat, followed by monitoring to compare the populations or communities in the newly created rocky habitat to those in comparable habitats unaffected by the discharge.

As part of restoring the value of rocky habitats, assessment of natural recovery after an impact has been removed should occur in most cases. Such assessment is the focus of the remaining chapter.

MONITORING ROCKY HABITATS

With the exception of creating rocky habitats to mitigate rocky habitats that were destroyed by ship groundings, the primary purpose of monitoring is to determine whether recovery is occurring after an impact has been removed, how fast it is occurring, and when the area has fully recovered. In addition to simply understanding how recovery is proceeding, the results of monitoring may also have regulatory consequences and may be of interest to the general public, particularly those who desire to use the formerly impacted area for recreational or commercial purposes. Assuming the impact has been removed and the substratum was not altered, there is generally no need to monitor the recovery of physical and/or chemical parameters as they should return to "natural", pre-impact conditions. For example, in areas where sediment runoff from coastal development is stopped, it takes some time for the sediment to be removed by natural re-suspension and transport. Thus, it would be necessary to monitor sediment cover to determine the time frame for natural removal and ensure the recovery of organisms.

[4] For an overview of a project to compensate for the effects of a power plant discharge, see Reed and Schroeter (2004).

Monitoring restoration after the removal of an impact can test the efficacy of restoration techniques and threats to rocky habitats, increase understanding of rocky habitat ecology in general, and reveal fundamental population and community patterns needing further investigation. Ultimately it is knowledge of the mechanisms producing observed patterns that will allow accurate predictions about the effects of particular impacts and how best to restore an area after impacts are removed. Well-designed monitoring programs have a great potential to contribute to that knowledge.

HOW TO MONITOR

There is an enormous amount of information about rocky habitats, sampling designs and methods, and data analyses and interpretation associated with monitoring. It is impossible to adequately review all of the available information in this chapter. The purpose of this section is to give an overview of what needs to be considered in any restoration monitoring project for rocky habitats. Developing a monitoring plan for a particular restoration site requires consulting technical references and experts as well as considering other factors such as selection of suitable sites, sampling and monitoring methods, and study time frame. Following are several recommended considerations when developing a restoration monitoring plan.

A detailed discussion on Consulting experts has been presented in Volume One of this document and should be applied to each habitat type discussed in Volume Two. Also, see Chapter 15 entitled the "Selection of Reference Sites or Conditions" for a discussion on the need for comparison sites.

Deciding What to Monitor

Organisms that cannot be easily seen with the unaided eye (i.e., those approximately less than 0.5 centimeters in size) are not generally monitored, but there is an enormous diversity of taxonomic groups (e.g., barnacles to sea lions), sizes, characteristics (e.g., attached seaweeds versus highly mobile fish), and abundances among the larger organisms found in rocky habitats. It is usually impossible to monitor enough to be able to test hypotheses concerning recovery for all of them. Therefore, one of the first tasks of any monitoring program is to decide what to monitor. If the impact was selective (e.g., intense fishing for species X that eliminated the species from the habitat), then a sampling program that only monitors the recovery of species X, its predators, and its competitors is appropriate. If the effect of the impact was more widespread among species, then a few species that are abundant and characteristic of the habitat may be selected and monitored with the assumption that if they recover, associated species that were not sampled have likely recovered as well (Foster et al. 2003). The most usual approach to this latter situation is to design a sampling program that samples characteristic and common species, and assesses the abundance of other species greater than 0.5 centimeters in size. For example, 0.5 meter by 0.5 meter quadrats might be used to sample common and characteristic limpets, but other snails are also counted in the same quadrats. While the other snails may not be abundant enough for powerful statistical analyses using this quadrat size, they might be used in community analyses that pool all species and examine changes in community similarity over time (Foster et al. 2003).

Monitoring Approaches

Restoration monitoring can be qualitative, quantitative, or a mixture of both. When quantitative sampling cannot be done, reports based on periodic visits to the restored site and comparison site(s) by experts familiar with unimpacted habitats may be sufficient. It may be that no suitable natural site is available for comparison. In this case, recovery trends based on sampling the restored sites might be qualitatively compared to what the literature and/

or experts suggest would be expected in a natural site. The most rigorous approach is quantitative sampling of the restored site and one or more natural areas to test hypotheses concerning the degree of recovery. This approach is discussed further in this chapter.

Monitoring Designs for Quantitative Hypothesis Testing

A fundamental problem with testing hypotheses about recovery after restoration is that there is usually only one restoration site. If the restoration is thought of as a "treatment" in the statistical sense, one site means there is only one replicate in space. Without an estimate of the treatment variance due to treatment replication, it is impossible to rigorously determine if any differences between the restoration and natural sites are due to the restoration activity or simply due to "location." Samples within a restoration site are not replicates of restoration; they are subsamples of one restoration replicate (Hurlbert 1984). To avoid this problem, one can repeatedly sample the restoration site and comparison site(s) before and after restoration occurs using Before After Control Impact (BACI) or Before After Control Impact Paired (BACIP) designs. The BACI designs use replication in time rather than space to estimate treatment effects. The resulting data can be used in various statistical tests to examine the efficacy of the restoration, including testing the differences in the mean abundances of a particular species between the restoration and comparison sites (Steward-Oaten et al. 1986). This approach has been used to examine the effects of a thermal discharge on rocky habitats in central California (Schiel et al. 2004). While this recent study considered what changes occurred as a result of the discharge, the same approach could be used to determine recovery after the impact is removed by comparing differences between the impacted and natural areas before and after the impact is removed. This approach obviously requires that monitoring starts before restoration begins.

In most cases, sufficient pre-restoration data from the relevant sites cannot be obtained. The best design in these cases is to sample the restored and comparison sites over time after restoration using an After Control Impact (ACI) design, and assess recovery relative to how similar the restored site is to the comparison site(s). This can be done by comparing the abundances of particular species in the two types of sites, or some measure of community structure such as similarity. This approach has been used to assess the recovery of cleared plots relative to control plots at six sites in California (Foster et al. 2003). The similarity of biological assemblages in the control plots - the equivalent of comparison sites in restoration monitoring - to each other over time was used to define a similarity envelope. As the cleared plots recovered, their similarity to the control plots was calculated, and when the similarity of the cleared plots to the control plots fell within the range of similarity of the control plots to each other, the cleared plots were considered recovered. Other multivariate techniques can also be used to assess community recovery (Clarke 1993; Clarke and Gorley 2001).

(*Note: This can only be done effectively if MANY species with various characteristics are monitored; otherwise multivariate analyses do not have enough species with which to work.*)

STRUCTURAL CHARACTERISTICS OF ROCKY HABITATS

As previously mentioned, rocky habitats are not typically restored and monitored. If practitioners decide to restore rocky habitats, they must first understand the structural characteristics of the habitat and how they relate to the project goals. The structural characteristics described in this section refer to some of the habitat's biological, physical, hydrological, and chemical features (potential parameters for baseline information and monitoring restoration) and abiotic factors that may influence each characteristic during the restoration process. These characteristics include:

Biological

- Habitat created by rocky substrates

Physical

- Geomorphology and topography

Hydrological

- Currents and Tides
- Wave energy
- Water source (associated with water quality)

Chemical

- Salinity

Not all structural characteristics described in this chapter, however, need to be measured. In most cases, it is not necessary to monitor the physical and chemical environment of rocky habitats during restoration unless the practitioner wants to determine the length of time it takes for the contaminant/pollutant to be naturally removed. The physical and chemical sections of this chapter simply provide some background information on the ecology of rocky habitats such as the role each characteristic plays in supporting the habitat's structure and plant and animal life, and whether any of these characteristics may be parameters for gathering baseline information and monitoring restoration progress. Parameters primarily monitored during rocky habitat restoration are those which relate to the habitat's biota, as discussed in the "Functional Characteristics of Rocky Habitats" section of this chapter.

Parameters selected for measurement will vary depending on the goals of the project. The methods mentioned in this chapter are just a few of many methods that can be used to sample, measure, and monitor the habitat's characteristics. Some methods mentioned may be high-tech and not typically used by laypersons. Thus, data using these methods may be available from various scientists and researchers from federal, state, and local government agencies and academia who have performed assessments prior to restoration efforts in the study area.

Described below are the structural characteristics previously listed, as well as their influence on rocky habitats and methods to monitor each characteristic, whenever possible, before, during, and after restoration.

BIOLOGICAL

Habitat Created by Rocky Substrates

Rocky habitats, as previously discussed, consist of both rocky bottoms and rocky shores. Rock bottoms (subtidal) consist of solid, consolidated substrate such as bedrock, as well as reefs and banks found on the seafloor. The solid seafloor provides an attachment surface for sessile organisms as well as a rough three-dimensional surface that encourages water mixing and nutrient cycling (Stephenson and Stephenson 1972; Cowardin et al. 1979; Bertness et al. 2001). In some cases, organisms such as polychaetes and fishes are found in or near finer sediments between crevices of the rocky substrates. Rocky shores (Figure 5) are distinguished from rocky bottoms by sharp environmental gradients from low rocky intertidal to upper intertidal zones. They include wetland environments that are distinguished by bedrock, stones, or boulders and located along marine and freshwater shorelines (Lewis 1964; Stephenson and Stephenson 1972; Cowardin et al. 1979; Bertness et al. 2001).

Figure 5. Rocky shoreline in Maine. Photo courtesy of William Folsom, NOAA National Marine Fisheries Service. Publication of the National Oceanic and Atmospheric Administration (NOAA), NOAA Central Library. http://www.photolib.noaa.gov/coastline/line1315.htm.

Rocky habitats have several functions, including high primary productivity, biomass export, wave energy reduction, spawning and nursery habitat for fish, invertebrate habitat, and bird and mammal feeding grounds. In many marine areas, rocky substrates are covered with kelp species such as *Laminaria* spp. and *Agarum cribrosum* (found in subtidal zones only), seaweeds, and many gastropods (Lewis 1964; Bertness et al. 2001; Murray et al. 2002). Predation, grazing, and physical factors are important in controlling the zonation of sessile species in these habitats.

Rocky habitats can be divided into three zones: the splash zone, intertidal zone, and subtidal zone (Figure 6). The splash zone acts as a boundary extending above the high water level. The width of this zone may vary depending on factors such as light and shade variations, exposure to waves, and tidal range. This zone is characterized by organisms that can tolerate extreme changes in desiccation, salinity, and temperature; therefore, very few species can thrive in this environment. Commonly seen in this zone are lichens and blue-green algae. Lichens are colonizers of bare rock and are slow growing yet long lived. Blue-

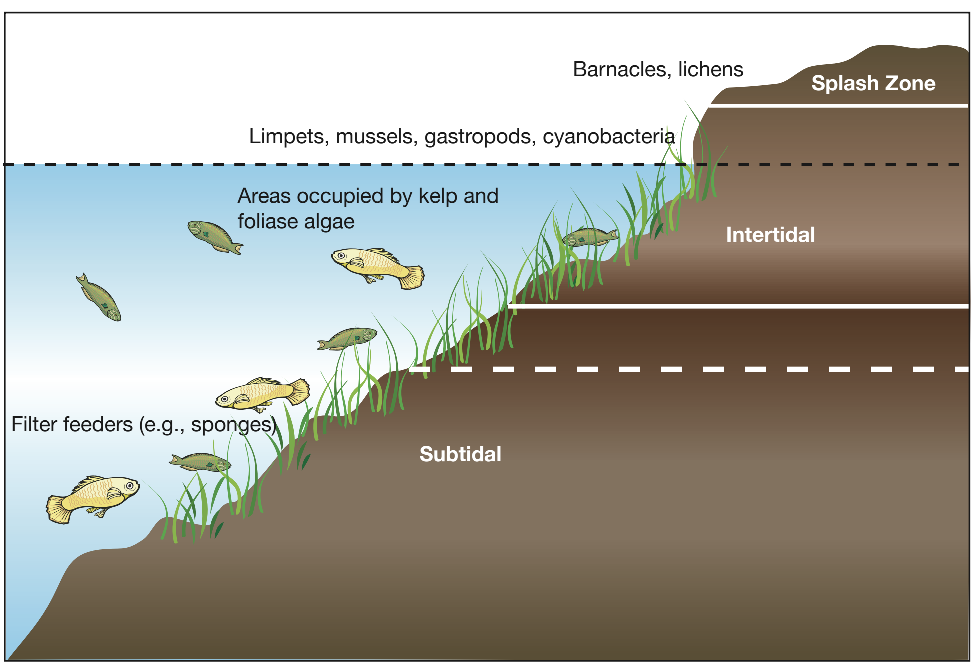

Figure 6. Zonation patterns within a rocky habitat from the shoreline to the ocean's bottom. Figure provided by Brenay Major, intern of NOAA National Centers for Coastal Ocean Science.

green algae, commonly known as cyanobacteria, are small, photosynthetic bacteria that form large colonies which can be seen by the naked eye. Both lichens and blue-green algae adapt to long periods of exposure to air, heat, cold, rain, and predation by land animals and seabirds (Stephenson and Stephenson 1972; Little and Kitching 1996; Bertness et al. 2001). Frequently, you may also see shorebirds such as pipers and wandering tattlers foraging this area for food such as crustaceans and small fish primarily seen in small pools of water on the surface called tide pools.

The high intertidal zone, which is found between the low and high water level, is biologically rich, supporting a diverse assemblage of plants and animals. Animal inhabitants (e.g., limpets, gastropods, mussels, etc.) and vegetation (e.g., algae) are able to attach themselves securely to the rocks during high tides or pulsating waves (Lewis 1964; Raffaelli and Hawkins 1996; Bertness et al. 2001; Murray et al. 2002). Waves also play a positive role in supporting small organisms by assisting in shaping and reforming cliffs, gaps, and caves within this zone that provide habitat for the organisms such as invertebrates and small fishes (such as sculpin and blennies). Organisms in this area are not only exposed to tides and waves, but also to light which can make rock surfaces very dry if waves are reduced. Mobile animals occupying this area (as well as the splash zone) avoid desiccation (drying out) by hiding under moist or completely wet algae, or in rock crevices or tidepools. The lower area of the intertidal zone is covered by water except for a short period of time during the lowest tides. Most plants and animals in the low intertidal area can only survive for short periods without water. Moss, red encrusting algae, sea anemones, and hermit crabs are examples of species inhabiting the lower area of the intertidal zone (Bertness et al. 2001).

Other organisms that occupy intertidal zones include:

- Nudibranchs
- Hydroids
- Sea stars (Figure 7)
- Sea urchins
- Mussels
- Brittle stars (Figure 8), and
- Sea cucumbers

Rocky subtidal zones are areas below the tides where light is reduced as it travels toward the ocean's floor. If water is relatively clear within subtidal zones to depths of around 30 meters, large kelp is often seen dominating this area, some of which can produce canopies that float

Figure 7. Starfish and anemones in a cold water rocky community. Photo courtesy of L. Stewart, OAR/National Undersea Research Program. Publication of the NOAA Central Library. http://www.photolib.noaa.gov/nurp/nur03503.htm

Figure 8. Brittle star on rocky substrates. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

on the surface (e.g., giant kelp, *Macrocystis*). These canopies also reduce light reaching the ocean's bottom, so organisms found below kelp canopies adapt to low light availability (Kennely 1989). Other species commonly found in subtidal zones include worms, sea stars, sea urchins, sea anemones, sponge, various gastropods, red algae (Rhodophyta), brown algae including kelp (Phaeophyta) and green algae (Chlorophyta) (Stephenson and Stephenson 1972; Sebens 1985; Little and Kitching 1996; Bertness et al. 2001). Subtidal foundation species perform important functions such as altering patterns of water movement (Jackson and Winant 1983; Eckman et al. 1989), which in turn influence food and larval supply, and provide refuge from predation similar to rocky intertidal areas (Bertness et al. 2001).

Sampling and Monitoring Methods

There are several methods to map rocky habitats which can also be used for pre-monitoring and post-monitoring of restoration and natural recovery efforts. For pre-monitoring purposes, these methods can be used to determine habitat characteristics, identify activities occurring near the habitat that may influence restoration progress, and verify whether the habitat is in a suitable location for restoration. These methods can also be used in post-monitoring efforts to determine if the habitat's structure changed over time.

Photography - may be used in the intertidal and subtidal zones to characterize benthic substrates and identify the type of substrates present (Lundalv 1971). Divers can use underwater cameras to conduct quantitative surveys of large rocky areas. Selected areas can be photographed at various intervals over time to show changes occuring within their biocoenoses[5]. Photographs can then be analyzed in a stereo comparator and stereo microscopes in connection with organism density, cover, size distribution, and biomass on the rocky substrates (Lundalv 1971).

PHYSICAL

Geomorphology and Topography

Geomorphology refers to the study of the nature, origin, and historical changes that have taken place, particularly those caused by erosion and deposition. The nature of rocky habitats consists of bedrock, stones, and boulders. The shape and structure of rocky habitats are influenced significantly by weathering, currents, waves, and tidal action (Pethick 1984; Bird 2000). These habitats are also formed as a result of faulting and earthquakes (Pethick 1984). Rocky bottom (subtidal) habitats are formed when rocky substrates are transported and laid down along the ocean's bottom by means of weathering and waves. The composition of the subtidal community is influenced significantly by slope of the rock and nature of the substrate. Horizontal and gently sloping substrates, for example, are normally dominated by macroalgae, whereas vertical rock structures may be dominated by epifaunal invertebrates (Lundalv 1971). This may be due partially to higher light levels on horizontal surfaces than vertical structures and therefore, flat and sloping rock surfaces provide a more suitable environment for macroalgae growth and survival (Bertness et al. 2001). If construction along the coast or destructive dredging on the ocean's bottom takes place during a restoration project, geomorphology and topography may be changed, thereby affecting vegetation and animals by creating an unfavorable environment (i.e., altering the slope of vertical structures where certain species of organisms are found and exposing them to more sunlight).

The movement of rocky substrates will vary based on size of the substrate and the energy regime of the habitat. Boulders, for example, are moved mainly by high energy waves that occur during severe storms, while smaller substrates can be transported by waves with average energy (Pethick 1984; Trenhaile 1987).

[5] A group of networking organisms that inhabit a particular area and form an ecological community.

In some cases, extreme waves may break off pieces of rocky substrates from established rocky habitats, thereby changing the habitat's shape. Rocky substrates that are put in place by practitioners to restore rocky habitats can be dislodged by intense waves or by some other means influencing geomorphology and topography, as well as affecting biota. As a result of dislodged rocks, restoration progress towards maintaining and supporting various species may be restricted. Modifications may then have to be made to the restoration project, such as replacing dislodged rocky substrates and adjusting the timeline for monitoring progress toward achieving a naturally sustainable rocky habitat.

Differences in topography and roughness of rock types are important features that define the rocky habitat. These characteristics can disperse wave energy, potentially influencing nutrient and food distribution, which in turn influence species diversity and abundance (Archambault and Bourget 1996). Crevices and tide pools can also influence distributional patterns by providing microhabitats for mobile and sessile organisms. During restoration, if a rocky habitat is significantly altered because of construction such as the use of heavy machinery, organisms that occupy these areas may be disturbed or destroyed. Textural roughness of the rock also plays a role in rocky shore communities by increasing water retention, providing refuge for benthic recruits (Littler 1980), and acting as a pool for shore-based contaminants (e.g., oil). As previously mentioned, topography and geomorphology play a significant role in supporting organisms and should be considered when developing a restoration plan. Monitoring topography and geomorphology changes and noting, whenever possible, of the source responsible for the change, can help the practitioner determine whether modifications can be made so that the project can be continued or whether the project should be discontinued because the source responsible for degrading the habitat is constant.

Measuring and Monitoring Methods

Line chain transect - The quality of the surface topography influences the number of refuge locations for living marine organisms and drainage from the rock surfaces (i.e., the persistence of intertidal pools) (Trudgill 1988). An index of rugosity (roughness) can be measured using a line/chain transect (Figure 9) over a given area by extending the chain/line taut along the contours of the surface of an area, and then allowing the line to relax within the crevices. The relaxed measured length along the contours of the surface divided by the taut length provides the rugosity (Trudgill 1988).

Aerial photographs or satellite images - The abundance of rocky shores along the coastline may be mapped using aerial photographs or satellite images. Maps, aerial photographs, videos, and other information providing data shoreline geophysical characteristics are useful when selecting restoration sites (Murray et al. 2002). As maps are made at a variety of different spatial scales, they must be chosen for use based

Figure 9. Monitoring a rocky shoreline. The transect is located within the rockweed (*Fucus*) dominated stratum, and markers define the locations of randomly-selected, permanent quadrats. Photo courtesy of Michael Foster, Moss Landing Marine Laboratories, California.

in part on the scale necessary to select a suitable site.

Ground truthing - Shoreline data may also be obtained by "ground truthing" the site, or from trained observers boating close to the shore or walking along the shoreline. These individuals can gather quantitative information on the habitat's physical characteristics and determine whether the potential study area is suitable for restoration (Littler and Littler 1987; Murray et al. 2002).

Side-scan sonar imagery - A new mapping scheme for characterizing seafloors, based primarily on the interpretation of side-scan sonar imagery, has been developed to easily map and identify rock, gravel, and soft sediments (Barnhard et al. 1998). With the use of a geographic information system (GIS), these and other available data (e.g., seismic profiles, grab samples, submersible dives, and cores) can be referenced to a collective geographic base, superimposed on bathymetric contours, and then incorporated into surficial geologic maps of the study area. This digital representation of the seafloor encompasses depth, bottom type, and other features that allow analysis of rocky habitats (Barnhard et al. 1998).

HYDROLOGICAL

Currents and Tides

Continuous current flows occur along rocky shores and help to shape the rocky structure and influence species zonation. Some species can survive when exposed to continuous current flow, while others cannot and may easily be swept away. Periwinkles (*Littorina saxatilis*), for example, live in the upper intertidal zone (splash zone) and are exposed to waves for short periods of time (Lees et al. 1980; Nybakken 1982; Little and Kitching 1996). Vegetation and animals living on rocky shores must be able to adapt to continuous water flow. The rising and descending tides also affect life on rocky shores. Once the tide descends, plants and animals on rocks are exposed to air and therefore must be able to adapt to environmental changes in order to survive until the tide rises again. Organisms which live very low on the shore, on the other hand, are only briefly exposed to air.

Subtidal rocky habitats are generally located near areas where strong tidal currents and turbulent waters are common (Denny et al. 1985; Denny 1988; Paine and Levin 1981; Bertness et al. 2001). Organisms on rocky bottoms must therefore be firmly attached to the substrate or seek protection within cracks and crevices. Water movement also directly impacts the survival of benthic rocky bottom organisms when exposed to high hydrodynamic forces. These forces may improve the transport of gases, nutrients, and food; influence the movement of benthic substrate such as sediment and rock; and influence the impacts of flow on predation (Riedl 1971; Denny 1988; Paine and Levin 1981). Current flow should be considered when selecting a restoration site and monitoring the restoration effort because currents influence the biological community (as previously discussed) and can cause substrates to be moved that may affect restoration progress by shifting geomorphology.

Measuring and Monitoring Methods

Current profilers - Current profilers are instruments to measure the velocity and direction of currents. The most commonly-used current profilers are acoustic Doppler current profilers (ADCP). This instrument involves the use of underwater sound to measure vertical profiles of horizontal currents. The ADCP transmits acoustic pulses from a transducer along four beams. The transducers receive backscattered echos from small particles and plankton present in the water currents. The ADCP then converts the backscattered sound into elements that identify water current velocity, measure current speed and direction, and make a profile of the measurements (Appell et al. 1987; Fitzgerald et al. 2003).

Wave Energy

As previously discussed, waves can influence the vertical elevation of the biological community. Wave energy also influences the rates of recovery, whether through natural processes or restoration. Severe wave action can remove individual kelp plants and sessile organisms from their place of attachment, particularly in exposed areas compared to sheltered areas, or overturn these hard substrates on which they are attached, destroying the kelp and other macroalgae and disturbing faunal communities (Murray et al. 2002). For example, intertidal fucoid algae found along moderately wave-exposed rocky intertidal areas along the California coast decreased in size and abundance when exposed to greater wave energy in intertidal areas (Blanchette et al. 2000). Increased wave forces may limit the activity of mobile species, whereas a decline in wave energy may increase thermal and dessication stress because the intertidal habitat is not frequently dampened by wave splash or spray (Bertness et al. 2001). As a result of increased or reduced wave energy, progress towards successfully restoring a rocky habitat may be affected and modifications to the monitoring plan, such as extending the monitoring timeline to observe any changes in biota, may need to be considered.

Sampling and Monitoring Methods

Wave force meter - Waves can be measured by estimating cumulative water motion or maximum wave force directly. Wave force can be measured directly using a wave force meter (Bell and Denny 1994). This device is simple and inexpensive to construct, and can easily be used in large numbers. A number of recorders were used to quantify maximal daily water energy and velocities at three intertidal habitats on the central coast of California (Bell and Denny 1994). This device has proven to provide accurate estimates for wave energy in intertidal habitats. Wave energy can also be measured indirectly using biological indicators such as the presence of an indicator species, or physical indicators such as fetch or the distance that waves travel (Murray et al. 2002).

Wave buoys - Wave buoys are also used to assess wave energy. They are fixed at certain locations in the ocean and record information about wave conditions. Wave buoys use electronic sensors to measure wave heights, wave directions, and time periods between waves (Davies 1996). This method may be relatively expensive to use, so data gathered using this method, particularly near the potential restoration site, may be available from scientists in the field. Such data sharing encourages collaborative efforts between experts and other practitioners. Other sources that provide methods for measuring wave energy, direction, height, and periods include: Draper et al. (1974), Brumley et al. (1991), and AshokKumar and Diwan (1996).

Water Source

The health and growth of rocky habitat biological communities can be modified by water quality. In some instances, the source of water inflow entering rocky habitats may be polluted by effluents or metals, or may bring with it freshwater that dilutes salinity levels which in turn affects the rocky habitat biota (discussed further in the "Salinity" section of this chapter) (Ardisson and Bourget 1997). Sources responsible for negatively affecting the biological community of rocky habitats include:

- Pollutants from upland areas
- Increases in freshwater discharge from channels or creeks that have been diverted for various purposes (e.g., construction)
- Industrial discharges (e.g., heavy metals)

- Sewage outfalls, drains, and contaminated river flows, and
- Oil and chemical spills

By identifying the source of water input, the practitioner will be more prepared to handle impacts to the habitat and select parameters suitable for following progress of restoration efforts over time.

The biological community of rocky habitats can also be affected by degraded water quality as a result of turbidity or pollutants entering the habitats. Industrial effluent discharges, for example, can influence species diversity, abundance, and spatial distribution of the intertidal fauna (Littler and Murray 1975). Researchers assessed the effects of a low volume discharge of raw sewage on rocky marine intertidal communities near Wilson Cove, San Clemente Island, California. Results showed that near the outfall pipe, species diversity, standing stocks of large, canopy-forming intertidal macrophytes (which largely had been replaced by a low-growing algal turf) and an abundance of suspension-feeding animals were reduced. The most productive macrophytes, however, were those in the sewage outfall area (Littler and Murray 1974). In other cases, macroinvertebrate populations in rocky intertidal areas exposed to domestic sewage had higher energy contents than those in unpolluted areas and grazed greater proportions of blue-green algae and bacteria in the polluted area (Littler and Murray 1978). Other forms of pollutants such as industrial and agricultural chemicals as well as oil can also affect animals such as birds that breed along rocky habitats and feed on fish and molluscs there. If rocky habitats are polluted, some birds may migrate to more suitable feeding areas because organisms are no longer edible, thereby affecting the restoration project if the goal was to restore or maintain bird communities (Ferns 1993). Because of the tremendous impact that water quality has on the biological community of rocky habitats as well as restoration progress, water quality monitoring and water source identification should be considered when developing a restoration plan, as they can influence progress toward restoring a naturally sustainable rocky habitat.

CHEMICAL

Nutrient Concentrations

Nutrients that support rocky ecological communities are primarily from decayed plants and animals. In some cases, additional nutrients in the water may result from terrestrial runoff. Plant life such as algae can be found attached to rocks on the shorelines and on hard bottom substrates. Like other aquatic vegetative species, algae use the sun's energy to produce organic material that can be used by organisms. Other types of algae such as kelp that are found in deeper waters use their leaf blades to help recycle nutrients in the water column. Waves, currents and tides also distribute organic material throughout the water column for plant and animal use. For instance, kelp and other types of algae on rocky substrate absorb nutrients from the water while the nutrients are being transported by tides, etc., to support plant growth (see Chapter 5: "Restoration Monitoring of Kelp and Other Macroalgae" for more details).

Salinity

Salinity changes can affect rocky substrate biota, particularly in estuarine areas or close to the mouth of coastal rivers (Carriker 1967; Dethier and Schoch 2000; Murray et al. 2002), and thereby affect restoration progress. A decrease in salinity levels, for example, may be caused by precipitation (e.g., rainfall) or inflow of freshwater (e.g., diverted streams or channels) to estuaries and marine systems; an increase in salinity may occur as a result of chemical runoff. Such changes in salinity can shift the distribution and abundance of plants and animals that occupy rocky habitats (Ardisson and Bourget 1997; Witman and Grange 1998). If the goal of the restoration effort at a designated site is to increase or sustain vegetation and animals, a significant change in salinity can prevent this habitat from supporting biota and becoming naturally sustainable.

In estuaries along the Danish Straits, species diversity of marine benthic macroalgae declined due to reduced salinity levels compared to marine-freshwater green algae (Middleboe et al. 1997). Another study showed that reduced salinity levels in the shallow waters of a rocky fjord caused a decline in mussels (*Mytilus galloprovincialis)* and marine predators such as mobile invertebrates (Witman and Grange 1998). Large numbers of marine predators were seen just below the lower boundary of the low salinity levels (LSL) during February and April 1993. Approximately 20 to 80 percent of the mussel population was consumed below the LSL boundary, which indicates that the LSL represents a spatial refuge from predation. In some cases, salinity changes may indirectly affect intertidal communities, most notably plant and animal distribution and abundance, by affecting the toxicity of pollutants such as heavy metals (Vernberg and Vernberg 1974). Overall, changes in salinity levels within a rocky habitat being restored can ultimately affect restoration progress towards sustaining the habitat's biological community.

Measuring and Monitoring Methods

Refractometer - Salinity can be measured using a hydrometer, refractometer or a salinity meter. A refractometer is a hand-held instrument used to measure salinity. This instrument measures the bending of light between dissolved salts as it passes through seawater (Rogers et al. 2001). Salinity is measured on a calibrated refractometer by first placing a few drops of the seawater sample under the transparent slide, and then reading the salinity measurement through the eye piece (Rogers et al. 2001).

Hydrometer - A hydrometer is used to determine salinity by placing the instrument into a tall flask with the sample water and taking a reading at eye level at the water's surface, at the bottom of the meniscus[6] (Rogers et al. 2001). Hydrometers are typically calibrated for use at a specific temperature and a conversion chart must be consulted to estimate salinity of a sample taken at a different temperature (Rogers et al. 2001).

CTD Instrument - A conductivity, temperature, and depth (CTD) instrument can be used to measure salinity in deeper water. This instrument is lowered through the water column and continuously records conductivity, temperature, and depth. Salinity is then calculated in practical salinity units (psu) based on conductivity because electric current passes readily through waters that have higher salinity levels. Therefore if conductivity of the water is known, then salinity can be determined.

[6] The semi-circular-shaped surface at the edge of a liquid column.

FUNCTIONAL CHARACTERISTICS OF ROCKY HABITATS

The primary functions of rocky habitats include:

Biological

- Providing habitats and shelter for vegetation, fish, and invertebrates
- Providing breeding, feeding, and nursery grounds for many marine species
- Providing a hard structure for substrate attachment
- Providing refuge from larger predators

Physical

- Protecting coastal areas from erosion

By performing these functions, rocky habitats are able to support important recreational and commercial fisheries and their food sources, as well as maintain plant and animal diversity and abundance. Understanding how rocky habitats function is important to the success of restoration efforts. Monitoring should be performed to determine whether the habitat is functioning efficiently and to track the success of the restoration project or evaluate natural recovery. This section concentrates on the biological and physical functions performed by rocky substrates. Also provided are some methods to sample, measure, and monitor species affiliated with each of the functional characteristics. For example, rocky substrates may be used as breeding and feeding grounds by many species of animals. These functions can be estimated by counting the number of individual animals and identifying the species type using the habitat for these reasons. Not all functional characteristics described here, however, are expected to be measured. The following information illustrates the role each characteristic plays in the functioning of the habitat. Restoration practitioners must determine what functional characteristics should be monitored in order to meet the goals of their particular project.

BIOLOGICAL

Provides Habitat and Shelter

Rocky habitats provide shelter for many aquatic species. The crevices within the rocky shores shelter organisms such as snails, crabs (Figure 10), and lobsters. Oysters and mussels are also found on rocky substrates along the shoreline. Sessile species such as barnacles, tunicates, soft corals, and sea anemones attach to rocky substrates. Fishes such as striped bass and toadfish occupy rocky habitats that extend deep into the water. As these habitats have great species diversity and abundance, food must be readily available for all levels in the food chain.

Vegetation such as macroalgae is commonly found on rocky substrates in the intertidal and subtidal zones because these areas are not exposed to extreme light intensity, high temperatures, and desiccation as in upper shorelines (Barnes and Hughes 1988). Seaweed, for example, grows in both rocky intertidal and subtidal zones, although most seaweed biomass and productivity is subtidal. These macroalgae types also provide nutrition to mobile organisms that

Figure 10. Kelp crab (*Pugettia producta*) on rocky substrate. Photo courtesy of Russell Bellmer, Project Leader, United States Fish and Wildlife Service.

live throughout the tidal zone (similar to other species of macroalgae) and are tolerant to light and air exposure (Stephenson and Stephenson 1972; Barnes and Hughes 1988; Little and Kitching 1996). The most common seaweed types include red, brown, and green algae. Kelp species such as giant kelp (*Macrocystis*), bull kelp (*Nereocystis luetkeana*), and winged kelp (*Alaria marginata*) (Figure 11) are also present in subtidal rocky zones.

Species grow at different zones on the rocky shoreline. Seaweed *Microcladia coulteri,* for example, lives on other plants that inhabit rocks between the high intertidal and subtidal zones; feather boa kelp lives on rocks between the middle of the tidal zones; sea moss (green algae) grows between the high and middle intertidal zones (Little and Kitching 1996).

Measuring and Monitoring Methods

Vegetation - Percent cover of macroalgae can be determined using quadrats, with biomass determination requiring destructive sampling. A quadrat is a square, rectangular, circular, or other shaped area used as a sample unit. They can be used to identify and assess vegetation composition, species richness, abundance, and biomass in a given area. Quadrats can be fixed so that a sample area can be measured repeatedly (Albert and Lehman 2001; Murray et al. 2002), or sampled in combination with photography to determine the percent cover and evaluate species recovery (Choi et al. 2001).

Line transects - Line transects and plot-based sampling methods can also be used to study rocky intertidal macrophyte populations, as well as populations of animals such as mussels that may cover extensive areas of the substrate (Murray et al. 2002). The frequency and cover of macrophyte populations can be documented using these methods. If available, collected data can be compared with records from earlier studies to determine whether species composition and abundance have changed over time. Figure 12 shows researchers observing, measuring, and documenting growth of vegetation along an intertidal rocky habitat.

Many mobile and sessile organisms are also found either on the shoreline or ocean bottom. In some cases, some organisms can be found at both locations. Animals commonly found along rocky habitats (both in the intertidal and subtidal zones) include:

Figure 11. Boulder shoreline in central California. The lower shore is dominated by winged kelp, *Alaria marginata*. Photo courtesy of L. McConnico, NOAA Monterey Bay National Marine Sanctuary, California.

Figure 12. Researchers assessing growth of vegetation on an intertidal rocky habitat. Photo courtesy of Russell Bellmer, Project Leader, United States Fish and Wildlife Service.

- Limpets
- Chitons
- Crustaceans
- Lobsters
- Sea urchins (Figure 13)
- Hydroids
- Barnacles
- Fishes (Figure 14) (Barnes and Hughes 1988)

Provides Breeding Grounds

The rocky shores provide breeding grounds for birds, amphibians, reptiles, and fish. Following are several examples of the value provided by this habitat to different species of organisms. Many animals breed in various locations along rocky areas most suitable for them. Birds, for example, nest in crevices that are further inland on the shore to avoid being swept away by waves; amphibians and reptiles nest in moister areas with adequate protection to avoid predation; some fish breed in rocky habitats near upwelling areas where currents transport food. Garibaldi (*Hypsypops rubicundus*) prefer rocky bottom habitats in southern Baja California as breeding grounds (Sikkel 1998). From the shores of Baja, California to Alaska, the California sea lion (*Zalophus californianus*) uses rocky habitats as breeding grounds. The breeding population of *Z. californianus* along San Nicolas Island, California usually peaks at the beginning of July. During the 1969, 1970, and 1971 breeding seasons, at least 2957, 2271, and 3500 sea lion pups, respectively, were born on San Nicolas Island (Odell 1975).

Provides Feeding Grounds

Rocky habitats act as net exporters of nutrients to marine and terrestrial ecosystems (as feeding grounds). They provide food for sea and shore birds, otters, and other marine organisms. When marine organisms such as fish or algae die, they decompose and become detritus. Detritus forms the base of the food chain for soft-bottom habitats, and it serves as food for filter feeders, such as barnacles, in other habitats. Deposit- and filter-feeding worms, clams, and other invertebrates are food for birds and fish that forage along rocky habitats. The transfer of biomass from the rocky intertidal habitat to other habitats ties the health and productivity of kelp and rockweed in the rocky intertidal area to that

Figure 13. Sea urchins attached to rocky substrates. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

Figure 14. Black and yellow rockfish (*Sebastes chrysomelas*) seeking shelter within rocky substrates. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

of soft-bottom dwellers (e.g., dungeness crabs, *Cancer magister*) and flatfish (e.g., halibut, *Hippoglossus stenolepis*) (Lees et al. 1980; Sanger and Jones 1984; Alaska Department of Fish and Game 1993).

Crevices within rocky substrates may act as a food basin for many species. They also provide feeding grounds for resident organisms and non-permanent residents such as gulls, egrets and ducks, gulls, terns, and skimmers. Molluscs or small fishes occupy shallow water crevices along the shore, allowing easy access for birds to feed on them periodically. Barnacles, hydroids, oysters, and mussels also receive nutrients from incoming currents along the shore. Crustaceans and other invertebrates feed on the algae that are attached to the rock surface. Fish tend to feed on algae, sea urchins, bivalves, and shrimp species that are present (Vrtiska et al. 2003).

The rocky intertidal zone is also an important foraging area for the California sea otter (*Enhydra lutris*) which must live close to abundant food supplies to maintain their high metabolism. Otters use rocky shores as resting areas and for foraging on faunas such as shore crabs. The rocky intertidal zone is also a critical foraging area for waterfowl, such as black, surf, and white-winged scoters (*Melanitta nigra, M. perspicillata,* and *M. fusca*), and harlequin ducks (*Histrionicus histrionicus*) which feed predominantly on mussels (*Mytilus* spp.). While many shorebirds are associated with mudflats, surfbirds (*Aphriza virgata*) and black and ruddy turnstones (*Arenaria interpres* and *A. melanocephala*) prefer to forage on rocky substrates and gravel beaches (Alaska Department of Fish and Game 1993). Mammalian species such as rats, rabbits, deer, and even sheep will also forage on available rocky shores (Feare and Summers 1985).

Sea urchins (e.g., *Stronglyocentrotus* spp.) are common grazers of kelp that is attached to rocky substrates. Snails and small crustaceans also graze on kelp fronds. Limpets (*Ancylidae)* as well as other species of mollusks can also be found grazing on algae attached to rocky substrates (Forrest et al. 2001) (Figure 15). Researchers have recorded grazing activity of organisms such as gastropods on intertidal rocky substrates (Forrest et al. 2001). Grazing occurrences for limpets (e.g., *C. tramoserica)* are positively correlated to gastropod numbers in nearby areas during low tide. Densities of gastropods measured when limpets were inactive during low tide demonstrated good estimates of grazing activity throughout high tide.

Provides Nursery Grounds

Rocky habitats are important nursery areas for juvenile fauna such as fish. Rockfish (*Sebastes*

Figure 15. A limpet attached to rocky substrate. Photo courtesy of Russell Bellmer, United States Fish and Wildlife Service.

spp.) and other fish species use this habitat as nursery areas because food is readily available and the rocky structure provides protection for juveniles against predation and extreme tidal current (Carlson and Straty 1981). The rocky substrate is an important feature for nursery grounds, as well as the presence of algae that grows on the hard substrate. In some cases, the mat of algae growing on rocky substrates is also used by some species as nursery areas. Giant kelp (*Macrocystis pyrifera*) which form underwater forests and/or kelp beds attach to rocky substrates and provide nursery areas for reef fishes (Holbrook et al. 1990). These examples show that rocky substrates directly and indirectly support numerous fauna types, and therefore any disturbance to rocky substrates can disrupt their ecological community.

Provides Refuge from Predation

The crevices within rocky habitats provide protection against predation for some species such as polychaetes, crustaceans, and juvenile fish (Bertness et al. 2001). Gastropods and amphipods, for example, hide in crevices within the rocky substrates to avoid predation by fish (Wennhage and Pihl 2002). In some instances, the gastropod's shell color is similar to rock coloration and therefore, they are able to camouflage themselves. In the San Juan Archipelago, the acorn barnacle (*B. glandula*) seeks refuge from predation in the higher intertidal rocky shores (Schubart et al. 1995). Polychaetes and juvenile fish also seek refuge in crevices to avoid being preyed upon by birds.

Provides Substrate Attachment

Algae (e.g., kelp and other macroalgae) (Figure 16) are commonly found attached to rocky substrates (Schiel and Foster 1992). To maintain growth and reproduction, algae consume nutrients that are readily available in the water column. Rocky substrates not only provide a place of attachment for kelp, but kelp in turn provides attachment surfaces for many sessile and drifting life forms of various sizes. Some species such as barnacles, bryozoa, and foraminifera also attach themselves to leaves of kelp for support against currents (Hogan and Enticknap 2003). Blades of kelp also filter nutrients in the water column that can be utilized by sessile organisms attached to the kelp and

Figure 16. Rocks along the Massachusetts coast covered with the brown algae *Ascophyllum nodosum.* Photo courtesy of Mary Hollinger, NOAA National Oceanographic Data Center. Publication of NOAA Central Library. http://www.photolib.noaa.gov/coastline/line0738.htm.

rocky substrates. The most common sessile organisms found attached to rocky substrates and kelp include bryozoans, sponges, tunicates, cup corals, and anemones (Coates 1998; Carrington 2002). These organisms are able to grow by consuming nutrients that are transported by waves throughout the water column or washed onto the shore.

Sampling and Monitoring Methods

Practitioners should ensure that a restoration monitoring plan includes comparison sites, organisms to be sampled, and a sampling design. Once this is accomplished, sample distribution in space and time must be specified. It is not necessary to consider sample allocation in space if all individuals in the restored and comparison sites are sampled. In this case, the true population abundances are known, not estimated, and restored and comparison sites can be directly compared. Restoration or natural recovery sites may be so large that this cannot be done, except perhaps for species with very large individuals such as marine mammals or birds. For smaller species, it is usually necessary to estimate abundances from sub-samples taken within the restored and comparison areas. In BACI designs (as discussed previously in the 'Monitoring Designs for Quantitative Hypothesis Testing' section), it is often best to sample fixed (permanent) sub-areas that represent the entire site. These might be stratified depending on the distribution of the organisms to be sampled. In ACI designs, random allocation of samples is required if an estimate for the entire restoration site is desired. These may be allocated completely at random or at random within pre-defined strata. For example, it is well known that organisms occur within zones on rocky shorelines. If one knows that species X only occurs over a particular vertical range on a rocky shore, then species X should only be sampled within that range or stratum. If it is sampled in all zones, there will be many samples with zero abundance, the variance of the abundance estimates will increase, and the ability to detect change will decline.

Strata are commonly defined by first sampling along transects across the environmental gradient that directly or indirectly causes the stratification (e.g., vertical height on rocky shorelines, depth on subtidal rocky bottom) (see Choat and Schiel 1982 for sampling procedures). Other stratification may occur, such as designating crevices as a stratum because they are the only sub-habitat where abalone are found. Such strata within subtidal rocky habitats are often difficult to visually characterize because of poor visibility. Side-scan sonar can provide very accurate substrate characterizations, but may be difficult to use at depths less than 30 meters, particularly if there are seaweeds in the water column obstructing the sensor. Stratification can greatly increase the ability to detect changes, but requires a good understanding of the natural history of the habitat.

Allocation in time must also be considered, specifically how often and for how long monitoring should occur. In BACI designs, each sample time is a replicate, so sampling frequency is particularly important. In ACI designs, allocation in time might be roughly estimated from the literature on recovery for similar habitats. As mentioned earlier, recovery in rocky habitats seems to range from one to ten years, so planning to sample yearly for ten years might be a reasonable starting point.

Presented are several methods to sample, measure, and monitor various animal species in order to track their abundance, distribution, and diversity.

Fish - Purse seining can be used to sample fish along the shoreline. Purse seine nets are projected from land and used mainly in shallow waters close to the shoreline. The seine net is supported by floats, weights, and poles (Hart and Reynolds 2002). The floats keep the net afloat at the surface. The lower part of the net contains weights that sink the bottom of the net below the surface of the water. The net is then stretched out using poles that are attached on both sides of the net. Persons holding the net surround the shoal of fish and then pull the net ashore using the attached poles. Fish caught in the net are then identified and counted (Hart and Reynolds 2002).

Fish distribution and density estimates can be determined using belt-transect surveys, but such surveys require the use of scuba diving equipment in the shallow subtidal zone (Rogers et al. 2001). Survey nets can also be used to assess fish assemblages (Pihl et al. 1994). Samples of macrovegetation can also be collected with nets and used to compare fish assemblages with the vegetation biomass.

Underwater photography and baits/traps can be used to estimate fish and invertebrate densities and species composition in submerged intertidal rocky habitats. In some cases, macrofauna may be collected by trawling as well as hook and line fishing (Moore and Mearns 1980). Data collected using underwater photography (e.g., using a baited camera) can identify whether there is an increase in fish species abundance and density related to water column depth (Moore and Mearns 1980).

Marine Mammals - During aerial surveys, sea otter habitats may be classified as rocky, or sandy and rocky (Laidre et al. 2002). These animals may be radiotagged to calculate their maximum foraging depths and maximum distance from shore. These estimates may be used to approximate the offshore extent of sea otter habitat.

Aerial counts may be used to monitor the trend in numbers of seals along rocky habitats throughout each season (Frost et al. 1999). A linear model can then be developed to show the day, date, and time relative to tidal changes that significantly affected seal counts. This information will provide the practitioner with a good representation of the number of seals that generally occupy the rocky habitat and whether these numbers changed over time.

Invertebrates - Invertebrate density and cover can be assessed using video or digital cameras. A practitioner can select how frequent photographs are to be taken in designated areas within the restoration site over the length of the study. The images can then be analyzed by identifying species type and counting the number of organisms present in each image. Data collected from each image can then be compared to determine whether diversity of invertebrate abundance and distribution changed over time (see Murray et al. 2002).

Sampling units which include point quadrats and transects may also be used to define the spatial extent of the individual sample (Figure 17). Once strata are defined on rocky shorelines, the usual sample units are quadrats within which the abundances of organisms are determined. For organisms that occur as discrete individuals, such as sea stars, counts within the quadrats are the usual metric for abundance. The optimal quadrat size depends on the abundance and dispersion of the organism being sampled (Green 1979). If more than one species is counted in the same quadrat, some species will be sampled better than others (i.e., “one size does not fit all”). One solution to this problem is to use nested quadrats of different sizes. Many marine species such as some macroalgae, tunicates, and sponges spread by vegetative growth or are colonial, and individuals are very difficult to distinguish. Other species like barnacles can form very dense populations of small individuals. Percent cover is commonly used as the measure of abundance for these organisms. Counts and percent cover are usually done within the same quadrats. There are numerous ways to estimate cover, in part depending on how “layered” the organisms are. If a sample area has an overstory of 100

Figure 17. Sampling with count (number of individuals) and point quadrats (percent cover) in an intertidal mussel zone. Photo courtesy of Michael Foster, Moss Landing Marine Laboratories, California.

percent cover of seaweeds and an understory of barnacles, a single photo of the area cannot be used to estimate the cover of both seaweeds and barnacles. A good discussion of the various sampling units is included in Murray et al. (2002).

Quadrats are also used to define areas for destructive sampling for biomass estimates or to identify and count organisms too small or cryptic to be accurately counted in the field. To conduct destructive sampling, there should be good scientific justification (as discussed previously in the 'Deciding What to Monitor' section). Due to constraints such as wave and current motion, large plants in the water column, and time spent on the bottom with scuba diving equipment, intertidal sampling units must commonly be modified for efficient use underwater (examples in Coyer et al. 1999). Transects may also be used to collect field data by recording observations made or by collecting samples of species along a line or within a habitat. Line transects involve recording organisms in each sampling unit along the line (Murray et al. 2002).

The number of sample units taken within a particular restoration site or comparison site(s) are sub-samples, not true replicates of the "restoration" and "comparison" treatments. Sub-samples are important, however, because the number taken will affect the accuracy of the mean abundance estimate. It is the mean that is used in BACI analyses as described earlier, and the parameter that is usually used for similarity comparisons. Typically the number of samples needed to accurately define the mean can be found by plotting the mean versus the number of sub-samples used to calculate it and determining the number of sub-samples required for the mean value to stabilize. This number will change as the abundance changes in the restored area. A rough estimate can be obtained by pilot sampling in the comparison area. It is always better to take more rather than fewer samples.

PHYSICAL

Reduces Wave Energy and Erosion Potential

Rocky habitats act as a protective barrier against wave action and storms. As waves rush toward the shoreline, the rocky structure slows down the energy of the waves, thereby preventing erosion of the shoreline and elimination of the various ecological communities present. On upper rocky shores, for example, organisms that occupy rocky substrates cannot tolerate extreme wave energy compared to those located on the lower rocky shores. Thus, rocky structures help to reduce extreme wave energy before it reaches the upper portions of the rocky shores.

CHEMICAL

The chemical functions associated with rocky habitats are performed by epiphytes, algae, and filtering organisms that are found on the rocky substrates and *not* the rocks. These functions include modification of chemical water quality and dissolved oxygen, and supporting nutrient cycling. Chapter 5: "Restoration Monitoring of Kelp and Other Macroalgae" of this document provides detail information on the role of macroalgae in supporting rocky habitats.

PARAMETERS FOR MONITORING STRUCTURAL/FUNCTIONAL CHARACTERISTICS OF ROCKY HABITATS

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

Parameters to Monitor the Structural Characteristics of Rocky Habitats

Parameters to Monitor	Biological		Physical			Hydrological					Chemical	
		Habitat created by rocky substrates		Sediment grain size	Topography/Geomorphology		Currents	Tides/Hydroperiod	Water source	Wave energy		Nutrient concentration
Geographical												
Acreage of habitat types		●										
Biological												
Plants												
Species, composition, and percent cover of algae		●[7]										
Phytoplankton diversity and abundance		❍[8]										
Hydrological												
Physical												
Shear force at sediment surface							❍			❍		
Temperature									❍[8]			
Water column current flow and velocity							❍					
Wave energy									❍	●		
Chemical												
Salinity (in tidal areas)								●[9]	●[9]			
Toxics									❍			
Soil/Sediment												
Physical												
Basin elevations					❍							
Topography/Geomorphology (slope, basin cross section)					●							
Organic content					❍			❍				❍
Percent sand, silt, and clay					❍[7]							❍[7]
Sedimentation rate and quality				❍	❍		❍	❍				❍
Chemical												
Pore water nitrogen and phosphorus												❍[8]

[7] Key variable for rocky shore, alternative variable for rock bottom.
[8] Rock bottom habitat only.
[9] Key variable for rock bottom, alternative variable for rocky shore.

Parameters to Monitor the Functional Characteristics of Rocky Habitats

Functional Characteristics

Parameters to Monitor	Biological	Provides breeding grounds	Provides feeding grounds	Provides nursery areas	Provides refuge from predation	Provides substrate for attachment	Supports a complex trophic structure	Supports biomass production	Supports biodiversity	Physical	Reduces erosion potential	Reduces wave energy	Chemical	Modifies chemical water quality	Modifies dissolved oxygen	Supports nutrient cycling
Geographical																
Acreage of habitat types		●	●	●	●	●					●	●				
Biological																
Plants																
Species, composition, and % cover of:																
Algae		❍	❍	❍	❍	❍					❍	❍				
Herbaceous vascular		❍[7]	❍[7]	❍[7]	❍[7]	❍[7]					❍[7]	❍[7]				
Epiphytes		❍[8]	❍[8]				❍[8]	❍[8]	❍[8]					❍[8]	❍[8]	❍[8]
Invasives		❍	❍	❍	❍		❍		❍							
Interspersion of habitat types		❍	❍	❍	❍						❍	❍				
Phytoplankton diversity and/or abundance			❍[9]													
Plant health (herbivory damage, disease[9])			❍													
Biological																
Animals																
Species, composition, and % abundance of:																
Birds		●[7]	●[7]	●[7]	●[7]											
Fish		●[9]	●[10]	●[10]	●[10]											
Invasives			❍	❍	❍											
Invertebrates		●	●	●	●											
Hydrological																
Physical																
Fetch											❍[8]	❍[8]				
Current flow and velocity											❍[8]					
Wave energy		●	●	●	●						●					
Chemical																
Toxics		❍	❍	❍												
Soil/Sediment																
Physical																
Geomorphology (slope, basin cross section)		●	●	●	●	●					●					
Sediment grain size (OM[11]/sand/silt/clay/gravel/cobble)						❍					❍	❍				
Sedimentation rate and quality											❍					

[7] Key variable for rocky shore, alternative variable for rock bottom.
[8] Rock bottom habitat only.
[9] Key variable for rock bottom, alternative variable for rocky shore.
[10] Rocky shore habitat only.
[11] Organic matter.

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APPENDIX I: ROCKY HABITATS ANNOTATED BIBLIOGRAPHY

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

Addessi, L. 1994. Human disturbance and long-term changes on a rocky intertidal community. *Ecological Applications* 4: 786-797.

Author Abstract. The effects of human recreational activities on a rocky intertidal habitat on the coast of San Diego, California, USA were investigated. Organisms susceptible to collection for food, bait, or aquaria were identified and served as key species for the study of biota disturbance. This study examined three major aspects: (1) Distribution and activities of people along the shoreline were documented. (2) Distribution and density of echinoderms and molluscs inhabiting the cryptic underrock surface were sampled along an identified gradient of disturbance. (3) Densities of conspicuous organisms inhabiting the underrock surface at the most disturbed location detected in the spring of 1971 were compared with those detected in the spring of 1991. Surveys of human activity made during weekends with low tides exposing most of the intertidal zone (below 0 MLLW) during the daylight hours between December 1990 and August 1991 showed a definite pattern. People concentrated in an area with a 200 m radius centered on the primary accesses; areas farther from these points were less visited. The study site stood along a gradient of human disturbance, and the sampling of organisms along this indicated a gradient of biota disturbance as well. The density of all species was reduced in the more heavily visited intertidal area. The underrock community at the most heavily visited location changed substantially from spring 1971 to spring 1991. The density of most of macroorganisms decreased between the two dates, with the exception of the density of small gastropods, which increased. Even if more long-term studies are needed for determining the actual status of communities under the influence of human disturbance, the combination of spatial and long-term studies shows the importance of setting better policy and establishing more effective reserves in order to enhance and maintain species diversity and density.

Benson, B. L. 1989. Airlift sampler: Applications for hard substrata. *Bulletin of Marine Science* 44: 752-756.

Author Abstract. Airlift samplers (ALS) have been developed to efficiently and quantitatively sample subtidal benthic and epibenthic organisms. Washington State Department of Fisheries (WDF) biologists have used ALS's to collect quantitative samples of epibenthic organisms from natural and artificial reefs and benthic organisms from gravel substratum in Puget Sound, Washington. The primary advantage of ALS's, for these types of substrates, is their ability to collect the motile microinvertebrates (< 1 cm) missed by visual assessment and settling plate/substrate removal methods. ALS's used by WDF can collect organisms up to 5 cm in diameter. Operated by mobile divers, ALS's can sample with greater spatial precision and reach areas inaccessible to methods operated from surface vessels. Sampling capacity of an ALS is directly related to operating depth, sample mass and amount of compressed air available. Increasing depth or mass increases air consumption and generally reduces sampling capacity. See publication for additional information on the ALS method used to quantify subtidal benthic and epibenthic organisms.

Bokn, T. L, F. E. Moy and S. N. Murray. 1993. Long-term effects of the water-accommodated fraction (WAF) of diesel oil on rocky shore populations maintained in experimental mesocosms. *Botanica Marina* 36:313-319.

Author Abstract. The long-term effects of continuous doses (average hydrocarbon concentration = 129.4 mu g/L and 30.1 mu g/L) of the water-accommodated fraction (WAF) of diesel oil on 15 rocky littoral populations were determined at three tidal levels in experimental mesocosms over two years. At each tidal level, most species exhibited similar abundance changes in both oil-contaminated and control (average background hydrocarbon concentration = 5.6 mu g/L) mesocosms. Significant changes in species abundances attributable to oil (WAF) were demonstrated for only two of ten seaweeds and three of five invertebrates. Compared with the other mesocosms, significantly greater reductions in upper-level cover were recorded in the basin receiving the highest oil dosage for the seaweeds *Phymatolithon lenormandii* and *Fucus evanescens* together with lower recruitment of the barnacle *Semibalanus balanoides*. The mussel *Mytilus edulis* was strongly affected by the oil treatments and essentially disappeared from both oil-contaminated mesocosms. Numbers of the starfish *Asterias rubens* also fell to zero at the lowest tidal level in the basin receiving the highest oil dosage. There were no demonstrable differences in the abundance patterns of the gastropod *Littorina littorea,* the crab *Carcinus maenus*, and a total of eight brown (*Ascophyllum nodosum, Fucus serratus*, *F. vesiculosus*, *Laminaria digitata*), red (*Chondrus crispus*), and green (*Cladophora rupestris, Enteromorpha* spp., *Ulva lactuca*) seaweeds in the oil-contaminated compared with the control mesocosms.

Brosnan, D. M. and L. L Crumrine. 1994. Effects of human trampling on marine rocky shore communities. *Journal of Experimental Marine Biology and Ecology* 177:79-97.

Author Abstract. The effects of human trampling on two marine intertidal communities were experimentally tested in the upper-shore algal-barnacle assemblage and mid-shore mussel bed communities. On two shores, we trampled experimental plots 250 times every month for a year, and then allowed plots to recover for a further year. Results from the upper shore community showed that foliose algae were susceptible to trampling, and suffered significant declines shortly after trampling started. Canopy cover remained high in untrampled control plots. Barnacles were crushed and removed by trampling. Algal turf was resistant to trampling, and increased in relative abundance in trampled plots. In general the algal-barnacle community recovered in the year following trampling. In the mussel bed community, mussels from a single layer bed were removed by trampling. By contrast, mussels at a second site were in two layers, and only the top layer was removed during the trampling phase. However, mussel patches continued to enlarge during the recovery phase, so that by the end of the second year, experimental plots at both sites had lost mussels and bare space remained. Mussel beds did not recover in the 2 years following cessation of trampling. Control plots lost no mussels during the trampling and recovery phase. Barnacle and algal epibionts on mussels were significantly reduced by tramping. Overall, trampling can shift community composition to an alternate state dominated by low profile algae, and fewer mussels.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: Monitoring the Rocky Intertidal Communities Within the Gulf of the Farallones and the Northern Portion of the Monterey Bay National Marine Sanctuaries. Contact information: Jan Roletto, Gulf of the Farallones National Marine Sanctuary, San Francisco, CA 94123, Phone # (415) 561-6622 or Fax # (415) 561-, jrolletto@ocean.nos.noaa.gov: http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site04.html

Researchers have been conducting since 1995 a monitoring project on the rocky intertidal communities near Monterey Bay, south of Half Moon Bay approximately 20 miles. They collected baseline data on species abundance, diversity and distribution for assessment of natural and anthropogenic disturbances to rocky intertidal populations of algae and invertebrates. The site was assessed by establishing 12 quadrats (6 permanent and 6 stratified random quadrats) in the low, middle, and high algal zones. Each quadrat was 30 x 50 cm. A random point contact method (Foster et al. 1991) was used to assess species distribution, richness, and percent cover. Two photographs (f-stop of 5.6 and 8.0) were taken of each quadrat. Three 12 m transects were assessed at each location to determine the density of dominant species. Transects were positioned by a tape measure. Transects coincided with at least three permanent quadrats and a minimum of one transect began at the highest point devoid of vegetation and extended through each zone to the waterline. A 30 x 50 cm quadrat was placed at each meter mark and analyzed for presence/absence in the winter sampling and abundance measurements during the summer sampling. See contact or website for additional information on monitoring rocky shores.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: Successional and Seasonal Variation of the Central and Northern California Rocky Intertidal Communities as Related to Natural and Man-induced Disturbances. Mineral Management Service, Camarillo, CA. Contact information: Mary-Elaine Dunaway, Phone # (805) 389-7520, mary_elaine-dunaway@smtp.mms.gov. http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site12A.html

Researchers are conducting ongoing monitoring studies on rocky intertidal communities in areas influenced by natural and man-induced disturbances in Monterey Bay, CA. The first sample was taken March 13, 1984. Their objective was to supply the Mineral Management Service with a proposed Field Survey Plan for evaluating species composition and abundance of organisms and the effects of disturbance on organisms. Methods used include: Point-contact sampling along four vertical transects with descriptions of substrata and a map of transect locations; transects were arranged to cross over as many groupings as possible within each site in an area appropriate for field survey. See website or contact for additional information on methods used for monitoring rocky intertidal communities.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: A Quantitative Assessment of Human Trampling Effects on a Rocky Intertidal Community. Contact information: Kate Beauchamp, University of California at Davis, Davis, CA. http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site14B.html

Researchers conducted a quantitative assessment of rocky intertidal communities at the Natural Bridges site B, adjacent to Natural Bridges State Park, De Anza Mobile Estates and Long Marine Laboratories. Their objectives were to compare species diversity and density of organisms in an intertidal area with three levels of human usage and identify organisms that appear vulnerable to human trampling. Sampling was performed three consecutive days in December 1977 and three consecutive days in December 1978. Dominance diversity curves for animal numbers and wet weights of algae by season and site were constructed in twenty 10 x 10 cm plots and randomly placed within a 10 m^2 area within each of 3 sites. Each site experienced different levels of human disturbance (trampled, intermediate, untrampled). Plots were scraped of plants and animals and then collected. Shell lengths of mussels were also measured. *Pelvetiopsis limitata* was sampled in 24 random 1/4 m^2 plots with photos. Percent cover of *P. limitata* was determined by projecting slides on paper, tracing the outline of the algal covering and weighing the paper cut outs. Animals and algae were identified using Smith and Carlton (1975) and Abbott and Hollenberg (1976) respectively. See website or contact for additional information on quantifying the effects of trampling on rocky intertidal communities.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: Biodiversity of the Rocky Intertidal in the Monterey Bay National Marine Sanctuary: A 24-year Comparison. Institute of Marine Sciences, University of California, Santa Cruz, CA. Contact information: John Pearse, Phone # (831) 426-0542, pearse@biology.ucsc.edu. http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site14B.html

Pearse conducted quarterly sampling from fall 1971 to spring 1973 and from spring 1996 to spring 1997 throughout intertidal zones (site 15, Almar street, Monterey Bay Marine Sanctuary, CA) in order to evaluate biodiversity of the organisms there. The objective was to organize data collected in 1971 to 1973 on species found at selected rocky intertidal sites along the central California coastline and compare data with the data collected at the same sites during 1996 to1997. Data collected include: changes in species diversity, composition, and abundance. Students from the University of California at Santa Cruz resurveyed species richness in 1996 to 1997 at the same areas sampled in a 1971 to 1973 study. Relative abundance data on major plant and animal macroscopic taxa were taken. Relatively abundant, easily identified plants and animals abundance were estimated by counting absolute numbers or the number of 10 x 10 cm squares within a 50 x 50 cm quadrat that include the species. See website or contact for additional information on methods for evaluating biodiversity along rocky intertidal zones.

Fletcher, H. and C. L. J. Frid. 1996. Impact and management of visitor pressure on rocky intertidal algal communities. ECSA Meeting Special Issue. *Aquatic Conservation: Marine and Freshwater Ecosystems* 6: 287-297.

Author Abstract. Human trampling was investigated in order to quantify the 'recreational carrying capacity' of two rocky intertidal areas in northeast England. Estimation of 'recreational carrying capacity' was made by subjecting experimental plots in pristine areas of shore to different intensities of sustained trampling. The algal community was subsequently monitored for 16 months. Changes in algal community composition occurred at both sites at all intensities. Compositional changes were rapid (1-2 months) and timing was dependent on both trampling intensity and site. Trampling resulted in consistently reduced abundances of some species, for example fucoids, *Phymatolithon lenormandii* and turf species. Open space was present in greater quantities in trampled than untrampled plots. In the summer months, this was subsequently colonized primarily by *Enteromorpha* spp. Recreational carrying capacity is being exceeded in some areas at both sites in the summer months. Possible management strategies are discussed in the light of these experimental results.

Gilfillan, E. S., T. H. Suchanek, P. D. Boehm, E. J. Harner, D. S. Page and N. A. Sloan. 1995. Shoreline impacts in the Gulf of Alaska region following the *Exxon Valdez* oil spill. *Exxon Valdez* Oil Spill: Fate and Effects in Alaskan Waters, ASTM, Philadelphia, USA, pp. 444-481.

Author Abstract. Researchers sampled forty-eight sites in the Gulf of Alaska region (GOA-Kodiak Island, Kenai Peninsula, and Alaska Peninsula) in July/August 1989 to assess the impact of the March 24, 1989, *Exxon Valdez* oil spill on shoreline chemistry and biological communities extending hundreds of miles from the spill origin. Five of the Kenai sites and 13 of the Kodiak and Alaska Peninsula sites were sampled 16 months after the spill. Oiling levels at each site were estimated visually and/or quantified by chemical analysis. The chemical analyses were performed on sediment and/or rock wipe samples collected with the biological samples. Additional sediment samples were collected for laboratory amphipod toxicity tests. Mussels were collected and analyzed for hydrocarbon content to assess hydrocarbon bioavailability. Biological investigations at these GOA sites focused on intertidal infauna, epifauna, and macroalgae by means of a variety of common ecological techniques. For rocky sites the percentage of hard substratum covered by biota was quantified. At each site, up to 5 biological samples (scrapes of rock surfaces or sediment cores) were collected intertidally along each of 3 transects, spanning tide levels from the high intertidal to mean-lowest-low-water (zero tidal datum). Organisms (down to 1.0 mm in size) from these samples were sorted and identified. Community parameters including organism abundance, species richness, and Shannon diversity were calculated for each sample. As expected for shores so far from the spill origin, oiling levels were substantially lower, and beached oil was more highly weathered than in Prince William Sound (PWS). Samples of oiled GOA shoreline sediment were not statistically more toxic in bioassay tests than sediment from unoiled reference sites. As a consequence of the lower oil impact, the biological communities were not as affected as those in the sound. Biological impacts, although present in 1989 in the GOA, were localized, which is consistent with the patchy and discontinuous nature of much of the oiling in GOA. Some organisms were locally reduced or eliminated in oiled patches but survived in unoiled patches nearby. In areas where oiling occurred, impacts were generally limited to middle and upper intertidal zones. Analyses of mussel samples indicate that by 1990 little of the shoreline oil remained bioavailable to epifauna. Quantifiable measures of the overall health and vitality of shoreline biological communities, such as organism abundance, species richness, and Shannon diversity for sediment infauna, show few significant differences between oiled and reference sites in 1990.

Hawkins, S. J. and R. G. Hartnoll. 1983. Changes in a rocky shore community: An evaluation of monitoring. *Marine Environmental Research* 9:131-181.

Author Abstract. The basic aim of this study was to record the changes in the communities on a moderately exposed rocky shore by a program of repeated nondestructive sampling ('monitoring') and to determine the causes of these changes. Possible causative factors were investigated by the combined approach of analysing detailed sea-temperature and meteorological data for the period of the study and establishing manipulative field experiments. Fixed quadrats (2 m by 1 m) at three levels were visited at 6-8 weekly intervals for 30 months and the abundance and spatial pattern of major species assessed. Only certain of the changes could be atributed to the physical environmental-most were biologically controlled. For example, manipulative experiments showed that the blooms for ephemeral algae and the decline of *Patella* in the high-shore quadrat, and the decline of *Actinia* in the mid-shore quadrat, were due to decreases in the fucoid canopy. The conclusion must be that the monitoring of rocky shores as a means of detecting and measuring pollution is likely to be an unproductive investment of time and resources.

Lopes, C. F., J. C. C. Milanelli, V. A. Prosperi, E. Zanardi and A. C. Truzzi. 1997. Coastal monitoring program of Sao Sebastiao Channel: Assessing the effects of 'Tebar V' oil spill on rocky shore populations. *Marine Pollution Bulletin* 34:923-927.

Author abstract. Due to a pipeline rupture on May 15th 1994, 2700 m^3 of a crude oil reached the sea, affecting rocky shore communities, which have been monitored since 1993. These biological data, analyzed by BACI approach, were integrated to chemical and toxicological analysis of the oil. BACI approach can also be used to analyze data during and after restoration efforts have been completed. This will provide information on the status (survival and growth) of fauna and flora communities on the rocky shore. Results of Student's t-test did not indicate a significant difference between the percent cover average of the monitored populations (mussels and barnacles) from samples taken before and after the oil spill. The acute and chronic toxicity tests showed high toxicity of the oil. The lack of stress (i.e., mortality) on the populations can be mainly associated to: the sampling area was not highly contaminated despite the great amount of oil which reached surrounding areas; there were not enough physical (smothering) or chemical (toxicity) effects of the oil to alter the density of the populations which are considered moderately resistant to oil.

Miller, A. W. and R. F. Ambrose. 2000. Sampling patchy distributions: Comparison of sampling designs in rocky intertidal habitats. *Marine Ecological Progress Series* 196:1-14.

Author Abstract. Any attempt to assess species abundances must employ a sampling design that balances collection of accurate information for many species with a reasonable sampling effort. To assess the accuracy of commonly used within-site sampling designs for sessile species, we gathered cover data at 2 rocky intertidal locations in Southern California using a high-density point-contact method that maintained the spatial relationships among all points. Different sampling approaches were compared using simulated sampling. Different sampling units (single points, line transects, and quadrats) were modeled at high and low sampling efforts. Sampling units were either distributed randomly or with stratified random methods. Sampling accuracy was assessed by comparing cover and species richness estimated by the sampling simulations to the actual field data. Randomly placed single point-contacts provided the best estimates of cover but are usually not logistically feasible in the rocky intertidal, so ecologists typically use quadrats or line transects. With quadrats, some form of stratified random sampling usually gave estimates that were closer to known values than simple random placement. In nearly all stratified cases, optimum allocation of sample units, where quadrats are allocated among strata according to the amount of variability within each stratum, yielded the most accurate estimates. With 1 exception, line transects placed perpendicular to the elevational contours (vertical transects) approached or exceeded the accuracy of the best stratified quadrat efforts. The estimates for rare species were consistently poor since sampling units often missed such species altogether, suggesting a systematic bias. Species richness was substantially underestimated by all sampling approaches tested, whereas these same approaches accurately estimated diversity (H'). These results illustrate the difficulty of obtaining accurate cover estimates in rocky intertidal communities.

Minerals Management Service Program. 2001. Shoreline Rocky Intertidal Monitoring. United States Department of the Interior, Coastal Marine Institute of University of California, Santa Barbara, University of California, Santa Cruz and University of California, Los Angeles. Contact information: Mary.Elaine.Dunway@mms.gov, http://www.mms.gov/eppd/sciences/esp/profiles/pc/PC-00-02-03-04-05.htm

Researchers conducted studies monitoring the health of rocky intertidal habitats along the mainland of Southern California adjacent to oil and gas activity. Data was collected as field notes, slides and videotaped, and were analyzed and placed in a database.

Photos, counts, and measurements of selected species (e.g., black abalone, owl limpets, and seastars) were collected at four sites in San Luis Obispo County, four sites in Orange County, two sites in Ventura County and nine sites in Santa Barbara County. Minerals Management Service (MMS) biologists assisted with collecting data in Santa Barbara and Ventura Counties. Slides are scored and maintained at the respective University campuses. The role of the university scientists and trained technicians is to maintain field equipment, write annual and three-year reports and participate in MARINE committees.

Data collected by several MMS funded efforts and the MMS Intertidal Team allowed MMS to understand the interaction between oil and rocky intertidal resources and provided linkages between academic institutions. See contact for additional information on the project conducted.

Pagola-Carte, S. and J. I. Saiz-Salinas. 2001. Changes in the sublittoral faunal biomass induced by the discharge of a polluted river along the adjacent rocky coast (N. Spain). *Marine Ecology Progress Series* 212:13-27.

Author abstract. Sublittoral hard bottom assemblages such as rock bottoms in the 'Abra de Bilbao' Bay (N. Spain) were described in terms of biomass in order to record spatial changes on scales of a few km that reflect the prevalence of perturbation gradients. This method is useful for not only monitoring rock bottom communities after anthropogenic impacts but also for restoration monitoring of rock bottom communities to evaluate the gradual increase or decrease in functionality of the habitat. Several criteria and levels of data aggregation were proposed and tested in an attempt to obtain information on the degree of redundancy achieved by such communities for further monitoring programs. The area of study is at present recovering from a highly stressed situation of turbidity and sedimentation. In this way, the fauna/flora biomass ratio (AN) proved to be a useful descriptor indicative of several environmental conditions from healthy to grossly perturbed on rocky communities. See publication for additional information on methods used for evaluating faunal biomass in hard bottom communities. In addition, the high degree of redundancy shown by the macrozoobenthos allows efforts to be concentrated on only the faunal component, using different approaches and data aggregation levels. As a result, the cost-effectiveness of monitoring programs could increase considerably. Moreover, the use of several techniques (univariate, multivariate) and approaches (taxonomic, trophic, mixed) is recommended for the monitoring of hard bottom communities, in order to test the robustness of the results obtained and achieve other complementary perspectives upon the biota with the same data sets. In this case study, relevant information was acquired on the possible temporal changes of intermediate zones of the 'Abra de Bilbao' due to the biological recovery of the area. Therefore, an adequate combination of biomass values and the concepts of redundancy-sufficiency is suggested as a realistic way of developing future monitoring programs for rock bottoms along with other hard bottoms in various areas.

Renones, O., J. Moranta, J. Coll and B. Morales-Nin. 1997. Rocky bottom fish communities of Cabrera Archipelago National Park (Mallorca, Western Mediterranean). *Scientia Marina* (Barcelona) 61: 495-506.

Author Abstract. In the present study, the fish communities of the rocky bottoms of Cabrera Archipelago (Balearic Islands) are analyzed and provide data for future evaluation and monitoring of any changes produced by management or during restoration projects. Visual counts were carried out by diving along transects situated in areas of rocky blocks at depths of -10 m, -25 m and -41 m and at vertical cliffs -15 m deep. In the 10 stations studied, 48 species belonging to 19 families have been recorded. The increase in depth principally produced a specific impoverishment and a decrease in the density of mesophagous and macrophagous carnivore species. This tendency became more noticeable changing from the infralittoral to the circalittoral stage. In the infralittoral stage the substrate rugosity was a more important factor than depth in the structure of the fish community. However, other specific characteristics of each zone such as algal cover, hydrodynamic conditions and fishing pressure, as well as habitat changes with size of some species, also affected the specific composition and demographic structure of the fish community.

Roletto, J., N. Cosentino, D. A. Osorio and E. Ueber. 2000. Rocky intertidal communities at the Farallon Islands, pp. 359-362. In Browne, D. R., K. L. Mitchell and H. W. Chaney (eds.), Proceedings of the Fifth California Islands Symposium. U. S. Department of the Interior, Minerals Management Service, Pacific OCS Region 770 Paseo Camarillo, Camarillo, CA.

Author Abstract. The rocky intertidal communities of the Farallon Islands, within the Gulf of the Farallones National Marine Sanctuary, have been monitored since 1993. Methods used included point-frames, haphazard shore search, and photographic recording. A total of 221 taxa have been documented. Eight species are considered to be rare in this region or outside the limit of their normal range: *Branchioglossum undulatum, Myriogramme variegata*, *Cirrulicarpus* sp., *Hommersandia palmatifolia, Lithophyllum proboscideum, Mazzaella cornucopiae, Peyssonnelia pacifica*, and *Ulva conglobata.* Three algal species commonly found on the California mainland, *Fucus gardneri, Pelvetia fastigiata,* and *Pelvetiopsis limitata*, were not observed on any of the Farallon Islands. The mean annual percent cover for algae and sessile macroinvertebrates at the South Farallon Islands ranged from 122 to 255%. *Corallina, Mazzaella, Ulva, Mastocarpus, Mytilus,* and *Anthopleura* were the dominant taxa found on the islands. Algal species known to be negatively impacted by oil spills are common and abundant on the Farallon Islands. These sites can be used as either controls or to monitor the effects of recovery of the intertidal zones after an oil or diesel spill.

Schoch, G. C. and M. N. Dethier. 1996. Scaling up: The statistical linkage between organismal abundance and geomorphology on rocky intertidal shorelines. *Journal of Experimental Marine Biology and Ecology* 201:37-72.

Author Abstract. The objective of this study was to test for a statistical relationship between species abundance and a suite of physical factors so that inferences can be made about species distributions over large spatial scales if geomorphology is known. This has application to oil spill damage assessments, inventory and monitoring programs, global change and biodiversity studies where economical or logistical constraints dictate a reliance on data collected from relatively localized areas but there is a need to extrapolate to broad spatial scales. Complex shorelines can be partitioned into relatively distinct segments with generally homogenous abiotic characteristics. These segments can be characterized using common geomorphological parameters, thus differentiating horizontal (among-segment) and vertical (within-segment) characteristics. Shoreline segments with similar characteristics can then be statistically clustered into groups of like habitats. This technique was applied to 5 km of rocky shoreline on San Juan Island, Washington and then analyzed the relationship between 3 clusters of geomorphologically homogenous shoreline segments and local floral and faunal abundances. Using standard transect techniques at 3 elevations, we compared the variance in abundance of organisms (i) among 3 transects within one homogenous shoreline segment selected from a moderate-angle bedrock segment cluster; (ii) among 3 shoreline segments from the same moderate-angle bedrock cluster; and (iii) among 3 separate clusters representing low-angle, moderate-angle and high-angle bedrock segments. Researchers hypothesized that variance in organismal abundance would be low among transects and among similar segments but high among segments from different clusters. See publication for additional information on techniques used for determining organism abundance on rocky intertidal shorelines.

Sousa,W. P. 1979a. Disturbance in marine intertidal boulder fields: The non-equilibrium maintenance of species diversity. *Ecology* 60: 476-497.

Author Abstract. Small boulders, with a shorter disturbance interval, support only sparse early successional communities of the green alga, *Ulva* and barnacles. Large, infrequently disturbed boulders are dominated by the late successional red alga, *Gigartina canaliculata*. Intermediate-sized boulders support the most diverse communities composed of *Ulva*, barnacles, several middle successional species of red algae, and *G. canaliculata*. Comparison of the pattern of succession on experimentally stabilized boulders with that on unstable ones confirms that differences in the frequency of disturbance are responsible for the above patterns of species composition. The frequency of disturbance also determines the degree of between-boulder variation in species composition and diversity. Small boulders sample the available pool of spores and larvae more often. As a result, a greater number of different species occur as single dominants on these boulders. Boulders with an intermediate probability of being disturbed are most variable in species diversity. Observations on the local densities of 3 species of middle successional red algae over 2 yr-long periods indicate that most of these are variable in time. More local populations went extinct or became newly established on boulders than remained constant in size. These species persist globally in the boulder field mosaic by colonizing recent openings created by disturbances. These results lend support to a nonequilibrium view of community structure and, along with other studies suggest that disturbances which open space are necessary for the maintenance of diversity in most communities of sessile organisms. See publication for additional information on techniques used for evaluating marine intertidal boulder field disturbances.

Sousa, W. P. 1979b. Experimental investigations of disturbance and ecological succession in a rocky intertidal algal community. *Ecological Monograph* 49: 227-254.

Author Abstract. Mechanisms of ecological succession were investigated by field experiments in a rocky intertidal algal community in southern California. The study site was an algal-dominated boulder field in the low intertidal zone. The major form of natural disturbance which clears space in this system is the overturning of boulders by wave action. Algal populations recolonize cleared surfaces either through vegetative regrowth of surviving individuals or by recruitment from spores. Boulders which are experimentally cleared and concrete blocks are colonized within the first month by a mat of the green alga, *Ulva*. In the fall and winter of the first year after clearing, several species of perennial red algae including *Gelidium coulteri, Gigartina leptorhynchos, Rhodoglossum affine*, and *Gigartina canaliculata* colonize the surface. If there is no intervening disturbance, *Gigartina canaliculata* gradually dominates the community holding 60-90% of the cover after a period of 2 to 3 years. If undisturbed, this monoculture persists through vegetative reproduction, resisting invasion by all other species. During succession diversity increases initially as species colonize a bare surface but declines later as one species monopolizes the space. Several contemporary theories concerning the mechanisms of ecological succession were tested. The early successional alga, *Ulva*, was found to inhibit the recruitment of perennial red algae. Selective grazing on *Ulva* by the crab, *Pachygrapsus crassipes*, accelerates succession to a community of long-lived red algae. Grazing by small molluscs, especially limpets, has no long-term effect on the successional sequence. See publication for additional information on techniques used for evaluating rocky intertidal disturbances.

Stekoll, M. S. and L. Deysher. 1996. Recolonization and restoration of upper intertidal *Fucus gardneri* (Fucales, Phaeophyta) following the *Exxon Valdez* oil spill. *Hydrobiologia* 326-327: 311-316.

Author Abstract. The *Exxon Valdez* oil spill in March 1989 and subsequent cleanup caused injury to intertidal *Fucus gardneri* populations especially in the upper intertidal. A survey in 1994 in Prince William Sound, Alaska showed that the upper boundary of *Fucus* populations at oiled sites was still an average of 0.4 m lower than the upper boundary at unoiled sites. Restoration of severely damaged *Fucus* populations was started on a small-scale at a heavily oiled rocky site in Herring Bay, Prince William Sound. Experiments employed mats of biodegradable erosion control fabric to act as a substratum for *Fucus* germlings and to protect germlings from heat and desiccation stress. A series of plots was covered with mats made from a resilient coconut-fiber fabric in June 1993. Half of the mats were inoculated with *Fucus* zygotes. A series of uncovered control plots was also monitored. There was no enhancement of *Fucus* recruitment on the rock surfaces under the mats. Dense populations of *Fucus* developed on the surface of all of the mats by the summer of 1994. The natural rock surfaces in the control plots, both inoculated and not, were barren of macroscopic algal cover. By September 1994, the juvenile thalli on the mats were approximately 2 cm in length. Inoculating the mats had an effect only in the upper region of the intertidal. It is expected that the thalli will become fertile during the 1995 season. These thalli may serve as a source of embryos to enhance the recovery of new *Fucus* populations in this high intertidal area.

Teruhisa, K., N. Masahiro, K. Hiroshi, Y. Tomoko, M. L. Research and O. Kouichi. 2003. Impacts of the Nakhodka heavy-oil spill on an intertidal ecosystem: An approach to impact evaluation using geographical information. *Marine Pollution Bulletin* 47: 99-104.

Author Abstract. A major heavy-oil spill from the Russian tanker Nakhodka occurred in the Sea of Japan on 2 January 1997. Researchers investigated the impacts of this spill on a rocky intertidal ecosystem along the southern coast of the Sea of Japan. They selected Imago-Ura Cove as our study site to observe temporal changes along the oiled shore, because minimal cleaning effort was made in this area. Field surveys were conducted every autumn and spring from 1997 to 2000. Researchers measured coverage by macroalgae in 1x1-m^2 quadrats and counted the animals in 5x5-m^2 quadrats along the intertidal zone. Changes in the ecosystem caused by the oil spill were analyzed by applying a geographical information system (GIS) to the Sea of Japan for the first time. The GIS showed that following the accident there were heavily oiled areas in sheltered regions, but these decreased over the three years. It also showed that coverage by macroalgae and the number of animals increased, although some species of algae with microscopic sporophyte generations, and some populations of perennial shellfish, remained stable or decreased during the study period. GIS was able to trace temporal changes in intertidal communities resulting from the impacts of heavy oil on flora and fauna at a spatial scale of 10-100 m. GIS is thus a practical tool for visualizing, analyzing, and monitoring changes in an ecosystem polluted by oil, taking into account topographic differences along the coastline. The methods used here not only allows the impact to be evaluated but will also allow restoration efforts that are performed to be monitored and evaluated on rocky shores.

Zhuang, S., K. Wang and L. Chen. 2001. Study on invertebrate communities in rocky intertidal zones influenced by human activities. *Journal of Oceanography of Huanghai and Bohai Seas/Huangbohai Haiyang Qingdao* 19: 54-64.

Author Abstract. Researchers found that *Chthamallus challengeri* was the most dominant species in rocky intertidal communities, and the dominance and function of chief dominant species (*Ostrea denselamellosa, Littorina brevicula, Vignadula atrata, Mytilus edulis*) and common species (*Patelloidae spp., Acanthochiton rubrolineatus, Nereis spp., Anthopleura spp*.) show marked differences, though the faunal composition in the community at 6 stations seemed similar. Three kinds of K-dominance curve based on Riv, RB and RD were used in the study. It was noticed that RB- and RIV-K-dominance curves were more useful to interpret the variation in species diversity and community structure, which was imposed by disturbance and pollution, and the result showed that all communities at 6 investigated stations were disturbed and polluted by human activities though those at Zhifu Islet and Yangma Islet were less disturbed. It was also suggested that the community diversity index ($H_{B'}$ sub(B'), $H_{IV'}$, J) based on RB and RIV were suitable for illustrating the community structure and population distribution, and the 6 stations arranged in order of magnitude of H' value to be Zhifu Islet, Yangma Islet, Shigoutun, Yantai Hill, Yudai Hill and Moon Bay. The variations in community composition and structure in the investigated intertidal zones resulted mainly from human activities such as collection, tourism, water eutrophication and urban sewage discharge. For additional information on methods used for monitoring invertebrates on disturbed rocky shorelines see publication.

APPENDIX II: ROCKY HABITATS
REVIEW OF TECHNICAL METHODS MANUALS

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

Babcock, M. M., G. V. Irvine, P. M. Harris, J. A. Cusick and S. D. Rice. 1996. Persistence of oiling in mussel beds three and four years after the Exxon Valdez oil spill, pp. 286-297. In Rice, S. D., R. B. Spies, D. A. Wolfe, B. A. Wright (eds.), Proceedings of the Exxon Valdez Oil Spill Symposium. American Fisheries Society Symposium 18.

Author Abstract. Dense beds of the mussel *Mytilus trossulus* affected by Exxon Valdez crude oil in Prince William Sound and along the Kenai and Alaska peninsulas were intentionally left untreated during shoreline cleanup activities in 1989-1991. In 1992 and 1993, mussels and sediments from 70 mussel beds in Prince William Sound and 18 beds along the Kenai and Alaska peninsulas were sampled to establish the geographic extent and intensity of Exxon Valdez oil persisting in mussel beds. Sediments collected in 1992 and 1993 from 31 of the oiled mussel beds in the sound had total petroleum hydrocarbon (TPH) concentrations greater than 10,000 mu g/g wet weight. The highest concentrations were in sediments collected from Foul Bay (62,258 plus or minus 1,272 mu g TPH/g, mean plus or minus SE). Five of the 18 beds sampled along the Kenai Peninsula showed sediment TPH concentrations greater than 5,000 mu g/g. The mean concentration of total polynuclear aromatic hydrocarbons (TPAH) in mussels from these same beds ranged up to 8.30 plus or minus 0.26 mu g/g (Squirrel Island) in Prince William Sound and 4.01 plus or minus 1.54 mu g/g along the Kenai Peninsula (Morning Cove, Pye Islands). Polynuclear aromatic hydrocarbon fingerprints of mussel tissue collected from surveyed sites indicated the contaminant source was Exxon Valdez oil. In 1993, mean TPH concentrations in sediments and mean TPAH concentrations in mussels were lower by more than 50% compared with these concentrations in 1992. Some beds showed little reduction in oil. Almost all the beds showing only small decreases in hydrocarbons were in protected, low-energy areas, where there probably was little remobilization of residual oil underlying the beds. This study has produced analytical evidence showing that substantial residual Exxon Valdez oil persists in sediments underlying mussel beds in the area affected by the spill. Residual crude oil is a source of chronic contamination of mussels and their predators. In the more-protected intertidal areas, natural flushing and remobilization of Exxon Valdez oil will be slow; some of these mussel beds potentially can be manually cleaned.

Davies, J., J. Baxter, M. Bradley, D. Connor, J. Khan, E. Murray, W. Sanderson, C. Turnbull

and M. Vincent. 2001. Marine Monitoring Handbook. UK Marine Science Project, and Scottish Association of Marine Science. Joint Nature conservation Committee, English Nature, Scottish Natural Heritage, Environment and Heritage Services, http://www.jncc.gov.uk/marine/mmh/Introduction.pdf.

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

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

Author abstract. Natural resource managers need to understand the natural functioning of and threats to ecosystems under their management. They need a long-term monitoring program to gather information on ecosystem health, establish empirical limits of variation, diagnose abnormal conditions, and identify potential agents of change. The approach used to design such a program at Channel Islands National Park, California, may be applied to other ecosystems worldwide. The design of the monitoring program began with a conceptual model of the park ecosystem. Indicator species from each ecosystem component were selected using a Delphi approach. Scientists identified parameters of population dynamics to measure, such as abundance, distribution, age structure, reproductive effort, and growth rate. Short-term design studies were conducted to develop monitoring protocols for pinnipeds, seabirds, rocky intertidal communities, kelp forest communities, terrestrial vertebrates, land birds, terrestrial vegetation, fishery harvest, visitors, weather, sand beach and coastal lagoon, and terrestrial invertebrates (indicated in priority order set by park staff). Monitoring information provides park and natural resource managers with useful products for planning, program evaluation, and critical issue identification. It also provides the scientific community with an ecosystem-wide framework of population information.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: Recovery of Rocky Intertidal Assemblages Following the Wreck and Salvage of the F/V Trinity. Monterey Bay National Marine Sanctuary, Monterey, CA. Contact information: Andrew DeVogelaere, Phone # (831) 647-4213, andrew.p.devogelaere@noaa.gov. http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site19.html

Researchers Foster, Walder and DeVogelaere performed recovery efforts of rocky intertidal assemblages. Recovery efforts were done 100 m south of Point Pinos on Trinity wreck site. The recovery of the F/V Trinity, a 51-foot steel hull seiner, on April 20, 1996 resulted in 251 m^2 of physical and 287 m^2 of chemical influence to the rocky intertidal habitat. Researchers investigated biological damage and recovery. They also tested a potential restoration technique to enhance recovery. Evaluations were made on low intertidal surf grass, mid intertidal mussel and mid/high intertidal red algae assemblages. Recovery rates within surf grass, mussel, and red algal assemblages were determined by sampling species composition and percent cover of sessile organisms in 0.25 x 0.25 m plots within areas where new rock surfaces were exposed. Sampling was performed in June, August, and December of 1996, June and December of 1997 and June 1998. Plots were established on recently disturbed horizontal rock surfaces in the surf grass, mussel and red algal assemblages. Each disturbed plot was matched with a control plot (wreck control) that was placed in the undamaged habitat adjacent to disturbed plots and another (spill control) was placed outside the potential chemical spill area for comparisons to be made. Point quadrat technique described by Foster et al. (1991) was used to determine percent cover. Plots were photographed in June 1996 and every June following to show temporal change. Recovery of rubble beds, newly exposed vertical rock surfaces and sand plots were qualitatively assessed. Additional information on methods used can be retrieved from this reference.

DeVogelaere, A. P., M. Jacobi, R. Walder and M. Foster. 1999. A Summary of Rocky Shore Monitoring Projects in the Monterey Bay National Marine Sanctuary: Rocky Intertidal Monitoring Protocols. Monterey Bay Fitzgerald Marine Reserve, Moss Beach, CA.. Contact Information: Bob Breen, Phone # (415) 728-3584. http://montereybay.nos.noaa.gov/research/techreports/rockyshores99/rocky99_site01B.html

Researchers are conducting ongoing research on rocky intertidal shoreline which began 1995 on the Fitzgerald reserve - B, near Monterey Bay in California. Their objectives are to monitor changes in the intertidal communities due to human impacts such as trampling. Seven monitoring sites were selected of 100 square meters each. Barriers were placed around three of the experimental sites at every low tide and restricted from public access. The remaining four are used as control sites and are not restricted from access. Two of the control sites are mussel beds. Sites are surveyed monthly for species abundance using PVC quadrats and photoquadrats are to be taken periodically of the sampling area. See contact for additional information on techniques used for monitoring rocky shores. Data that has already been collected since 1995 can be obtained by getting in touch with the contact person mentioned above.

Harris, R. R., S. D. Kocher, J. Gerstein, F. Kearns, D. Lindquist, D. Lewis, J. Leblanc, W. Weaver and N. M. Kelly. 2002. Monitoring Fish Habitat Restoration Project. California Coastal and Salmonid Restoration Monitoring and Evaluation Program. University of California, Berkley, Center for Forest and Center for the Assessment and Monitoring of Forestry Environmental Resources. Draft Final Report to the Department of Fish and Game. http://www.dfg.ca.gov/nafwb/pubs/2003/200303_Interim_Protocol_Manual.pdf

This document provides monitoring protocols for fish habitat restoration projects such as rock bottoms. Projects conducted were designed to: improve fish movement through streams or prevent fish from entering man-made facilities, develop better conditions for one or more fish life stages, prevent erosion and sediment transportation through streams, control planting of vegetation (e.g., removal of exotic plants), and improve management practices. The types of monitoring performed included: implementation monitoring to evaluate whether or not a specific action has occurred as planned; effectiveness monitoring to evaluate whether or not the implemented action has yield preferred effects; validation monitoring in which a model is used to predict performance or events is evaluated; and trend monitoring in which ecological and environmental changes over time are evaluated. Monitoring protocols include: photography timing, field sampling, and permanent markers for photo points. Timing refers to sequential photographs being taken over time to show changes in site conditions. Photo field sampling is performed when a site consists of many features (e.g., road improvements, crossing streams, rolling dips, or riparian plantings). These photos provide a good representation of the site. Permanent markers are used to easily relocate photo points for subsequent photographs. Additional information on methods used can be obtained from this report.

Minerals Management Service Program. 2001. Shoreline Rocky Intertidal Monitoring. United States Department of the Interior, Coastal Marine Institute of University of California, Santa Barbara, University of California, Santa Cruz and University of California, Los Angeles, CA. Contact information: Mary.Elaine.Dunway@mms.gov. http://www.mms.gov/eppd/sciences/esp/profiles/pc/PC-00-02-03-04-05.htm

Researchers conducted studies monitoring rocky intertidal sites along the mainland of Southern California adjacent to oil and gas activity. The objective was to monitor the health of rocky intertidal habitats adjacent to OCS oil and gas activities in the Pacific Region and to understand the connection between changes that occurred and their potential causes. This study included about a third of the total number of monitored sites supported by 14 federal state, local agencies and private organizations. Data were collected in the form of field notes, slides, and videotape and analyzed and placed in a database. Photos, counts and measurements of selected species (e.g., black abalone, owl limpets, and seastars) were collected at four sites in San Luis Obispo County, four sites in Orange County, two sites in Ventura County and nine sites in Santa Barbara County. Slides were scored and maintained at the University campuses. Data collected was used by the trustees to evaluate impacts from the oil spill on rocky intertidal areas. Additional information on methods used and results of this study are described in this report.

Murray, S. N., R. F. Ambrose and M. N. Dethier. 2002. Plots or Quadrats. In Methods For Performing Monitoring, Impact and Ecological Studies on Rocky Shores, pp. 97-100. United States Department of the Interior, Minerals Management Service, Pacific OCS Region.

Chapter 5 in this document discusses the use of transects, plots and quadrats to estimate cover, density, or biomass of attached and mobile organisms on rocky shores. Quadrats and plots are positioned randomly in an area, or targeted for specific conditions. They can be permanently fixed at a specific locaton so that the same location is sampled repeatedly over time or placed in a different location during sampling. Band transects are used for sampling large and uncommon species of an area that are distributed over large region. These transects function regardless of other sampling units or in conjunction with transects that are positioned for line-intercept or point contact sampling. Plots are used to estimate densities of relatively uncommon species in an area when a sampling region expands over approximately several meters, and for sampling species in certain microhabitats (e.g., deep cracks and crevices). The author concludes that to determine species abundance, line transects and plots or quadrats provides accurate estimates using appropriate sampling strategies. Further information on the methods used for sampling rocky shore organisms can be seen in this document.

Murray, S. N., R. F. Ambrose and M. N. Dethier. 2002. Boulderfields. In Methods For Performing Monitoring, Impact and Ecological Studies on Rocky Shores, pp. 108-111. United States Department of the Interior, Minerals Management Service, Pacific OCS Region.

Authors describe quantitative sampling methods used in rocky intertidal areas. Researchers Pless and Ambrose (unpublished observations) sampled boulderfields in order to compare their communities with that of solid rock benches. The horizontal edges of a leveled sampling quadrat were vertically launched onto the substratum and contours marked with a lumber crayon or chalk. The extent of available substratum was assessed; the total area of rock substrata within the lumber chalk marks was estimated using small wire quadrats of different dimensions (2x2 cm, 4x4 cm, 5x5 cm, 10x10 cm) as a visual reference. Boulder surface was measured separately by top, side, or bottom within sampling quadrat borders. The top of solid rock benches were also measured, however if the surfaces were not relatively flat the sides were measured as well. Macroscopic organisms were sampled within the marked borders of the 0.25m^2 quadrats. Estimates were determined separately for each substratum surface orientation category (top, side, bottom), which is useful for some purposes but not necessary for an inventory. Boulders were temporarily overturned to assess the abundances of organisms found on their undersides. Macrophytes cover and sessile macroinvertebrates were estimated using visual counts of individual species in an area in order to determine biomass. Further information on the methods used for sampling physical structure of boulder fields and the organisms that reside there can be seen in this document.

Murray, S. N., R. F. Ambrose and M. N. Dethier. 2002. Quantifying Abundance: Density and Cover. In Methods For Performing Monitoring, Impact and Ecological Studies on Rocky Shores, pp. 117-147. United States Department of the Interior, Minerals Management Service, Pacific OCS Region.

Chapter 6 describes the use of plots and quadrats for quantifying density and cover. Direct counts are used for measuring density of mobile intertidal invertebrates. Once organisms are counted, the numbers are converted to density or the number of individuals per unit area of intertidal surface. Quadrats are used for sampling intertidal seaweeds and macroinvertebrates. Counted individuals are marked once they are observed so they traced. If organisms are abundant (>50) a hand-held mechanical counter is used because the counting process can be done faster. Additional information on quantifying density is discussed in the document.

There are three methods described in this document for estimating percent cover of rocky intertidal populations. These methods include: (1) The use of scanning plots to visually estimate the planar surface area of a plot covered by the species or material to be measured. Researchers then divide plots into subsections to make easy estimates and enhance accuracy of estimates made; (2) Determining the number of point intercepts along a line or within an area. Species percent cover is calculated by dividing the number of its point intercepts by the total number of points distributed within the sampled area of plot; and (3) Tracing silhouettes or photographic images of organisms by planimetry or with image analysis software. Additional information on estimating percent cover is discussed in the document.

Oregon Watershed Enhancement Board. 1999. Oregon Aquatic Habitat: Restoration

and Enhancement Guide. Phone # (503) - 986-0178. http://www.oweb.state.or.us/publications/habguide99.shtml

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

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

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

Puget Sound Water Quality Action Team. 1997. Recommended guidelines for sampling marine sediment, water column and tissue in Puget Sound. In Puget Sound Protocols and Guides, Puget Sound Water Quality Action Team, Olympia WA. http://www.psat.wa.gov/Publications/protocols/protocol.html

This document provides guidelines for sampling marine sediment, water column, and tissue for the chemical analysis of metals and organics as well as microbiological and bioassay testing. Also provided are recommended methods for sampling, quality control, and quality assurance procedures, field health and safety protocols and documentation requirements. These guidelines were established to help standardized methods that are used in various Puget Sound monitoring and regulatory programs. By standardizing field sampling and measurement methods researchers can produce comparable data when conducting studies in Puget Sound. The document also aims to consolidate and enhance access to marine sampling guidelines and field information for a variety of matrices and target analytical parameters. It allows practitioners to utilize the information to suit the goals of their project but by no means state that all sampling *must* be performed using these methods. Some of the protocols presented in this chapter include guidelines for: collecting environmental samples in Puget Sound; measuring organic compounds; measuring metals; measuring conventional variables; and conducting laboratory bioassays.

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

Author Abstract. Long term monitoring of estuarine nekton has many practical and ecological benefits but efforts are hampered by a lack of standardized sampling procedures. This study develops a protocol for monitoring nekton in shallow (<1m) estuarine habitats for use in the Long term Coastal Monitoring Program at Cape Cod National Seashore. Sampling in seagrass and salt marsh habitats is emphasized due to the susceptibility of each habitat to anthropogenic stress and to the abundant and rich nekton assemblages that each habitat supports. Extensive sampling with quantitative enclosure traps that estimate nekton density is suggested. These gears have a high capture efficiency in most habitats and are small enough (typically 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.

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

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

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

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

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

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

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

United States Environmental Protection Agency (USEPA). 1993. Volunteer Estuary Monitoring. In Ohrel, R. L. Jr., and K. M. Register (eds.), A Methods Manual. U.S. Environmental Protection Agency, Washington, D. C., Office of Water. EPA Report- 842-B-93-004. 176 pp. 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 are 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.

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

This document has been developed to provide guidance for project managers when developing monitoring programs and describes the importance of volunteer monitoring. Described in the document are parameters that are monitored in stream habitats but will vary depending on project goals as well as methods used for sampling and conducting surveys. Some methods described in this document include a watershed survey, a visual assessment that describes the geography, land, and water use, and potential and current pollution sources, history of the stream and its watershed; biological monitoring of macroinvertebrates which involves collecting, processing, and analyzing aquatic organisms that can help determine health of the habitat. Surveys may be performed by using the rock rubbing method which involves randomly picking a rock from the bed and removing organisms from the rock surface or the stick picking method which collects several sticks from the stream, place in water and then remove it to examine organisms present on the stick over a pan; and water quality examination by measuring stream flow, temperature, turbidity, dissolved oxygen, pH, fecal bacteria, nutrients, total solids, conductivity, and alkalinity. Additional information on methods and parameters used for monitoring stream habitats are described in detail in this document.

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

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

APPENDIX III: LIST OF ROCKY HABITAT EXPERTS

The expert listed below has provided his contact information so practitioners may contact him 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. In addition to this resource, practitioners are encouraged to seek out the advice of local experts as well faculty members and researchers at colleges and universities. Engineering, planning, and landscape architecture firms also have experts on staff or contract out the services of botanists, biologists, ecologists, and other experts whose skills are needed in restoration monitoring. These people are in the business of providing assistance in restoration and restoration monitoring and are often extremely knowledgeable in local habitats and how to implement projects on the ground. Finally local, state, and Federal environmental agencies also house many experts who monitor and manage coastal habitats. In addition to the National Oceanic and Atmospheric Administration (NOAA), the Environmental Protection Agency (EPA), the Army Corps of Engineers (ACE), Fish and Wildlife Service (FWS), and the United States Geologic Survey (USGS) are important Federal agencies to contact for assistance in designing restoration and monitoring projects as well as potential sources of funding and permits to conduct work in coastal waterways.

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GLOSSARY

Abiotic - non-living

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

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

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

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

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

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

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

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

Anoxic - without oxygen

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

Apical - the tips of the plants

Aquatic - living or growing in or on water

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

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

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

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

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

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

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

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

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

Biogenic - produced by living organisms

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

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

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

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

Canopy formers - plants that form a diverse vertical habitat structure

Carnivores - organisms that feed on animals

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Cryptofauna - tiny invertebrates that hide in crevices

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

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

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

Dataloggers - an electronic device that continually records data over time

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

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

Detritivorous - the practice of eating primarily detritus

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

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

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

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

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

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

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

Duration - a span or interval of time

Ebb - a period of fading away, low tide

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

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

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

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

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

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

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

Ephemeral - lasting a very short time

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

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

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

Eukaryotic - organisms whose cells have a nucleus

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

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

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

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

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

Exotic species - plants or animals not native to the area

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

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

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

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

Flooding regime - pattern of flooding over time

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

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

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

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

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

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

Frequency - how often something happens

Fronds - leaf-like structures of kelp plants

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

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

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

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

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

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

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

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

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

Herbivory - the act of feeding on plants

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Infauna - plants that live in the sediment

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

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

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

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

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

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

Intertidal - alternately flooded and exposed by tides

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

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

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

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

Lacunar - a small cavity, pit, or discontinuity

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

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

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

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

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

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

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

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

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

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

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

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

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

Mast - the nuts of forest trees accumulated on the ground

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Nonresponse error - a type of survey error that occurs when a significant proportion of the survey sample do not respond to the questionnaire and are different from those who do in a way that is important to the study

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

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

Nuisance species - undesirable plants and animals, commonly exotic species

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Pelagic - pertaining to, or living in open water column

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

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

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

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

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

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

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

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

Piscivorous - feeding on fish

Planktivorous - eating primarily plankton

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Regime - a regular pattern of occurrence or action

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

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

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

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

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

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

Riverine - of, or associated with rivers

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Statistical protocol - a method of a analyzing a collection of observed values to make an inference about one or more characteristic of a population or unit

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

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

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

Subtidal - continuously submerged; an area affected by ocean tides

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

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

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

Temporal - over time

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

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

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

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

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

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

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

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

Trophic - refers to food, nutrition, or growth state

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

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

Unconsolidated - loosely arranged

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

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

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

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

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

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

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

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

Zooplanktivorus - animals that feed upon zooplankton

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

References

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