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# Coral Reef Biological Criteria: Using the Clean Water Act to Protect a National Treasure

Office of Research and Development | National Health and Environmental Effects Research Laboratory

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# Coral Reef Biological Criteria
## Using the Clean Water Act to Protect a National Treasure

by

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# Notice and Disclaimer

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This manual provides technical guidance to states, territories, and commonwealths to establish water quality criteria and standards under the Clean Water Act (CWA), to protect aquatic life from the effects of pollution. Under the CWA, states and territories are to establish water quality criteria to protect designated uses. State and territorial decision makers retain the discretion to adopt approaches on a case-by-case basis that differ from this guidance when appropriate and scientifically defensible. While this manual constitutes the U.S. Environmental Protection Agency's (EPA) scientific recommendations regarding biological criteria to help protect coral reef ecosystem quality and aquatic life, it does not substitute for the CWA or EPA's regulations; nor is it a regulation itself. Thus, it cannot impose legally binding requirements on EPA, states, territories or the regulated community, and might not apply to a particular situation or circumstance. EPA may change this guidance in the future.

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This document can be downloaded from EPA's website for Biological Indicators of Watershed Health: http://www.epa.gov/bioindicators

# Preface

The Earth is a Blue Planet.
Oceans cover about 70% of the globe.
Coral reefs are the largest living structures on the planet.
Coral reefs are one of the most threatened
marine ecosystems.

## Intended Audience

This manual has been written to support coral reef managers in United States jurisdictions (see map in Figure P-1), including:

- Caribbean Basin (Commonwealth of Puerto Rico, U.S. Virgin Islands, and Navassa Island)
- Gulf of Mexico (Flower Garden Banks)
- Atlantic Ocean (southeast Florida and the Florida Keys)
- Pacific Ocean (American Samoa, Commonwealth of the Northern Mariana Islands, Guam, Hawaii, Pacific Remote Island Areas)

When the term “state” is used throughout the manual it is intended to represent any U.S. jurisdiction, which includes states, territories, tribes and commonwealths. In all jurisdictions with coral reefs, the Clean Water Act applies to marine and coastal systems within the 3-mile territorial waters.

"State" in this document includes all states, territories,
tribes, and commonwealths.

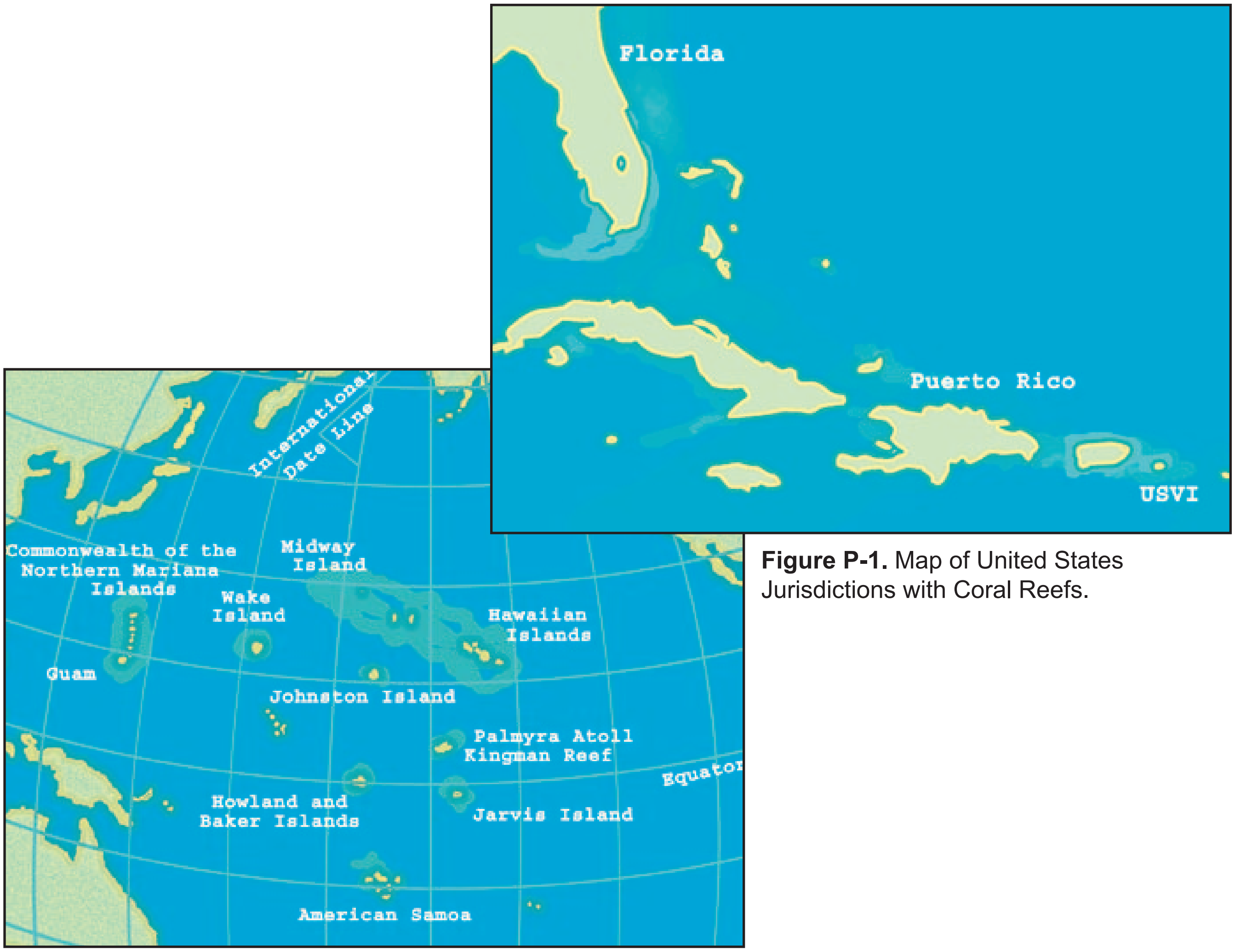


**Figure P-1.** Map of United States Jurisdictions with Coral Reefs.

Coral reef ecosystems are managed by a variety of federal and state agencies (Table P-1).

**Table P-1.** Managers whose decisions potentially impact coral reef ecosystems.

| Types of Managers | Role | Scale |
|---|---|---|
| Policy Makers | Develop laws and regulations | Federal/Regional/State |
| Environmental Managers | Implement and enforce federal/ state/territorial environmental laws and regulations | Regional/State |
| Natural Resource Managers | Manage parks, sanctuaries, refuges, etc. | Federal/Regional/State |
| Local Government Managers | Enforce land-use rules, permits and zoning | Local |

***Coral reef managers*** work for many different organizations both within government (at the federal, state, and local levels) and for non-profit organizations. While they all have a general responsibility to protect coral reefs, their authorities and roles can be quite varied, including:

- Pollution prevention, including various permitting authorities
- Coral reef protection
- Coral reef restoration
- Fisheries management
- Park/sanctuary management

This document uses the general term coral reef manager in reference to all of these roles.

**Coral Reef Managers** work for many different organizations both within government (at the federal, state, and local levels) and for non-profit organizations. While they all have a general responsibility to protect coral reefs, their authorities and roles can be quite varied, including: pollution prevention, including various permitting authorities; coral reef protection; coral reef restoration; fisheries management; and park/sanctuary management.

Reef managers and government scientists aren't the only people interested in protecting coral reefs. All U.S. citizens are stakeholders. The Clean Water Act includes many opportunities for citizens and other stakeholders to comment, understand and influence regulatory decisions either during mandated public comment periods or through citizen lawsuits (USC33, §1365 and §505). Stakeholders include:

- Residents of local communities adjacent to coral reefs
- Tourists and the tourism industry
- Fishermen and other marine-based industries
- Land-based industries and commercial enterprises
- Conservation and environmental groups
- Research organizations
- Educational institutions

Citizen suit provisions USC33, §1365 and §505.

## Why You Should Read This

Coral reef managers have challenging jobs. This is truer now than ever before. **First** and foremost, coral reef ecosystems are declining, threatened by a variety of human activities including polluted runoff from agriculture and land-use practices, over-fishing, ship groundings, coastal development and climate change, as well as with natural stressors such as tropical storms, bleaching and disease that may also be increasing due to human actions. **Second**, coral reef managers are often faced with a lack of information, lack of resources, and lack of political will to take the actions necessary to protect or restore coral reef ecosystems. **Finally**, coral reef managers must navigate a complex web of federal, state, and local legislation—legislation that is too often duplicative, difficult to understand, and challenging to coordinate.

If you are a coral reef manager, you are already aware of many on-the-reef approaches to management. This document will show you how to use the Clean Water Act (CWA) and coral reef ***biological criteria*** (biocriteria) as part of a comprehensive framework to organize your protection efforts and make them more meaningful through enforceable coastal and watershed regulations.

If you are a stakeholder, this document will show you how the CWA and other management tools can be combined into a comprehensive watershed-based management approach for coral reefs and other coastal ecosystems.

The responsibility for implementing coral reef biocriteria lies with the state and federal coral reef managers. However, to be successful, their actions must be guided and informed by the knowledge, energy and resources of scientists and other stakeholders.

**Biological Criteria:** A description of the desired natural aquatic community based on the numbers and kinds of organisms expected to be present in a water body and serve as the standard against which assessment results are compared. Biocriteria can also be used to determine aquatic life use attainment and can be formally adopted into a state's water quality standards (EPA 2002).

## How to Use This Manual

**Ask the Right Questions.** This document is organized—in general—around broad questions that correspond to the needs of coral reef managers. The questions are part of the scientific and management discussion, and are topics with which most coral reef managers will be readily familiar. These questions are also essential to the development of scientifically sound coral reef biocriteria.

- Why do we care about coral reefs?
- What do we want to protect?
- What should we measure?

- How do we assess reef condition?
- How are the reefs doing (are they getting better or worse)?
- How do we account for reef variability?
- What's causing reefs to change?
- What can we do to protect reefs?
- Do our efforts protect reefs?

These questions are the titles for chapters that describe the basis for biocriteria development under the CWA. Although the manual is intended as informational, rather than a "how-to" document, the issues related to these questions become a part of biocriteria development (Table P-2).

**Key Terms**

Where appropriate, this manual defines important terms in these text boxes. The first time a key term appears in the document, it will be both italicized and bolded.

Important concepts are emphasized in these boxes.

Important legislative citations are emphasized in these boxes

Many states have incorporated biocriteria for freshwater and estuarine waterbodies. Examples of their development and application can be found at EPA's Biocriteria Website (http://www.epa.gov/waterscience/biocriteria). Much of the information in this report draws from this combined experience. Information on planning, assessment and management needs for development of coral reef biocriteria are outlined. Table P-2 briefly summarizes some of the important steps, which are sometimes simultaneous and iterative, and where in this report these steps are discussed.

**Table P-2.** Top ten steps for establishing a coral reef biocriteria program, who is usually responsible for completing those steps, and where in this report the steps are discussed.

| # | Steps to Coral Reef Biocriteria | Responsible Parties | Chapters |
|---|---|---|---|
| | **Planning** | | |
| 1 | Establish aquatic life protection goals for state waterbodies and identify designated uses | State water quality agency, coral reef managers and stakeholders through a public process | 1, 2, 3 |
| 2 | Develop an antidegradation policy and implementation procedures | State water quality agency with public notification and participation | 1 |
| 3 | Develop a conceptual coral reef Biological Condition Gradient (BCG) to target potential decision points | State water quality agency, reef scientists and managers | 6 |
| | **Assessment** | | |
| 4 | Develop indicators that are relevant, efficient and responsive to human disturbance | State water quality agency and reef scientists | 4 |
| 5 | Characterize reference conditions (minimal human disturbance) and select decision thresholds (criteria) that support designated uses | State water quality agency and reef scientists | 6, 7 |
| 6 | Initiate a long-term monitoring program to determine aquatic life use attainment | State water quality agency and reef scientists | 5 |
| | **Management Response** | | |
| 7 | Report reef conditions and status of attainment for designated uses and aquatic life use goals | State water quality agency | 1, 8 |
| 8 | Determine cause(s) of any impaired waterbodies | State water quality agency and reef scientists | 9 |
| 9 | Implement management activities that restore the biological condition of impaired waterbodies | State water quality agency, reef scientists, reef and watershed managers with notification of stakeholders | 9 |
| 10 | Review aquatic life protection goals and the relationship to designated uses | State water quality agency, reef and watershed managers with stakeholders through a public process | 1, 2, 3 |

Additional material is provided in the Appendices, including a list of Acronyms and Abbreviations (A), a Glossary (B), a Bibliography (C), and Common Questions and Their Answers (D).

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# Executive Summary

The Clean Water Act (CWA) (33 U.S.C. § 1251 et seq. 1972) can be a powerful legal instrument for protecting water resources, including the biological inhabitants of coral reefs. The objective of the CWA is to restore and maintain the chemical, physical and biological integrity of water resources. The full intent of the CWA may be obscured by its name. *Clean water* is a goal partly because clean water supports biological communities; but the communities themselves are also protected. Biological integrity is a long-term objective of the CWA and, like its physical and chemical counterparts, biological standards and criteria can be defined to protect valued aquatic resources. The valued resources for coral reefs are the organisms that form the living reef community. Coral reef communities are, in fact, a national treasure.

Biological criteria (biocriteria) are an important addition to existing management tools for coral reef ecosystems. Simply stated, biocriteria are expectations set by a jurisdiction for the quality and quantity of living aquatic resources in a defined waterbody. Biocriteria follow the same process and can draw on some of the same CWA authorities as the more familiar chemical and physical criteria. Biological criteria can be part of a state's water quality standards which include 1) designated uses to reflect goals for the waterbody, 2) numeric or narrative criteria (thresholds) to protect and support the designated uses, and 3) antidegradation policies to help protect all waters from deterioration. The CWA requires that states have water quality standards, monitor conditions regularly, and submit reports summarizing water quality assessments, usually every two years. Reporting is a critical element: If criteria are not met, the waterbody is reported as impaired—this triggers a series of management actions to determine the cause of impairment and then restore the waterbody and its resident biota.

Water quality standards for biological condition provide an opportunity to reverse the decline of coral reef condition. Although chemical and physical standards are intended to protect biota, they are not always sufficient. Biological standards, by tracking the condition of reef living systems, establish a direct process to determine whether a waterbody is achieving its biological goals. Biocriteria are complementary; they do not supersede or replace physical and chemical criteria. Biocriteria may be particularly important for coral reefs because bioassessments reflect the integrated effects of multiple and cumulative stressors, detect impairment that might be missed by physical and chemical criteria (e.g., overfishing or habitat loss), resonate with managers and stakeholders, and have been found (at least in freshwater systems) to be cost effective.

Physical, chemical and biological criteria are intended to augment and support decision making and management through a defined regulatory process. Water quality standards must be scientifically sound, defensible to jurisdictional stakeholders (including the regulated community), and able to withstand legal challenge. Many states have implemented biological assessment programs for rivers, streams, estuaries and wetlands and are moving through the formal process to adopt biocriteria. A systematic and defensible approach has emerged from this process. This manual provides information and experience gained in these freshwater programs for application to development of coral reef biocriteria.

An extensive technical literature is available to connect readers to the legal and regulatory background developed for freshwater and estuarine resources. This document does not repeat or replace that literature, but provides a synopsis with focused application to coral reefs. It is intended to address questions often asked by coral reef managers, scientists, and stakeholders in the context of biocriteria. Included are approaches for determining what to protect, what to measure, reef assessments, thresholds, and response variability. Also included are brief descriptions of procedures for determining cause of waterbody impairment and gauging the success of management programs.

Biocriteria are not a stand-alone proposition—they should build on existing programs to manage and protect coral reefs. In fact, biocriteria provide a framework that should help to link monitoring and reporting programs with regulatory and management decisions. Implementation of biocriteria should be viewed not so much as a new program but more as an opportunity to strengthen existing programs. Nine critical needs for coral reef conservation were summarized from the 2008 International Coral Reef Symposium (Dodge et al. 2008):

1. Cut $CO_2$ emissions by lowering our carbon footprint and ask our policy-makers to commit to low carbon economic growth.
2. Eliminate open access fisheries in coral reef ecosystems and instead establish and enforce regulations on user rights, total allowable catch, individual catch quotas, nondestructive gear, and other sustainable fisheries regulations.
3. Protect coral reef herbivores, including parrotfish, by banning the harvesting of these species for sale and commercial consumption.
4. Establish and strictly enforce networks of Marine Protected Areas that include No-Take Areas.
5. Effectively manage the waters between Marine Protected Areas.
6. Maintain connectivity between coral reefs and associated habitats; mangroves, sea grass beds, and lagoons contribute to the integrity of reef ecosystems and their continued production of ecosystem services.
7. Report regularly and publicly on the health of local coral reefs.
8. Recognize the links between what we do on land and how it affects the ocean.
9. Bring local actors together—including members of industry, civil society, local government, and the scientific community—to develop a shared vision of healthy reefs and a road map for getting there.

Biocriteria are worthy of this challenge. Within an integrated management approach, coral reef biocriteria can advance all nine needs (Fore et al. 2009).

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**Key Words:**
biocriteria, biological criteria, coral reefs, coral, Biological Condition Gradient, BCG, Clean Water Act, water quality criteria

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# 1. The Clean Water Act: A Critical Asset

> *"A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise."*
> *- Aldo Leopold, 1949*

Few can argue the beauty of coral reefs and the importance of preserving their integrity. Reefs worldwide are admired for the diversity of form, color, and movement. From solid massive corals to intricately branched gorgonians waving in the currents and brightly-colored fish darting among the crevices, a coral reef inspires the human imagination. And that's not all. Benefits to humans from coral reefs are legion. Coral reefs provide edible fish and invertebrates, shoreline protection, construction material, pharmaceutical products, tourism opportunities, serve a host of ecological purposes, and are a source of cultural and social interactions.

Despite the many natural benefits we receive from coral reefs, human actions threaten their existence. Stresses from air and water pollution, from food harvests, and from the physical presence of humans on and near reefs are creating environmental conditions that are detrimental to this vulnerable ecosystem. Concerted management, backed by strong community support, has made effective inroads toward protection of coral reefs and the valuable benefits they provide. Yet many reefs are still in decline and many are at increasing risk.

One of the most influential mechanisms available for aquatic resource protection is the U.S. Clean Water Act (CWA). It was enacted to protect the integrity of the Nation's waters, including biological components such as coral reefs. Many facets of the CWA are already employed in maintaining the high water quality imperative for coral reef persistence. However, the broad authority of the CWA is not being used to its full potential.

States are tasked under the CWA to adopt water quality standards that include criteria for acceptable physical, chemical and biological condition. Biological criteria (biocriteria) are simply thresholds for biological condition that are adopted by states as part of water quality standards. Biological thresholds are no different than chemical thresholds (i.e., concentration limits) for toxic pollutants—both establish goals for condition of the waterbody. A potential strength of coral reef biocriteria is the capacity to integrate ongoing reef management activities into community-held goals for coral reef condition.

The purpose of this manual is to describe procedures and concepts related to implementation of biocriteria for coral reefs. First, though, it is important to have a basic understanding of the CWA. The CWA represents the Nation's commitment to protecting and restoring the Nation's waters. While the CWA has traditionally been perceived and implemented to address end-of pipe chemical pollutants (Richmond et al. 2007), its mandate is much broader. The CWA is clearly intended to protect both water quality and biological resources, including coral reefs in territorial waters (Karr 1991; Jameson et al. 2001). Moreover, the CWA provides an opportunity to integrate scientific knowledge with community goals for management of coral reef resources (Keller and Cavallaro 2008; Fore et al. 2009).

## 1.1 The Clean Water Act: Integrity of the Nation's Waters

The overall objective of the Clean Water Act (CWA) is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. To achieve this objective, the Act sets out several national goals, including the goal of section 101 (a) (2): Wherever attainable, an interim goal of water quality that provides for the protection and propagation of fish, shellfish and wildlife and recreation in and on the water.

Federal Water Pollution Control Act
[As Amended Through P.L. 107-303,
November 27, 2002] 33 U.S. Code 1251 et seq.

Also known as: The Clean Water Act
Public Law 92-50033 U.S. Code 1251 et seq.

**Key Points regarding the Clean Water Act and Coral Reefs**

1. The objective of the CWA is to restore and maintain physical, chemical, and biological integrity
2. Coral reef organisms can be protected by the CWA at levels necessary to sustain biological integrity
3. Biological integrity includes integrity of all aquatic organisms residing in or migrating through a waterbody
4. Authority of CWA water quality standards extends to coral reefs in territorial seas, a belt of water extending seaward from the coast for three miles or more.

As one of several approaches to achieving these goals, Section 303 of the Act tasks states with adopting water quality standards. Water quality standards are provisions of state law or regulation that: define the water quality goals of a water body, or segment thereof, by designating the use or uses to be made of the water; set criteria necessary to protect the uses; and protect water quality through antidegradation provisions.

While the CWA gives the Environmental Protection Agency (EPA) an important role in determining appropriate minimum levels of protection and providing national oversight, it also gives considerable flexibility and discretion to states to design their own programs and establish protective levels. States adopt water quality standards to protect public health or welfare, enhance the quality of water, and serve the purposes of the Act. "Serve the purposes of the Act" (as defined in Sections 101(a), 101(a)(2), and 303(c) of the Act) means that water quality standards should: (1) include provisions for restoring and maintaining chemical, physical, and biological integrity of state waters, (2) provide, wherever attainable, water quality for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water (fishable/swimmable where attainable), and (3) consider the use and value of state waters for public water supplies, propagation of fish and wildlife, recreation, agricultural and industrial purposes, and navigation.

Integrity implies an intact condition, or the quality or state of being complete or undivided. ***Biological integrity*** means a natural, fully-functioning living system of organisms and communities plus the processes that generate and maintain them. The “living system” incorporates a variety of scales—from individuals to landscapes—and is embedded in a dynamic evolutionary and biogeographic context (Karr 2006).

> **Biological Integrity:** A balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of a region (Karr and Dudley 1981).

Biological integrity also means that reef organisms (including those in Table 1-1) have a clean, healthy environment to support them, including habitats for propagation, nurseries, and refugia. In this context, a fully functioning coral reef ecosystem may include adjacent supporting ecosystems such as seagrasses and mangroves.

**Table 1-1.** Biological diversity on coral reefs is evident from the number of species identified in two reports, one in Hawai’i (Eldredge and Miller 1995) and one in southern Gulf of Mexico (Tunnell et al. 2007). Even greater diversity may be found at other locations. Examples of different species morphologies are presented.

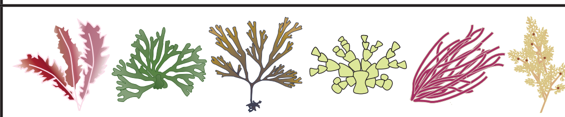
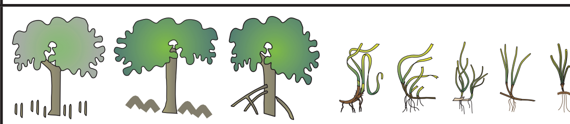
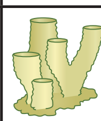
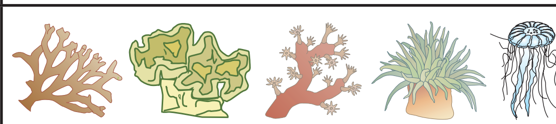
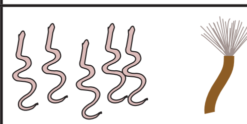
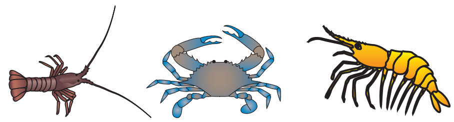
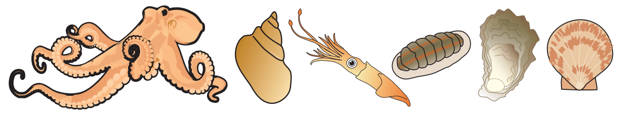
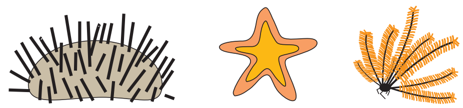
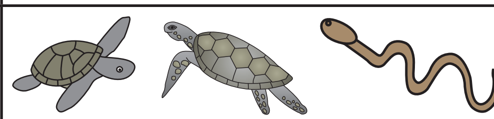
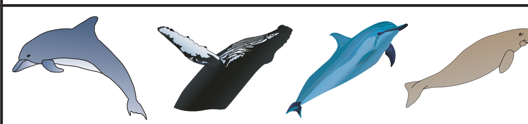
| | Hawai’i | Gulf of Mexico | Examples |
|---|---|---|---|
| “Algae” (Diatoms, red, green, blue-green and brown algae) | 100’s | 100’s |  |
| Foraminiferans (Phylum Granuloreticulosa) | 100’s | >100 |  |
| Mangroves, sea grasses (Division Magnoliaphyta) | | |  |
| Sponges (Phylum Porifera) | ~100 | ~25 |  |
| Corals, anemones, jellies (Phylum Cnidaria) | >200 | ~80 |  |
| Segmented worms, polychaetes (Phylum Annelida) | 100’s | ~40 |  |

**Table 1-1 (con't).** Biological diversity on coral reefs is evident from the number of species identified in two reports, one in Hawai'i (Eldredge and Miller 1995) and one in southern Gulf of Mexico (Tunnell et al. 2007). Even greater diversity may be found at other locations. Examples of different species morphologies are presented.

| | Hawai'i | Gulf of Mexico | Examples |
|---|---|---|---|
| Ostracods, crabs, shrimp (Phylum Arthropoda) | 100's | 100's |  |
| Bivalves, snails, octopus, mollusks, nudibranches (Phylum Mollusca) | 100's | 100's |  |
| Stars, urchins (Phylum Echinodermata) | >100 | ~50 |  |
| Tunicates (Phylum Chordata) | ~50 | ~25 |  |
| Vertebrates (Subphylum Vertebrata) | >1000 | 100's | |
| Fishes, sharks, rays | 100's | 100's |  |
| Turtles, snakes | ~20 | ~10 |  |
| Marine mammals | ~25 | ~10 |  |

## 1.2 Water Quality Standards

Coral reef protection and restoration under the Clean Water Act begins with water quality standards. ***Water quality standards*** are provisions of state or federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters sufficient to protect such uses (Figure 1-1). Additionally, water quality standards contain an antidegradation policy and implementation procedures, which describe what will be done to protect existing water quality. Water quality standards are intended to protect the public health or welfare, enhance the quality of water and serve the purposes of the CWA. State water quality standards have two important functions: They establish the water quality goals for a waterbody, and they provide a regulatory basis for controls beyond the so-called "technology based" requirements that the Act talks about in Sections 301 and 306.

> **Water Quality Standards:** are provisions of state or federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are to protect public health or welfare, enhance the quality of the water and serve the purposes of the Act (EPA 1994).

Water quality standards are the basis of a wide range of water quality management activities, including: (1) monitoring water quality to provide information to make decisions about whether or not a waterbody is attaining standards or is "impaired", (2) calculating total maximum daily loads (TMDLs) for waters impaired by one or more pollutants, (3) developing state water quality management plans which prescribe the regulatory, construction, and management activities necessary to meet the water body goals, (4) calculating National Pollution Discharge Elimination System (NPDES) water quality-based effluent limitations for point sources, (6) preparing various reports and lists that document the condition of the state's water quality, and (7) developing, revising, and implementing an effective control strategy for nonpoint sources of pollution (per CWA Section 319).

States are required to establish water quality standards that define the goals and pollution limits for all waters within their jurisdictions, including waters of the territorial seas. The CWA identifies territorial seas as a belt of ocean waters extending three miles (or more in some states) from shore. In essence, water quality standards translate CWA goals into measurable objectives, such as the protection and propagation of fish, shellfish and wildlife, or recreation in and on the water (EPA 1994).

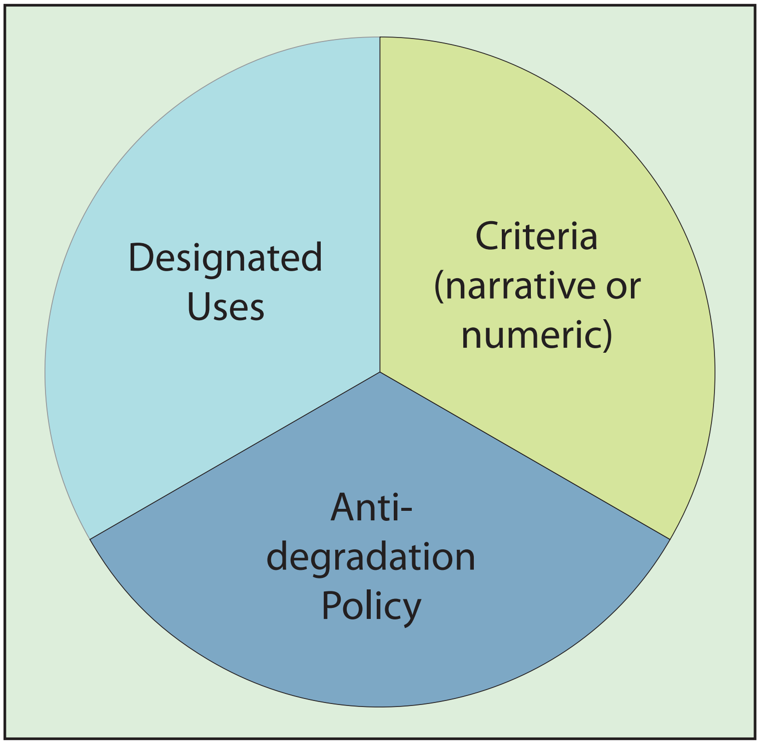



**Figure 1-1.** Components of Water Quality Standards

The responsibility for adopting water quality standards lies with state environmental agencies, but it is imperative that those affected by the standards are involved in the process. ***Designated uses***, in particular, should represent the values of the community. People are more likely to support actions that protect the environmental resources they value. It is also important that states consult with the EPA Regional Office at an early stage of development because EPA must review the standards to ensure they meet the requirements of the CWA. EPA will approve state standards that meet the requirements, but will disapprove those that do not and could promulgate federal standards in their place.

**Designated Uses:** Uses specified in Water Quality Standards for each water body or segment whether or not they are being attained (40 CFR 131.3f). Designated uses are a state's concise statements of its management objectives and expectations for each of the individual surface waters under its jurisdiction.

### 1.2.1 Designated Uses

The first step for developing water quality standards is to designate the purposes, or uses, to be protected for each waterbody. It is in designating uses that states establish the environmental goals for their water resources and are allowed to evaluate the attainability of those goals.

Designated uses are those uses specified in the water quality standards for each water body or segment, whether or not they are being attained (See 40 CFR 131.3 and 40 CFR 131.10). The "use" of a water body is the most fundamental articulation of its role in the aquatic and human environments, and all of the water quality protections established by the CWA follow from the water's designated use.

The overall objective of the CWA is to restore and maintain the chemical, physical and biological integrity of the Nation's waters. Biological integrity does not necessarily represent an aquatic system untouched by human influence, but does represent one that is balanced, adaptive and reflects natural evolutionary processes. Designated uses and criteria to protect those uses in state and tribal water quality standards programs provide one means of achieving biological integrity.

Over the years, states have created many different use classification systems ranging from a straightforward replication of uses specifically listed in Section 303 of the Act to more complex systems that express designated uses in very specific terms or establish sub-classifications which identify different levels of protection.

**California Example**

In their water quality standards, the State of California provides over 20 use classifications, including Municipal and Domestic Water Supply, Water Contact Recreation, Ocean and Commercial Sportfishing, Warm Freshwater Habitat, Cold Freshwater Habitat, Fish Spawning, Shellfish Harvesting, Marine Habitat, and Preservation of Areas of Special Biological Significance.

For coral reef ecosystems, instead of a generic ***aquatic life use*** or "protection of fish and shellfish" use, states may include in their water quality standards descriptions of goals (uses) and water quality criteria or conditions to protect those uses specifically tailored for coral reef viability or restoration. Aquatic life use is the designated use that is measured by biocriteria.

**Aquatic Life Use (ALU):** A beneficial use designation in which the waterbody provides suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms (EPA 2009a).

States often weigh the environmental, social and economic consequences of their decisions in designating uses. Reaching a conclusion on the uses that appropriately reflect the potential for a water body, determining the attainability of those goals, and appropriately evaluating the consequences of a designation, however, can be a complicated task. Appropriate application of this process involves a balancing of environmental, scientific, technical, and economic and social considerations as well as public opinion.

Section 131.10 of the CWA describes states' responsibilities for designating and protecting uses. The regulation requires that states: specify the water uses to be achieved and protected; requires protection of downstream uses; allows for sub-category and seasonal uses, for instance, to differentiate between cold water and warm water fisheries; sets out minimum attainability criteria; lists six factors of which at least one must be satisfied to justify removal of designated uses which are not existing uses; prohibits removal of existing uses; establishes a mandatory upgrading of uses which are existing but not designated; and establishes conditions and requirements for conducting use attainability analyses.

These provisions make a distinction between existing and designated uses and set out specific requirements to ensure protection of these two broad use categories. Designated uses are defined as those uses specified in water quality standards for each water body or segment, whether or not they are being attained. EPA interprets existing uses as those uses actually attained in the water body on or after November 28, 1975 (the date of EPA's initial water quality standards regulation), whether or not they are included in water quality standards. Designated uses focus on the desired or attainable condition while existing uses focus on the past or present condition. Section 131.10 then links these two broad use categories in a manner which intends to ensure that States designate appropriate water uses, reflecting both the existing and attainable uses of each water body.

The water quality standards regulation effectively establishes a "rebuttable presumption" that "protection and propagation/recreation in and on the water" uses of Section 101 (a) are indeed attainable, and therefore should apply to a water body unless it is affirmatively and credibly demonstrated that such uses are not attainable. This demonstration is often made through a "use attainability analysis", discussed at 40 CFR 131.3 (g) and 40 CFR 131.10 (g), (j).

Although a variety of approaches have evolved and become established in state programs, the current regulation is not specific about the level of precision states must achieve in designating uses.

### 1.2.2 Water Quality Criteria

The second step in developing water quality standards is to establish ***water quality criteria***.

To protect designated uses, states also adopt water quality criteria into their standards. Water quality criteria are elements of state water quality standards, expressed as constituent concentrations, levels or narrative statements, representing a level of water quality that supports a particular use. When criteria are met, water quality will generally protect the designated use (40 CFR 131.3, 40 CFR 131.11). Criteria can either be narrative (e.g., "No toxics in toxic amounts.") or numeric (e.g., "To protect aquatic life, the concentration of lead shall not exceed 65 ug/L as 1 hour average more than once every three years."). Most states typically have a mix of both as part of their standards (EPA 2002). When a water body is classified for more than one use, criteria necessary to protect the most sensitive use must be applied to the water body.

To better address the integrity goal and more fully protect aquatic life uses, many states are incorporating bioassessments and biocriteria into their water quality standards and/or overall water quality management strategies. Biological assessments are used to evaluate the condition of a water body using direct measurements of the resident biota in surface waters. Biological assessments integrate the cumulative impacts of chemical, physical, and biological stressors on aquatic life. Biological criteria, derived from biological assessment information, can be used to define state water quality goals for aquatic life by directly characterizing the desired biological condition for an aquatic life use designation. Biological criteria are narrative descriptions or numerical values that describe the reference condition of the aquatic biota inhabiting waters of a specific designated aquatic life use (EPA 1990). Biological criteria are often based on integrated measures, or indices, of the composition, diversity, and functional organization of a reference aquatic community. The reference condition describes potential biological conditions for water body segments with common characteristics within the same biogeographic region. Biological criteria can play an important role in water quality programs and when properly implemented, complement and support other methods and criteria.

For biological criteria, ***narrative criteria*** are statements that describe a desirable biological condition, such as "a balanced, healthy population of native aquatic life." States can define narrative biological criteria early in program development without conducting biological assessments. To support the narrative criteria, a state needs protocols that describe standardized procedures for data collection, analysis and interpretation. Once vetted through a rigorous scientific process, these protocols provide the legal and programmatic basis for numeric criteria (EPA 1990; Karr 1991).

***Numeric criteria*** identify specific values for measurements that are expected to support the designated uses. For example, assuming protection of coral reef ecosystem is a designated use, numeric biological criteria might include a minimum percentage of coral cover, a minimum number of coral species in a defined region, or a maximum number of nonindigenous fish—at whatever levels are deemed necessary to support the designated use (EPA 2002).

**Water Quality Criteria (WQC):** Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use.

**Narrative criteria:** Descriptions of conditions necessary for the water body to attain its designated use.

**Numeric criteria:** Specific numeric values expressed as maximum acceptable chemical concentrations, an acceptable range of physical factors or acceptable condition of biological resources.

The Clean Water Act (§304(a)(1)) authorizes EPA to recommend criteria for water quality that accurately reflect the latest scientific knowledge. These criteria are based solely on data and scientific judgments on pollutant concentrations and environmental or human health effects. Criteria developed under Section 304 (a) do not reflect consideration of economic impacts or the technological feasibility of meeting the chemical concentration in ambient water. Section 304(a) also provides guidance to states and tribes in adopting water quality standards. Criteria are developed for the protection of aquatic life as well as for human health.

In adopting water quality criteria to protect their waters, states may use EPA's recommended 304 (a) criteria, the 304(a) criteria modified to reflect site specific conditions, or they may use other scientifically defensible methods and develop their own. Site specific criteria may be appropriate in a number of instances, for example, if the species at the site are more or less sensitive than those in the data base used to develop EPA's criteria, or the physical and/or chemical characteristics alter the biological availability and/or toxicity of the chemical.

Currently, only a handful of states have numeric biological criteria as part of their standards, although many have developed quantitative protocols to determine whether waterbodies support their narrative expressions for aquatic life uses. States often refer to these protocols as biocriteria even though they are not yet codified into state law as water quality standards. Many states are moving toward more specific aquatic life uses and numeric biocriteria at the urging of EPA and other scientific review panels (Davies and Jackson 2006; NRC 2001).

### 1.2.3 Antidegradation

**Antidegradation:** A policy designed to prevent deterioration of existing levels of good water quality.

The third component of a state water quality standards program is the ***antidegradation*** policy.

A state's antidegradation policy (and implementation procedures) perform essential functions as part of the states' water quality standards. Designated uses establish the water quality goals for the water body, water quality criteria define the conditions necessary to achieve the goals and an antidegradation policy specifies the framework to be used in making decisions regarding changes in water quality. The intent of an antidegradation policy is to ensure that in all cases, at a minimum, water quality necessary to support existing uses is maintained (40 CFR 131.12 (a)(1)), that where water quality is better than the minimum level necessary to support protection and propagation of fish, shellfish and wildlife, and recreation in and on the water, that water quality is also maintained and protected unless, through a public process, some lowering of water quality is deemed to be necessary to allow important economic or social development to occur (40 CFR 131.12(2)), and to identify water bodies of exceptional recreational or ecological significance and maintain and protect water quality in such water bodies (so called Outstanding National Resource Waters, or ONRWs) (40 CFR 131.12 (3)).

Antidegradation plays a critical role in helping states to maintain and protect the finite public resource of clean water and ensure that decisions to allow reductions in water quality are made in a public manner and serve the public good.

The antidegradation policy is particularly important for waterbodies of exceptional or ecological significance (EPA 2009a). Coral reefs often inhabit waterbodies of exceptional or ecological significance.

High quality surface waters are an important and finite resource whose availability affects the health, welfare, and economic well-being of all the citizens of the United States. Antidegradation policies and procedures of states help ensure that water quality is conserved where possible and lowered only when necessary, and that those affected by the lowering of water quality have a say in the decision. As a result, antidegradation policies are well-suited to assist states and local communities in establishing and achieving goals for a particular waterbody.

Sensitive or highly valued water bodies can be identified and protected from degradation through "Outstanding National Resource Water (ONRW)" or related designations. In other water bodies, where water quality is better than the minimum necessary to support fish and aquatic life and recreation, water quality should be maintained unless there is a demonstrated need to lower water quality. Consistent with a watershed approach, states' antidegradation policies and procedures can be a basis for a systematic and accessible planning process that protects against development having negative impacts on water quality. Additional authorities exist at the local level beyond state, tribal and federal authorities which may allow additional protections to be put in place in accordance with the watershed management plan.

Antidegradation requirements are typically triggered when a regulated activity is proposed that may affect existing water quality. Such activities are reviewed to determine, based on the level of antidegradation protection afforded to the affected water body segment, whether the proposed activity can be authorized. "Antidegradation reviews" should be documented and subjected to public review and comment (e.g., as part of the public review of the water quality certification, NPDES permit, or other regulatory action).

Identifying the universe of activities that trigger antidegradation requirements is a fundamental and often controversial issue because of the number and variety of activities that can affect water quality. Clearly, a wide range of activities that affect water quality may be subject to antidegradation requirements, and states and tribes have considerable flexibility in applying antidegradation policies.

It is important to remember, however, that the federal antidegradation requirements do not create, nor were they intended to create, state regulatory authority over otherwise unregulated activities. It is the position of EPA that, at a minimum, states must apply antidegradation requirements to activities that are "regulated" under state or federal law (i.e., any activity that requires a permit or a water quality certification pursuant to state or federal law) and any activity that is subject to state regulations that specify that water quality standards are applicable. Although states have discretion to apply antidegradation requirements more broadly than minimally required, application of antidegradation requirements to activities that are otherwise unregulated under state and federal water law is not required by the federal water quality standards regulation.

Antidegradation policies are a powerful tool that states can use to maintain water quality and better plan economic and social development that might impact existing water quality. However, antidegradation policies are significantly underused by the states (63 Federal Register 129 1998).

## 1.3 Submittal and Approval of State Water Quality Standards

States are required to review their water quality standards at least once every three years, hold public hearings to review applicable water quality standards, and, if appropriate, adopt new and or revised standards. States can identify additions or revisions necessary to existing standards based on water quality reports, other available water monitoring data, previous water quality standards reviews, or requests from industry, environmental groups or the public. States are required to submit new or revised water quality standards (if any) to EPA for review and approval or disapproval. Finally, CWA section 303(c)(4)(B) authorizes the EPA Administrator to determine, even in the absence of a state submission, that a new or revised standard is needed to meet CWA requirements.

While water quality standards have been used to protect inland, estuarine and coastal waters, to date states have not specifically protected coral reefs with their standards. Water quality standards present an opportunity to develop specific goals for reef water quality and biological condition, and to use other CWA programs (like assessment, NPDES permits, ***TMDLS***, and nonpoint source management to help achieve those goals.

> **Total Maximum Daily Load (TMDL):** an example of a water quality improvement plan. A TMDL is the calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards (Keller and Cavallero 2008; EPA 2009a).

## 1.4 Emergence of Biological Criteria

The CWA's objective is that waterbodies maintain physical, chemical and biological integrity. Historically, however, regulatory agencies have attempted to attain biological integrity through chemical and physical criteria alone. This relies on a presumption that improvements in chemical and physical conditions will result in biological integrity (Yoder 1995) (Figure 1-2).

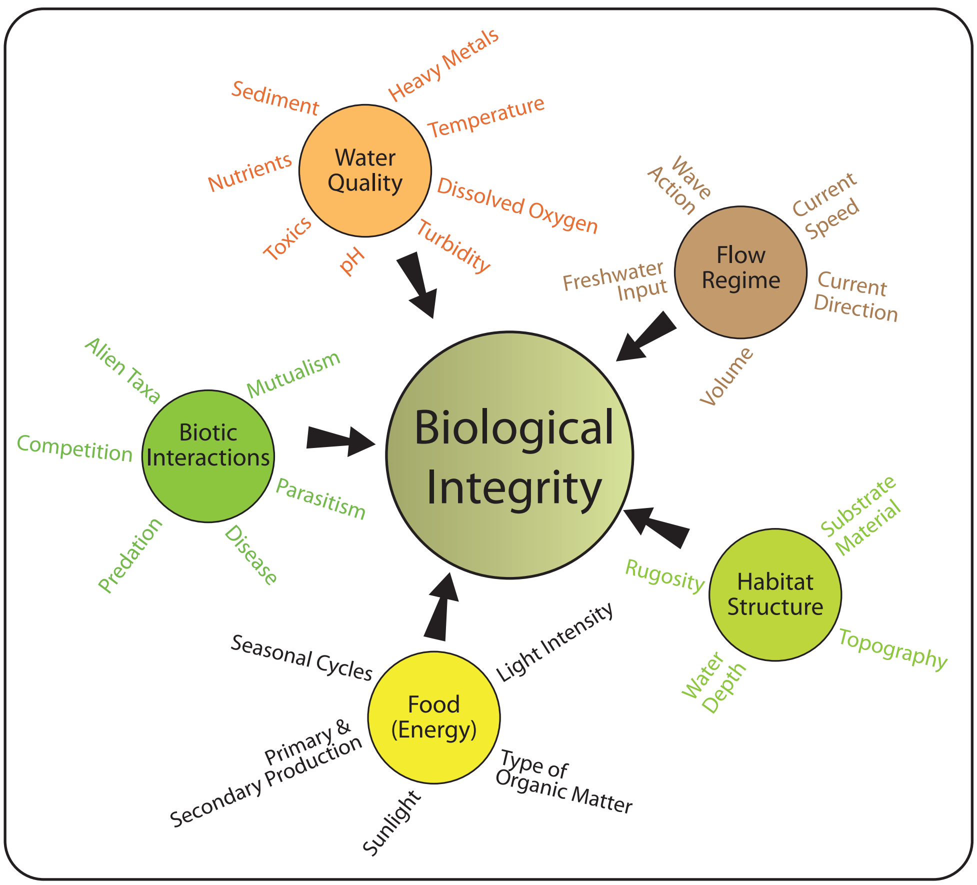



**Figure 1-2.** Five principal factors that influence and determine the integrity of surface water resources. SOURCE: Yoder (1995) modified from Karr et al. (1986).

Yet, some chemical pollutants are hard to measure and there are several physical factors critical to aquatic life, such as habitat structure, flow patterns, and energy sources that are altered by human activities and do not appear in state standards. Far and away the best means to evaluate and protect biological integrity is through ***biological assessment*** (Karr 2006 [see Appendix for other key biocriteria papers]; Figure 1-3).

**Biological Assessment (bioassessment):**
the evaluation of the biological condition of a waterbody using biological surveys and other direct measurements of resident biota in surface waters (EPA 2009a).

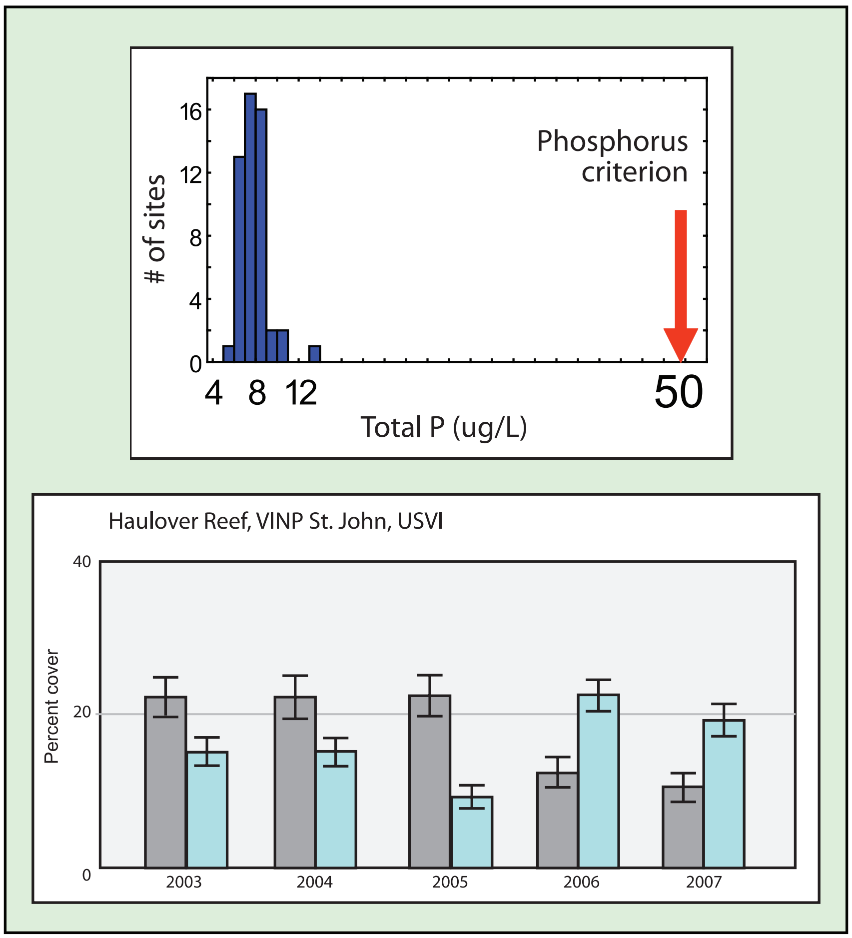



**Figure 1-3.** Biological assessments can sometimes detect impairment when chemical criteria do not. Top panel shows phosphorus values for USVI well below the criterion. In contrast, bottom panel shows coral cover (gray bars) being replaced by macroalgae (blue bars) at a reef in St. John (Waddell and Clarke 2008).

Biological assessments (bioassessments) are not intended to replace, but are a necessary complement to chemical and physical assessments. There are many advantages to biological assessments:

- Biological indicators reflect the cumulative exposure to fluctuating water quality conditions over time. Chemical and physical monitoring provides only a snapshot of water quality condition at the moment of sampling.

- Biological assessments reflect an integrated response of the system to multiple stressors. For example, coral reef organisms may be simultaneously exposed to elevated sea temperature, physical damage, and excess sediment loading, all of which are integrated into biological condition expressed at the level of individuals, populations and communities. Physical and chemical indicators are examined singly with little capacity for integrating effects of different stressors.

- Finally, bioassessments are commonly employed in coral reef ecosystems (Adler 1995; Fisher 2007), perhaps even more often than physical and chemical monitoring. Although most coral reef monitoring programs are designed only to track changes in condition over time, the application of bioassessment procedures is a common foundation for biocriteria development.

**Q: Is this waterbody meeting its designated use?**

- A state reports that their marine waters containing coral reefs are meeting designated uses because chemical and physical criteria such as dissolved oxygen, phosphorus, and turbidity have met the established criteria.
- However, monitoring data for various coral reef communities (stony and soft corals, fishes, seagrasses) show a marked decline in biotic condition.

**A:** If only chemical and physical criteria have been adopted by the state, then the waterbody is meeting its designated uses. The waterbody could only be considered impaired if biological criteria were in place and the biological condition, measured using acceptable bioassessments, did not meet the established thresholds.

The underlying premise of the CWA is to maintain waterbodies in natural condition. Thus, biocriteria are expressed as either numeric values or narrative expressions that describe the expected natural biological condition of aquatic communities in the waterbody. Expected conditions are derived from reference locations where there has been no (or minimal) human disturbance. Values for the measurements that define ***reference condition*** become the thresholds for criteria.

**Reference condition:** The chemical, physical and biological condition expected to be found in unimpaired waterbodies of a similar type. This can be determined by sampling at unimpaired or minimally impaired reference sites, from historical data and information, or through modeling and estimations.

Many ongoing efforts of federal and state agencies are protecting coral reefs under the aegis of the CWA and other federal, state and local authorities. Watershed programs, pollutant discharge permitting, ocean discharge regulations, dumping regulations, fisheries regulations, coastal zone management (see Chapter 9)—all work to protect aquatic resources from adverse human-generated effects. There is an opportunity to extend and set goals for coral reef protection through implementation of coral reef biocriteria.

Because biocriteria are direct endpoints for determining aquatic life use attainment, they must be developed through a scientific process that is sufficiently meaningful to guide effective management and sufficiently rigorous to withstand possible legal challenge. There are obstacles to overcome—as those developing freshwater biocriteria can attest—but we can learn from the successes of ongoing biocriteria programs.

There are many applications for bioassessment approaches and biocriteria. Some of these are iterated at the EPA Biocriteria Website (http://www.epa.gov/waterscience/biocriteria) and include support for enforcement and restorative assessments, setting protection priorities and restoration goals, assessment of water quality to identify impaired waters, contributing to stressor identification, supporting permit decisions, protecting watersheds and tracking restoration progress.

Many aspects of biocriteria development were pioneered in Ohio. Prior to 1978, Ohio's water quality standards reflected a single aquatic life designated use for all of the state's waters. In 1978, the standards were revised to account for the natural variability of aquatic ecosystems using a tiered classification scheme based on ecological components. It was recognized that environmental conditions for biological integrity varied for different populations and habitats. However, the water quality criteria linked to these classifications remained physical and chemical. In 1980, narrative biological criteria were developed for each ecological classification. These narrative biocriteria were the forerunners of the current numeric biocriteria adopted in state water quality standards in 1987 (Yoder and Rankin 1995; see Figure 1-4).

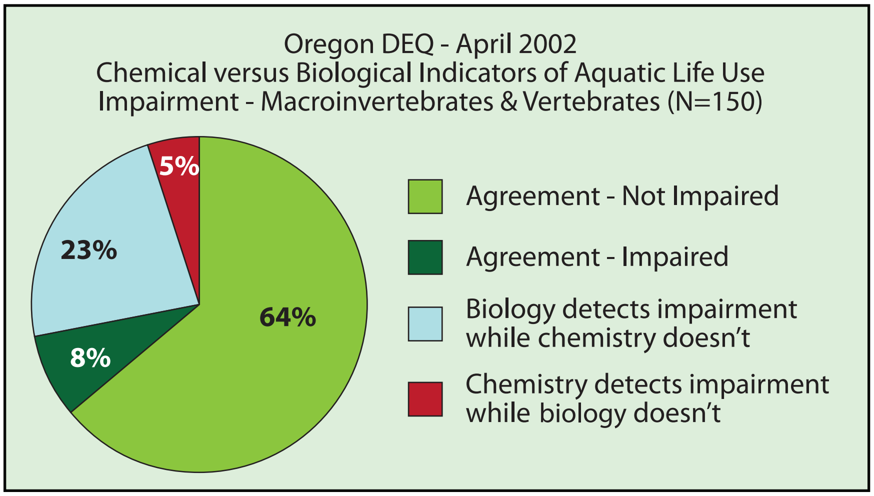



**Figure 1-4.** Disagreement between biological and chemical assessments. Data from Oregon Department of Environmental Quality (DEQ) illustrate that 23% of stream miles that would pass for chemical criteria would fail for biological criteria and that 5% of stream miles had chemical impairment that was not detected by biological assessments.

A typical example of the utility of bioassessments in a biocriteria program might be a fish kill experienced in Rock Creek Maryland in 2000 (Gerritsen et al. 2001). Investigation revealed a point-source pesticide spill as the likely cause. Biological assessments played a role in several aspects of the case. Routine biological monitoring provided historical data and a "before" picture of the integrity of the fish and macroinvertebrate communities. Standard methods recommended by EPA were used for all bioassessments. Sampling immediately after the event and then several months later provided legally defensible data for impact of the event and the degree of recovery. In 2001 the owner of a pesticide company pleaded guilty to federal CWA violations. The routine biological monitoring of this biocriteria program provided a powerful tool for documenting degradation from previous and historical condition and recovery. Data assisted enforcement agencies in assessing damage, levying fair and reasonable fines, and determining the rate of stream recovery.

# 2. Why Do We Care About Coral Reefs?

> *Every one must be struck with astonishment, when he first beholds one of these vast rings of coral-rock, often many leagues in diameter, here and there surmounted by a low verdant island with dazzling white shores, bathed on the outside by the foaming breakers of the ocean, and on the inside surrounding a calm expanse of water, which, from reflection, is of a bright but pale green color.*
> *— Charles Darwin, 1842*

The diverse communities that form coral reefs embody a natural beauty and mystique that have attracted people throughout the ages. Stony corals were once made into scarabs by ancient Egyptians, and Etruscans carved coral jewelry as early as 800 BC. The lure of coral reefs, particularly since the invention of SCUBA, now attracts millions of tourists annually to reef destinations and millions more enjoy reefs vicariously, reflecting on a healthy, diverse, interactive community of unique and colorful marine organisms (Figures 2-1 through 2-3). Coral reefs provide a source of food and shelter for a large variety of species including fish, shellfish, sponges, sea anemones, sea urchins, sea snakes, sea stars, worms, jellyfish, turtles, and snails.

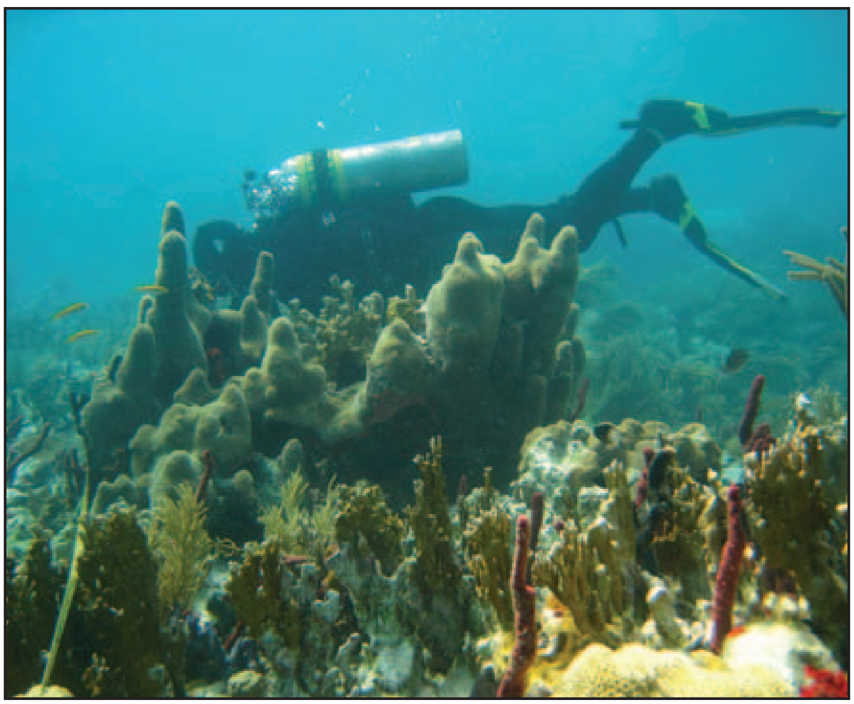


**Figure 2-1.** Scuba diver enjoying coral reef.

**Figure 2-2.** Victorian cameo brooch made from coral.

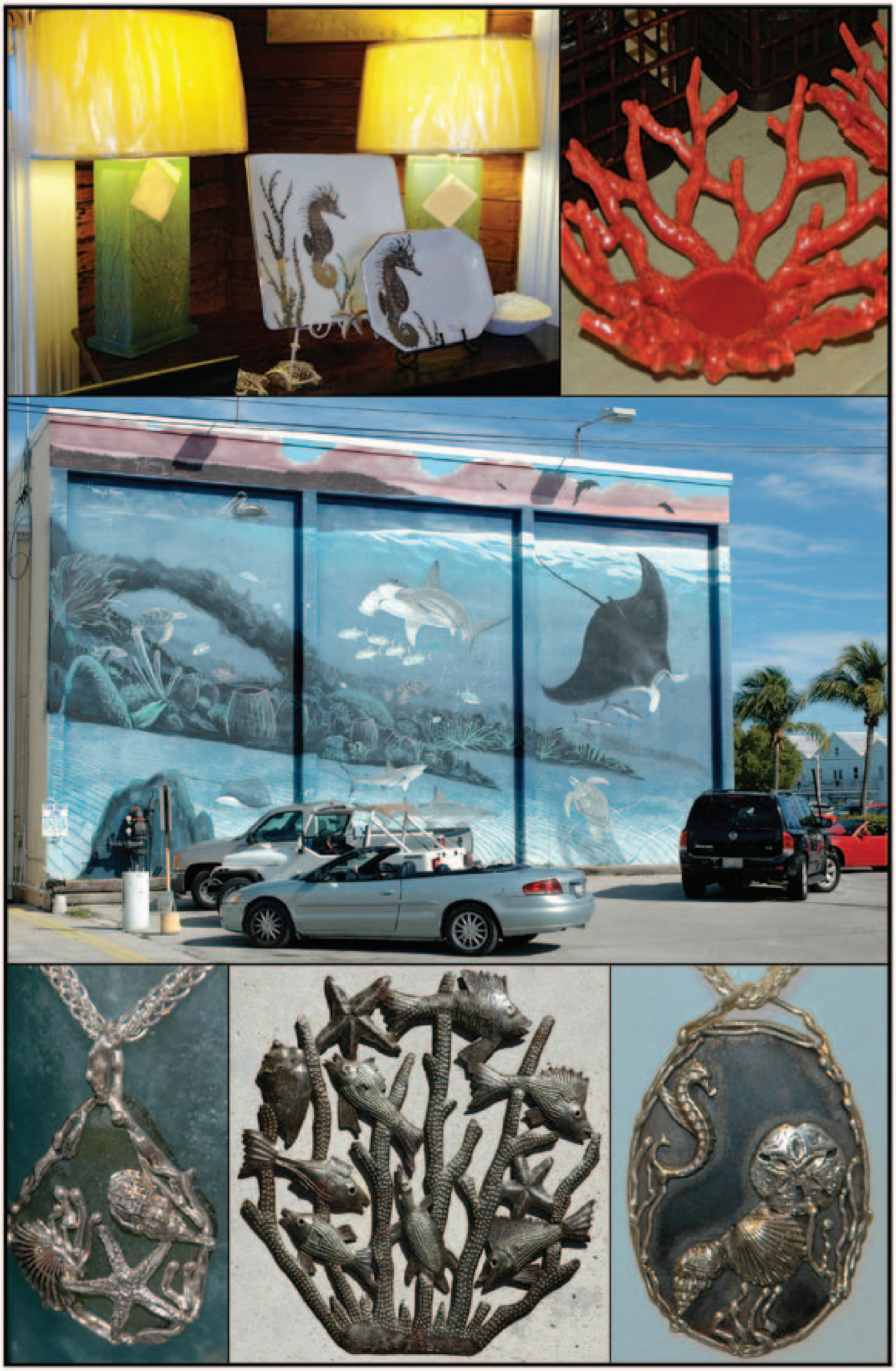


**Figure 2-3.** Coral reefs provide important graphic and design elements.

But natural beauty and biological diversity are not the only values attributable to reefs. Coral reefs provide numerous benefits, including protecting coastlines from ocean storms and floods, providing sand for beaches and coral rock for construction material, supporting subsistence fishing and recreation, and providing a sense of place, tradition and culture. Non-residents benefit from tourism opportunities, food products, aquarium fish, jewelry and curios, and future pharmaceutical and cosmetic products. Coral reefs are important sources of new medicines that can be used to treat diseases and other health problems.

Protection of these benefits and the ecosystems that provide them is an important objective for coral reef management. Human existence—certainly as we know it—would be at risk without functioning ecosystems.

Coral reef ecosystems include items one can count (***ecosystem structure***) plus the processes (function) that generate and maintain them. The structure of the coral reef ecosystem includes:

- The composition of the biological community including species, numbers, biomass, life history and distribution in space.
- The quantity and distribution of abiotic factors (non-living physical and chemical characteristics of the environment), including solar energy (amount of sun light), oxygen, $CO_2$, water, temperature, humidity, pH, and availability of nitrogen.
- The conditions of existence such as temperature, light, etc.

Coral reef ***ecosystem function*** includes:

- The synthesis and storage of organic molecules during the growth and reproduction of photosynthetic organisms (primary productivity).
- The trophic interactions (the relationships between the feeding habits of organisms in the coral reef food chain)
- Flow (fluxes) of nutrients and energy throughout the ecosystem.

**Ecosystem structure:** The physical and spatial aspects of an ecosystem that are contributed by the biotic and abiotic composition.

**Ecosystem function:** Physical, chemical, and biological processes that occur in ecosystems.

**Ecosystem services:** Benefits that human populations receive from functions that occur in ecosystems.

Both structure and function are integral components of ecological integrity. The benefits we derive from ecosystems are characterized as ***ecosystem services*** (73 Federal Register 70 2008). This definition includes direct use services, such as food and material, which are sometimes referred to as “goods”.

The concept of ecosystem services is receiving a lot of attention. A highly-collaborative, worldwide examination of ecosystems, the Millennium Ecosystem Assessment (MEA 2005), found that most ecosystems were in decline and that many life-sustaining benefits we receive from nature—such as clean air and water, fertile soil for crop production, pollination, and flood control—were becoming less and less available while the need for them was becoming greater and greater. Why more has not been done to stem the decline may lie in the relatively common perception that ecosystems are free and limitless, providing ample services into the foreseeable future at no real cost.

**Table 2-1.** Examples of goods and ecological services of coral reef ecosystems (adapted from various sources, including Spurgeon 1992; Moberg and Folke 1999; Costanza et al. 1997; MEA 2005).

| | | | |
|---|---|---|---|
| **Direct use (goods)** | **Renewable** Fisheries and pharmaceuticals | **Non-renewable** Construction materials (coral blocks and sand) and decorative items (curios and jewelry) | |
| **Indirect use** | **Physical** Shoreline protection, land accretion, lagoon formation, beach sand | **Biological** Ecosystem Integrity (biodiversity, genetic repository, ecosystem regulation, ecosystem resilience) | **Biogeochemical** Nitrogen fixation, $CO_2$ regulation, primary production |
| **Non-use** | **Information** Research, education, pollution record, climate record | **Social** Tourism and recreation, aesthetics, artistic inspiration, folklore, tradition, religion | |

There is evidence of this for coral reefs; many decisions and policies in coastal zones and watersheds (e.g., zoning and land-use permits) are implemented without knowledge or consideration of potential effects on reefs. Future protection of reefs may depend on reversing this perception. Research programs such as EPA's Ecosystem Services Research Program (URL: www.EPA.gov/ORD/ESRP) are providing information and tools to transform the way we account for ecosystem services, including those provided by coral reefs (Table 2-1), so they can be routinely considered in environmental management decisions. Incorporation of ecosystem services requires a more holistic, systems approach to analyze human-coral reef interactions. EPA's coral reef program is using a DPSIR framework which links Driving forces, Pressures, State, Impacts and Responses (See Appendix E).

There is little doubt that Americans care about coral reefs—we support numerous actions, both governmental and non-governmental, to study and protect coral reefs. Although we don't often think of reefs in economic terms, the following

Our appreciation of coral reefs is remarkable. A nation-wide poll by The Ocean Foundation (2007) found:

- 80% of American adults believe that healthy coral reefs are important to the overall health of the ocean
- 69% believe that coral reefs are important to human well-being

expenditures represent a valuation of the reef ecosystem:

- The Nature Conservancy pledged $20 million in contributed funds to support "The Caribbean Challenge", a commitment by Caribbean governments to protect 20 percent of their marine and coastal habitats by 2020 (TNC 2009a).
- Since 2003, the State of Florida has offered a "Protect Our Reefs" specialty automobile license plate (Figure 2-4) at an additional cost of $25 each; in 2008 alone, 43,985 coral reef plates were issued (Orlando Sentinel 2008).


**Figure 2-4.** State of Florida "Protect our Reefs" specialty license plate.

- Elected representatives understand the public concern for the welfare of reefs: the U.S. Government has established and funded (over $200M yr$^{-1}$) interagency programs (e.g., the Coral Reef Task Force), National Marine Sanctuaries, National Parks, and legislation (e.g., Coral Reef Conservation Act) specifically for protection of coral reefs.

**Quantifying Ecosystem Services**

The concept of ecosystem services is not new and services have been quantified by several authors (e.g., Spurgeon 1992, Pendleton 2009). Many studies place a monetary value on reef services—monetary valuation is widely applied, broadly accepted and can be highly influential in decisions and policies. But coral reefs provide more than direct (e.g., fishing, tourism) and indirect uses (e.g., habitat, shoreline protection), so a strictly monetary approach can overlook important benefits (see Bateman 1993). An approach used in environmental economics, called "total economic value", includes monetary values but also provides a context for non-monetary social, cultural and historical values. Total economic value includes direct and indirect uses, option values and non-use values. Option values reflect the willingness to preserve an option for potential future use and non-use value (existence or bequest value) is placed on a resource that will never be used. Many ecosystem valuation studies provide a total economic value (e.g., Gren et al. 1994), but incorporating non-monetary values into decision scenarios presents a significant challenge.

A few studies have extrapolated coral reef monetary values (direct and indirect uses) to a worldwide scale. Because of different approaches, the values range from $377 billion yr$^{1}$ (Constanza et al. 1997) to $30 billion yr$^{1}$ (Cesar et al. 2003), with a more recent estimate at $172 billion yr$^{1}$ (TEEB 2009). Global estimates are coarse and generally not useful for local decisions, however, they provide an important context. Valuation at the local scale is more relevant to most decisions. In 2000, NOAA's National Ocean Service initiated this Nation's first attempt to link socioeconomic monitoring and ecological monitoring in the Florida Keys National Marine Sanctuary (see NOAA 2009a). The baseline socioeconomic study showed that in 2000-2001, all uses of the artificial and natural reefs of the Sanctuary generated over $504 million in Sales/Output, including multiplier impacts. This generated $140 million in income in Montroe County, which supported almost 10,000 full and part-time jobs.

Many authors incorporate "ecological integrity", resilience, or biodiversity as an ecosystem service (Turner et al. 2005). Without these characteristics, the ecosystem would ultimately fail and other services would decline. The Millennium Ecosystem Assessment (MEA 2005) identified these as supporting services. This ecosystem "glue", which all other services depend upon, is often viewed as a biological service, directly benefiting components of the ecosystem and indirectly benefiting human society.

# 3. What Should Be Protected?

> *In the end we will conserve only what we love; we will love only what we understand; and we will understand only what we are taught.*
>
> *— Baba Dioum, 1968*

Tourism, recreation, and fisheries are examples of ecosystem services that we care about. Protecting these services and the economic values derived from them means protecting the plants and animals, the biota, that provide them. The CWA protects these aquatic life uses as the “fishable/swimmable” goal, that is, the “protection and propagation of fish, shellfish, and wildlife and recreation in and on the water” (Section 101(a)(2)). Making the connections between the ecosystem services provided by the biota and protection of the aquatic life use helps stakeholders understand how protection of the biological parts and processes of natural ecosystems also provides valuable economic benefits to society (Table 3-1). Sustainable fisheries, for example, depend on ecosystem functions to support the persistence of large, abundant fish and invertebrates. Only an intact, functioning ecosystem can support the production of large fish and invertebrates.

Although the aquatic life use goal is broadly protective, refined designated uses can make selection of indicators (Chapter 4) and establishing criteria (Chapter 5) more relevant to a particular waterbody and to stakeholders. Refined designated uses specifically describe the expected biological assemblage that the use depends on, for example “natural coral reef communities to support recreational diving,” “undisturbed fish nursery areas to support fisheries,” or “restricted spawning areas to support grouper propagation” specifically highlight the biological

**Table 3-1** Relationship of designated use, ecosystem function, biological components and ecosystem services.

| Designated Use | Ecosystem Function | Biological Components | Ecosystem Services |
|---|---|---|---|
| Coral reef communities | Nutrient cycling; herbivory | Rare and colorful fish and invertebrates; abundant herbivores such as urchins and parrotfish | Tourism and Recreation |
| Coral reef communities | Calcification and skeletal growth; photosynthesis and water clarity | Large, abundance scleractinian (stony) corals and crustose coralline algae to bind them | Shoreline Protection |
| Coral reef, seagrass, and mangrove communities | Competition and predation | Taxonomic diversity | Pharmaceuticals |
| Fish spawning, aggregation and nursery areas | Complex trophic structure and food web dynamics | Habitat and food provided by corals, seagrasses, and mangroves | Fisheries |

resources that are particularly important to stakeholders. The primary purpose of designated uses is to communicate the desired condition of water resources to water resource managers, the regulated community, and the stakeholders. The best designated uses translate easily into indicators that respond in predictable ways to degradation and can be assessed with data collected from the waterbody (EPA 2005).

Designated uses can also directly include human use goals, but these are secondary to aquatic life uses. If a particular human use goal is needed, such as navigation for ships that may require a decline in integrity, then a Usability Attainment Analysis (UAA) with extensive public hearings may be required. Some existing designated uses are aquatic life use goals and some are human goals (Table 3-2).

**Table 3-2.** Examples of designated uses relevant to coral reefs.

| Ecosystem Service | Designated Use | Used By |
|---|---|---|
| Aquatic Habitat | Coastal habitat protection and restoration | U.S. Virgin Islands (USVI) |
| | Preservation of natural phenomena requiring special conditions (National Parks) | USVI |
| Biodiversity | Propagation of shellfish and other marine life | Commonwealth of the Northern Mariana Islands (CNMI), Hawaii |
| | Conservation of coral reefs and wilderness areas | CNMI, Hawaii |
| Fisheries | Commercial, recreational and subsistence fishing | American Samoa |
| | Support and propagation of shellfish | American Samoa, Florida, Hawaii, USVI |
| Industrial | Industrial water supply | American Samoa |
| Research | Scientific investigations and oceanic research | CNMI, American Samoa |
| Shoreline protection | Coastal erosion and sediment control | USVI |
| Tourism and Recreation | Primary contact recreation (swimming, snorkeling, scuba diving, etc.) | American Samoa, CNMI, Hawaii, USVI |
| | Aesthetic enjoyment | American Samoa, CNMI, Hawaii |
| Transportation | Boat launch and harbor | American Samoa |
| | Commercial and recreational boating | American Samoa |

Not all state waterbodies are the same, and data collected from bioassessments, as part of a developing biocriteria program, may reveal unique and consistent differences among aquatic communities inhabiting different waters with the same designated use. Measurable biological attributes can be used to separate a waterbody use classification into two or more classes (EPA 2009b).

For example, if a state had an aquatic life use for protection of coral communities, there may also be unique aquatic communities found only in the higher quality waters that may need additional protection through more restrictive criteria (e.g., natural open water coral reef communities vs. shipping channel and harbor coral reef communities). These “refined aquatic life uses” can provide much great clarity of expectations as well as more specific criteria to better protect the use.

## USVI Case Study

In 2007, USVI Department of Planning and Natural Resources (DPNR) began revision of designated uses for three classes of waterbodies.

By 2009, the public comment period was completed and new designated uses are expected to come into effect in 2010. One major change is the inclusion of a definition of biocriteria, which lays the foundation for the various designated uses:

> Biocriteria: The Territory shall preserve, protect, and restore water resources to their most natural condition. The condition of these waterbodies shall be determined from measures of physical, chemical, and biological characteristics of each waterbody class, according to its designated use. As a component of these measures, the Territory may consider the biological integrity of the benthic communities living within waters. These communities shall be assessed by comparison to reference condition(s) with similar abiotic and biotic environmental settings that represent the optimal or least disturbed condition for that system. Such reference conditions shall be those observed to support the greatest community diversity, and abundance of aquatic life as is expected to be or has been historically found in natural settings essentially undisturbed or minimally disturbed by human impacts, development, or discharges. This condition shall be determined by consistent sampling and reliable measures of selected indicator communities of flora and/or fauna and may be used in conjunction with other measures of water quality. Waters shall be of a sufficient quality to support a resident biological community as defined by metrics based upon reference conditions. These narrative biological criteria shall apply to fresh water, wetlands, estuarine, mangrove, seagrass, coral reef and other marine ecosystems based upon their respective reference conditions and metrics.

A second major change is the proposed change to designated uses that highlights coral reefs and reef functions:

**Proposed Water Quality Standards Excerpted from USVI § 186-2. Class A Waters.**

- **(a) Best usage of waters:** Preservation of natural phenomena requiring special conditions, such as the Natural Barrier Reef at Buck Island, St. Croix and the Under Water Trail at Trunk Bay, St. John. These are outstanding natural resource waters that cannot be altered except towards natural conditions. No new or increased dischargers shall be permitted.
- **(b) Quality criteria:** Existing natural conditions shall not be changed. The biological condition shall be similar or equivalent to reference condition for biological integrity.

**Proposed Water Quality Standards Excerpted from USVI § 186-3. Class B Waters**

- **(a) Best usage of waters:** For maintenance and propagation of desirable species of aquatic life (including threatened, endangered species listed pursuant to section 4 of the federal Endangered Species Act and threatened, endangered and indigenous species listed pursuant Title 12, Chapter 2 of the Virgin Islands Code) and for primary contact recreation (swimming, water skiing, etc.). This Class allows minimal changes in structure of the biotic community and minimal changes in ecosystem function. Virtually all native taxa are maintained with some changes in biomass and/or abundance; ecosystem functions are fully maintained within the range of natural variability.
- **(b) Quality criteria:** The biological condition shall reflect no more than a minimal departure from reference condition for biological integrity.

**Proposed Water Quality Standards Excerpted from USVI § 186-4. Class C Waters**

- **(a) Best usage of waters:** For maintenance and propagation of desirable species of aquatic life (including threatened and endangered species listed pursuant to section 4 of the federal Endangered Species Act and threatened, endangered and indigenous species listed pursuant Title 12, Chapter 2 of the Virgin Islands Code) and for primary contact recreation (swimming, water skiing, etc.). This Class allows for evident changes in structure of the biotic community and minimal changes in ecosystem function. Evident changes in structure due to loss of some rare native taxa; shifts in relative abundance of taxa (community structure) are allowed but sensitive-ubiquitous taxa remain common and abundant; ecosystem functions are fully maintained through redundant attributes of the system.
- **(b) Quality criteria:** The biological condition shall reflect no more than a minimal departure from reference condition as observed at the least disturbed reference site(s) within Class C waters.

# 4. What Should We Measure?

One of the most meaningful ways to answer basic questions about the quality of waters is to observe directly the communities of plants and animals that live in them. Because aquatic plants and animals are constantly exposed to the effects of various stressors, these communities reflect not only current conditions, but also stresses and changes in conditions over time and their cumulative impacts. Bioassessment data is invaluable for managing our aquatic resources and ecosystems. We can use it to set protection and restoration goals, to decide what to monitor and how to interpret what is found, to identify stresses to the waterbody and decide how they should be controlled, and to assess and report on the effectiveness of management actions.

Understanding the purpose of bioassessments of the biological community of interest is essential, but it does little to narrow the list of possible measurements that could be made on coral reefs. Compendia of coral reef condition (e.g., Waddell and Clarke 2008) reveal a variety of measurements to characterize coral reefs and the stressors that threaten them. While there is no apparent limit to what might be measured, there is a limit on the time, cost and expertise needed to make the measurements. One solution is to select certain measurements or sets of measurements to serve as ***indicators***. These are signs or signals that relay a complex message in a simplified, useful manner. An indicator can be a measure, an index of measures, or a model that characterizes some critical component of the system.

**Indicator:** Information based on measured data used to represent a particular attribute, characteristic, or property of a system.

## 4.1 Selecting Indicators

**Indicator Guidelines**

- Relevance to purpose
- Relevance to ecological structure and function
- Responsiveness to human influence
- Power to detect differences
- Feasibility of implementation
- Interpretation and utility for management

There has been a long-standing interest in indicators both to characterize ecological condition (e.g., McKenzie et al. 1992; Cairns et al. 1993) and to inform regulatory applications and public decisions (e.g., Hunsacker and Carpenter 1990; Reams et al. 1992; Barber 1994; EPA 1995; McElfish and Varnell 2006). Different approaches for evaluating indicators are available, but most incorporate concepts similar to those presented by Jackson et al. (2000). Biocriteria require most of the same indicator characteristics. Indicator development for biocriteria entails an iterative process of review, testing, and analysis of candidate measurements.

*Relevance to purpose.* Biological assessments serve a variety of different purposes, and the purpose influences the type of indicators that will be used. Some common purposes include characterizing the current condition of the resource, determining the effectiveness of various management actions, determining the cause of undesirable conditions, identifying the consequences of uncorrected problems, or simply improving the information available to managers and stakeholders (EPA 2006a). Some indicators may address more than one purpose. For biocriteria development, the principal purpose is characterizing the condition of the resource in relation to reference conditions.

> The purpose for biocriteria is to help determine whether a waterbody meets its designated use(s).

*Relevance to ecosystem structure and function.* Measuring ecosystem structure and function is critical to determining the biological condition of a waterbody. Biological integrity is expected in areas with little or no human influence; areas under human influence probably exhibit some departure from integrity. Many taxonomic assemblages could be assessed to characterize biological condition, including reef fish, stony corals, octocorals, sponges, invertebrates, zooplankton, phytoplankton, macrophytes, and foraminifera. Reef condition may even be related to the condition of associated ecosystems such as sea grasses and mangroves. Stony corals, because they form the complex three-dimensional structures that so many species depend upon, are often selected as an assessment target. This, however, does not mean that assessments should be limited to one assemblage. Early development of freshwater biocriteria focused on fishes (Karr 1981) and has expanded to include insects and algae (EPA 1995).

*Responsiveness to human influence.* Perhaps one of the biggest challenges confronting coral reef managers is distinguishing effects of human activity. One way to evaluate responsiveness—at least local human activity—is to measure the responses of potential indicators across a gradient of human disturbance.

Measurements are made at sampling locations within and progressively removed from an area affected by humans (Figure 4-1). If human influence is significant, it can alter the responses of indicators that are sensitive to the activity. Indicators that demonstrate a reliable and consistent association with human disturbance (typically referred to as “metrics”) provide the best candidates for biocriteria development (Karr and Chu 1999). Field testing along a human disturbance gradient not only identifies which indicators are responsive, but will have the added benefit of honing protocols, identifying levels of indicator sensitivity and clarifying the sampling effort required to detect a prescribed level of change.

The primary challenge with field testing indicators is holding other confounding variables constant across the gradient of human disturbance. For example the natural influences of depth and wave action can have a significant effect on measures of coral reef condition. Other human influences such as fishing, trapping, or release of ballast water or sewage from passing ships may also influence coral reef condition.

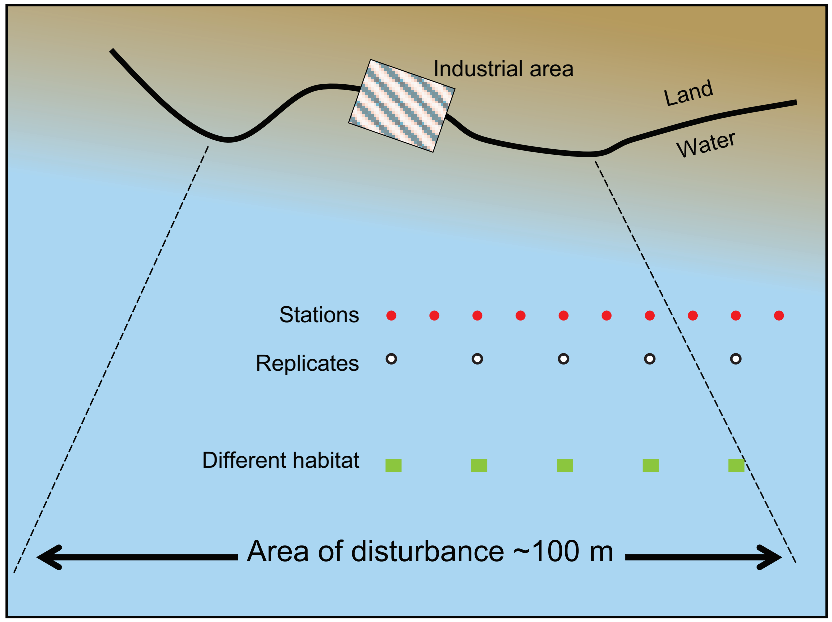



**Figure 4-1.** Schematic diagram depicting proposed sampling along a gradient of human disturbance. Shown are an industrial point source, the area of disturbance, locations of 10 sampling stations along the gradient, 5 replicate stations in a similar habitat type, and 5 stations in a different habitat type. Data from the 10 primary stations would be used to test for a biological response to disturbance, replicates would be used to evaluate precision of the assessment protocol, and data from stations in a different habitat would test for consistency of the biological response across different habitat types.

At this stage of indicator development, a consistent response to human disturbance must be documented in more than one setting to demonstrate that the indicator is reliable. Detailed information about the source of human influence may not be necessary, for example, changes in coral condition across a gradient of industrial land use can suffice. If connections can be made between certain types of human disturbance and specific biological indicators, this link can potentially identify causes of impairment and guide restoration plans; however a causal link is not necessary for indicator selection.

*Power to detect differences*. Useful indicators have the statistical power to demonstrate change. This simply means that, for the number of stations that will be surveyed, measurement errors are smaller than natural variability across the stations. In some cases differences among stations (or over time) may be small so that high measurement precision (low measurement error) will be needed to detect significant differences. In other cases, differences among stations may be large and precision will be less critical; recognizing this can save valuable time and resources. Field tests across human disturbance gradients are a good means to characterize the ability of indicators to detect differences. Indicator values within a small spatial scale are generally more alike than from a larger regional area, but stations across a human disturbance gradient are more likely to provide a wide range of responses.

*Feasibility of implementation*. The capacity of an agency to commit to long-term monitoring is sometimes overlooked in the early development of a biological assessment program. Resource assessment and trend detection generally require biological monitoring and reporting over many years; therefore, the indicators selected should represent measurements that can be expected to be sampled year after year given the available funds, equipment, expertise, and time.

Long-term monitoring is an essential component of effective biocriteria programs.

*Interpretation and utility for management.* Despite best intentions, it is possible to develop biological indicators that fulfill the above expectations but are not very useful as management tools. Some measurements may not be easily interpreted because interpretation requires additional information. Chemical and physical measurements, even those with clearly defined thresholds, don't necessarily reflect the status of biota. Without additional (biological) measurements, it may be more difficult to quantify how much reducing contaminant levels improved coral reef communities. Sometimes, measurements simply may not reflect the things we care about and therefore have little influence with stakeholders and managers. Measurement of topographic complexity, for example, will likely not be as persuasive to stakeholders as measurements of fish abundance and diversity, which depend on that complexity. Sometimes measurements may not respond within the time scale that is needed or expected by a manager; live coral cover, for example, may change too quickly to assess long term trends in reef condition.

## 4.2 Evaluating Indicators

The issues described above emphasize the importance of iterative evaluation of bioindicators. Testing, evaluation and re-testing will, in the long run, save time, money, and generate a more successful bioassessment program. A first step for evaluating indicators is to determine the question(s) to be answered and the taxonomic assemblages that are important both for characterizing biological condition and communicating reef value to stakeholders. Exploring the literature with these concepts in mind will narrow the list of candidates. Results from previous studies can be examined in the context of published evaluation information (e.g., Jackson et al. 2000). This "desktop" analysis of indicators should distill the list even further, identifying measurements that are relevant, feasible, discriminating, interpretable and potentially useful for management. These are the measurements that should be taken to the field for testing.

Carefully reviewing, testing and analyzing candidate measurements constitute a sound investment for a biocriteria program.

Field data have addressed a few of the important questions for biocriteria development in the U.S. Virgin Islands. Recent testing of candidate stony coral indicators found several measurements responded in a consistent and predictable manner to local human activity (Table 4-1). One gradient was selected along the south shore of St. Croix using an industrial ship channel as the center of a zone of human influence (Fisher et al. 2008). Another gradient was selected across the entrance to Charlotte Amalie, the major city of St. Thomas and a hub of cruise ship activity (unpublished). In both studies, a similar set of stony coral indicators showed a significant association with distance from the center of the zone of activity. However, disturbance gradient surveys may not always be as fruitful. For example, in the Florida Keys there is a small watershed and reefs occur relatively far offshore—what watershed influences there may be are likely diluted and more broadly distributed across the reefs. This does not mean that human activity doesn't affect the reefs, only that the disturbance gradient is hard to detect.

**Table 4-1.** Stony coral metric testing. Columns show the candidate metrics for stony coral, description of measurement, and whether the metric was significantly correlated with a gradient of human disturbance in St. Croix and St. Thomas, U.S. Virgin Islands (Fisher et al. 2008). Empty cells indicate that the metric did not correlate with disturbance.

| Candidate metric | Measurement | St. Croix | St. Thomas |
|---|---|---|---|
| **Abundance and Composition** | | | |
| Coral density | Number of corals per $m^2$ | | |
| Species richness | Number of species | Decrease | |
| Species frequency | Number occurrences | Depends on species | |
| Unique species | Number of taxa that are rare, unique or protected | | |
| Tolerant richness | Number of taxa | | |
| Intolerant richness | Number of taxa | | |
| **Physical Stature** | | | |
| Reef surface area | Total 3D surface area ($m^2$) of corals | Decrease | Decrease |
| Reef structure | Total volume ($m^3$) of corals per $m^2$ | Decrease | Decrease |
| Community topographic complexity | Coefficient of variation for coral colony surface area | Decrease | Decrease |
| **Biological Condition** | | | |
| Reef percent live coral | Average percent live coral for all colonies | | |
| Reef live surface area | Sum of live colony surface areas for all colonies | Decrease | Decrease |
| Reef live to dead surface area | Ratio of live to dead coral surface area for all colonies | | |

Field surveys in U.S. Virgin Islands also demonstrated the feasibility of the bioassessment protocol and demonstrated that measurement error (differences among divers making measurements) was low enough that differences among stations were statistically significant (Fore et al. 2006c). Although stony corals were examined in these studies, other assemblages could also be tested. Field testing could examine the potential of several assemblages simultaneously.

It may seem that the process for developing biological indicators is agonizing when answers for declining reef condition are needed quickly. However, biocriteria are legal thresholds and if precision, accuracy, measurement error, statistical design and protocol are not appropriate, carefully measured or documented, the stakeholders will (and should) actively oppose them. It is an iterative process that requires a rigorous approach and high quality, defensible procedures (Jackson et al. 2000; Fore et al. 2006b; Fore et al. 2006c). This should include development of Standard Operating Procedures with appropriate database management and documentation. It might also include intra- and extra-mural method validation/ variability studies and proficiency evaluations.

Ultimately, indicators could be combined into a “multimetric index”. Each indicator may signal a different structural and functional aspect of the ecosystem, so aggregation provides a broader reflection of any changes in condition. Indicators that are sensitive to human disturbance should be used in a multimetric index. Indicator responses can be adjusted to account for habitat variability (if necessary), and compiled spatially to provide a regional assessment of condition (see text box for hypothetical example).

A designated use to protect coral diversity, for example, can identify the assemblage (corals) and the purpose (diversity). An indicator for coral diversity might then include a measurement of the number of unique coral taxa found in a standardized reef area. Even so, field studies are still critical in characterizing responsiveness to human disturbance, to determine the power of the indicator to detect differences, and to generate feasible assessment methods (Table 4-2). Changes and re-evaluations should be considered a necessary part of this developmental process. The final suite of measurements that emerges still has to be incorporated into a survey design that meets logistical capabilities and the long-term commitment of the jurisdiction.

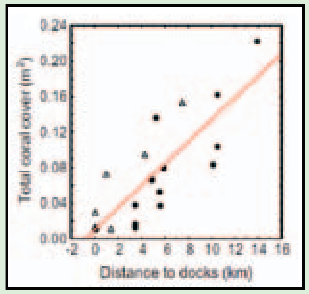
A common question is whether coral reef indicators should be able to identify or characterize sources of impairment. Identification of causes may require a measurement response that is so typical of a particular stressor that it is considered “diagnostic”. While advantageous, indicators that identify causation are not necessary for biocriteria. Biocriteria determine whether a waterbody has or has not attained its biological expectations. Biocriteria assessments provide an alert to impaired conditions and a trigger for actions that will determine cause and help restore condition.

Another question that often arises is whether biocriteria can trigger actions unrelated to the regulatory authority of the CWA. The answer is yes, because water quality standards are designed to determine attainment or impairment, not necessarily causation. Characterizing causation occurs after impairment is determined. Jurisdictions have all existing authorities available to them, including the CWA, to determine the cause(s) of impairment and take actions to restore an impaired waterbody (Fore et al. 2009). This is not unlike our approach to human health. If a routine checkup reveals a problem, e.g., an elevated white blood cell count, the doctor would order additional, related tests to determine the cause; but those tests would not be part of the routine screening. Chapter 9 provides a more complete discussion about responding to impaired waterbodies.

## Multimetric index to assess coral condition

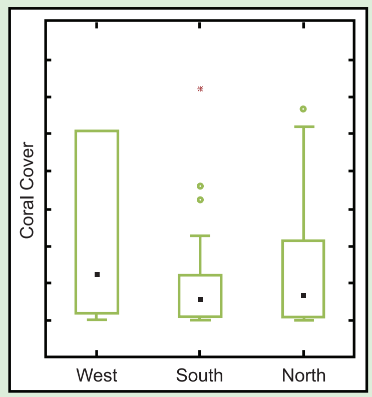
*1) Select indicators that correlate with human disturbance*

| Candidate Metric |
|---|
| # coral taxa |
| # coral colonies |
| Colony size |
| CV (colony size) |
| Coral cover |
| % living tissue |
| Live coral cover |
| % live coral |

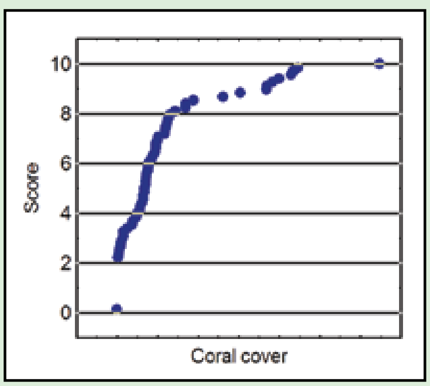



| Metric |
|---|
| # coral taxa |
| Colony size |
| CV (colony size) |
| Coral cover |
| Live coral cover |

*2) Adjust expectations for metric values based on habitat differences*

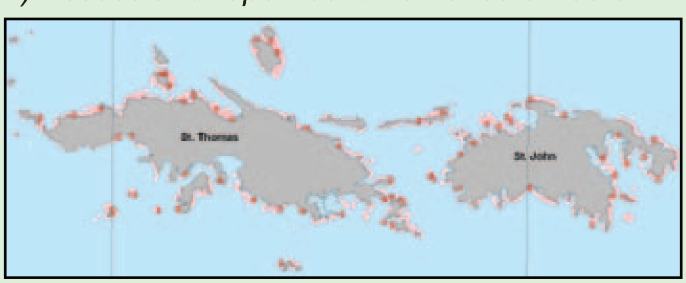



*3) Score metrics and calculate multimetric index*




| Metric scores for a reef site | |
|---|---|
| # coral taxa | 5 |
| Colony size | 4 |
| CV (colony size) | 8 |
| Coral cover | 4 |
| Live coral cover | 5 |
| Multimetric index (Average x 10) | 52 |

*4) Assess and report condition of coral reefs*




*"24% of coral reefs are impaired (below biocriteria threshold)"*

**Table 4-2.** Types of measurements and examples of indicators for coral reef benthic communities (adapted from Jameson et al. 2001 and Cooper et al. 2009).

| Type of measure | Example |
|---|---|
| **Organism** | • RNA/DNA ratio<br>• Stress genes and proteins<br>• Colony size<br>• Disease and bleaching<br>• Proportion of (live) tissue<br>• Tissue thickness<br>• Fecundity<br>• Growth rate |
| **Population** | • Density<br>• Size-frequency relationships<br>• Larval supply<br>• Recruitment |
| **Community** | • Taxa richness<br>- stony corals<br>- fish<br>- soft corals (Gorgonians)<br>- sponges<br>- macro- and micro-benthos<br>• Threatened and endangered taxa<br>• Proportions of sensitive and tolerant taxa<br>• Live coral cover; live coral surface area<br>• Trophic interactions |
| **Ecosystem** | • Primary productivity<br>• Calcification rates<br>• Bioerosion rates |
| **Landscape** | • Stony coral (skeletal) surface area<br>• Rugosity; topographic complexity<br>• Connectivity |

# 5. How Do We Assess Reef Condition?

The status of coral reefs in the U.S. has only recently been considered in terms of a formal, national assessment. Because coral monitoring and assessment is relatively new, there are no standardized monitoring programs, methods or data sets that can be used to compare across all U.S. jurisdictions. Nonetheless, scientific understanding and assessment of coral reef ecology has expanded dramatically during the past 15 years. The U.S. Coral Reef Task Force was convened in 1998 and three summaries of reef condition have been published since 2002 based on local monitoring programs and scientific studies (Turgeon et al. 2002; Waddell 2005; Waddell and Clarke 2008). In comparison, standardized methods for freshwater systems appeared only after about 30 years of monitoring (EPA 2006a).

> Coral reef monitoring is expensive, necessitating an efficient monitoring plan.

A consensus among U.S. coral reef scientists and managers is that their current ability to monitor both coral reef condition and threats is inadequate for protection (Guerry et al. 2005). One limitation for coral reef assessment, compared with biological monitoring of streams and lakes, is the expense associated with data collection in the marine environment. Coral reef monitoring requires boats, SCUBA, and the staff to manage the gear. Thus, the need for an efficient monitoring plan is particularly acute.

To assess coral reefs, we must first discover where they are. Stony coral and other reef-building organisms need hard substrate to settle and grow, and therefore occur in patterns across the sea floor where there is hardbottom substrate. When selecting locations for a coral survey design, time spent visiting locations with only sand and no hardbottom for corals translates into wasted time and resources. Until recently, little was known about the exact locations of coral reefs. Sonar mapping technology has now been used to create benthic habitat maps that accurately depict hardbottom substrate (Rohmann et al. 2005; NOAA 2009a), that is, areas that are potentially colonized by corals. These maps are useful because they identify limits and extent of potential coral reef areas and provide an essential tool to identify coral reef monitoring locations. In some cases, sonar mapping can detect hardbottom areas covered with sediment; corals may have previously inhabited these areas.

The benthic maps of hardbottom substrate are an effective way to provide estimates of the nearshore area that supports designated uses. For example, “70% of hardbottom areas support their designated uses of coral reef habitat similar to reference condition.” To make this calculation, the area of hardbottom substrate is needed. Hardbottom is specified because it is not useful to report coral reef condition for areas, such as soft sediment, that are incapable of supporting reefs.

Once the appropriate habitat type has been identified, e.g., hardbottom for coral reefs, a survey design may be used to select specific locations for data collection. The choice of survey design depends on the purpose of the survey. Typically, research studies are designed to answer specific questions about coral reef ecology; and a targeted sampling approach selects site locations according to scientific criteria. In contrast, for regional reporting of status and trends, selecting coral reef sites randomly provides an unbiased estimate of the condition of all coral reefs (Stevens 1994; Olsen et al. 1999).

**Different types of monitoring answer different questions**

**Probability sampling** allows estimates of aerial extent for:

> Status assessments: to characterize the condition of the resource and to address questions such as "*what percentage of coral colonies in the nearshore environment have greater than 50% living tissue*?"
>
> Trend assessments: to detect change over time and address questions such as "*has coral surface area decreased across the region?*"

**Targeted sampling** evaluates conditions and process at specific locations, and can be used to address questions such as "*how does sediment affect coral survival*?"

## 5.1 Probabilistic Sampling Design

As part of water resource monitoring, states should include a random survey design that is founded on random site selection. Why sample randomly? The key benefit is free information. If site selection is random, information from the sampled sites can be used to infer the condition of sites not sampled. Thus, results based on a random sample of sites can be scaled up to the entire population of sites within a region. The only other way to assess every site in a region would be to sample each one, i.e., take a census. Thus, random sampling is similar to polling in which the opinions from a random subset of households or individuals are used to predict an election outcome.

When sites are selected using a simple random sampling design, they will often be clumped on the landscape. EPA scientists developed a probabilistic survey design that is still random, but uses a more sophisticated selection algorithm to spread sampling locations more evenly across the landscape (EPA 2008a). EPA's probabilistic survey design is more efficient because sites are

**Census:** Sampling every member of the population, i.e., every site on every coral reef.

**Random Sampling:** Selects a subset of all coral reef sites to ensure that the sample is "representative" of all coral reefs and the estimate of condition is unbiased.

**Probabilistic Sampling:** A type of random sampling that yields a spatially balanced subset of sites, and avoids the clumping associated with simple random sampling.

far enough apart from each other that they contribute independent information about the condition of the resource. In other words, neighboring sites do not contribute redundant information about resource condition. The probabilistic survey design recommended by EPA for resource monitoring yields a more representative sample of resource condition while preserving random site selection and an unbiased sample.

Probabilistic surveys can also support the regional reporting required under the CWA (Section 305b) because they provide summary statistics for all areas included in the survey design, not just selected locations, segments or areas. The primary advantage of a probabilistic survey design for assessing coral reefs is that data from the sites sampled provide an unbiased estimate of biological condition for all coral reef areas. Furthermore, these regional estimates of coral reef condition can be compared through time (see also Section 6.3).

Regional sampling of coral reefs in the U.S. Virgin Islands provides an example of the consequences of different agency mandates for coral protection. Regional, random sampling of coral and fish within Buck Island National Monument (St. Croix) has been extensive and long-term (Figure 5-1). Extensive long-term monitoring has also been conducted at St. John's National Park. Although this sampling effort for federally-protected waters has been substantial, the data cannot be used to describe other segments of the USVI coastline that were not included in the survey design.

In contrast, EPA's probabilistic survey in USVI collected data from all coral reef areas in St. Croix because EPA's mandate is to assess the condition of the entire water resource (Figure 5-1). Although regionally more comprehensive for USVI's nearshore areas, EPA's survey was nonetheless restricted to coral reefs less than 12 m deep to minimize dive time.

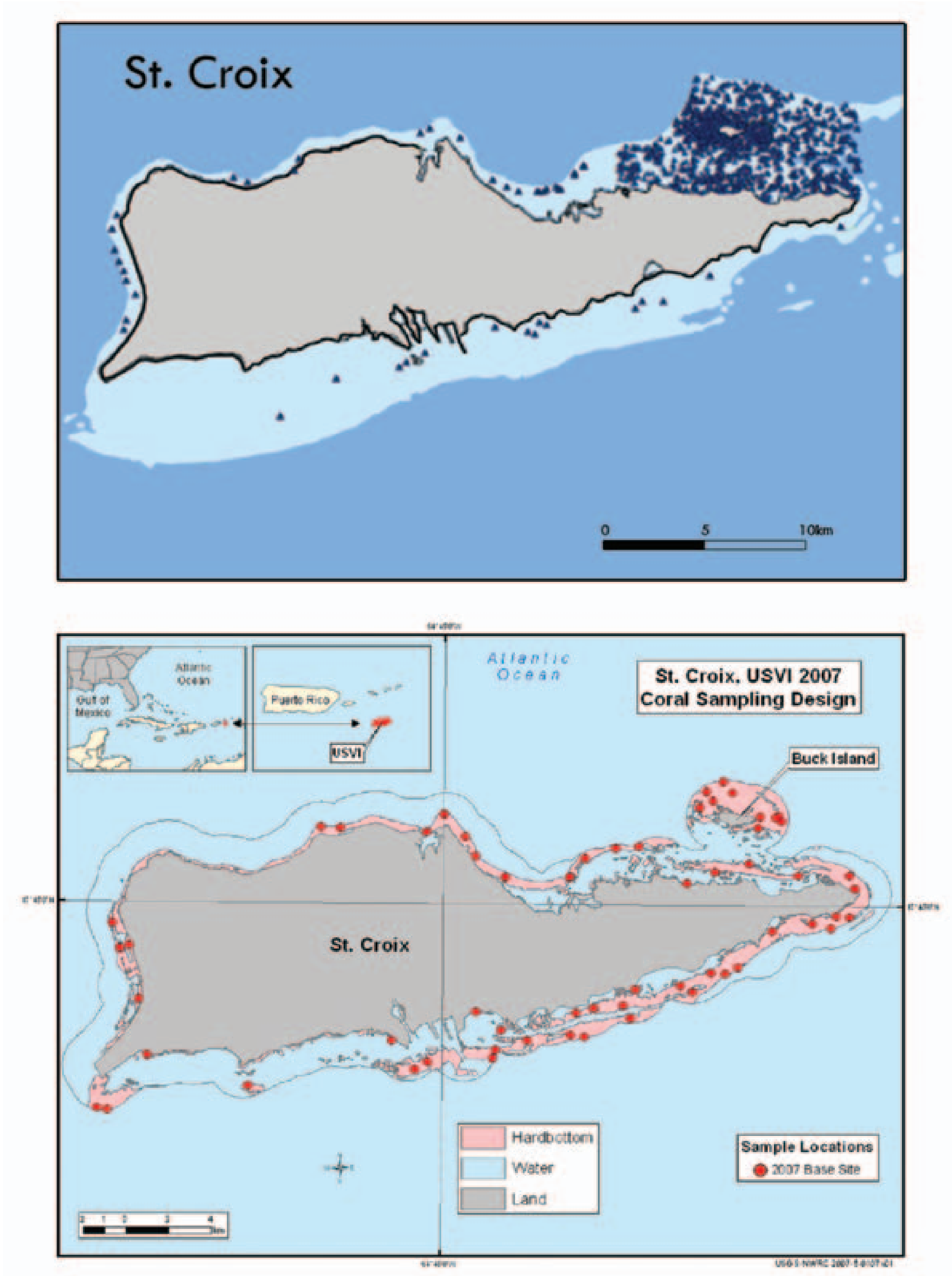



**Figure 5-1.** Contrasting survey designs for coral reefs around St. Croix, U.S. Virgin Islands. The top map shows sampling stations within Buck Island National Monument and limited sampling around the rest of the island (Waddell and Clarke 2008). The bottom map shows station locations for a probabilistic survey design conducted by EPA. Randomly selected locations are spread evenly across the hardbottom substrate (pink) occurring at <12m depth and within 1.5 km of shore. Data from this survey design represent the entire island.

To assess status or trend, the primary advantage of random site selection is that any summary statistics derived from the sites sampled will be representative of the entire population, including all the sites that were not sampled (Figure 5-2). In contrast, data from a non-random site selection might only be representative of the sites sampled and their immediate surrounding area.

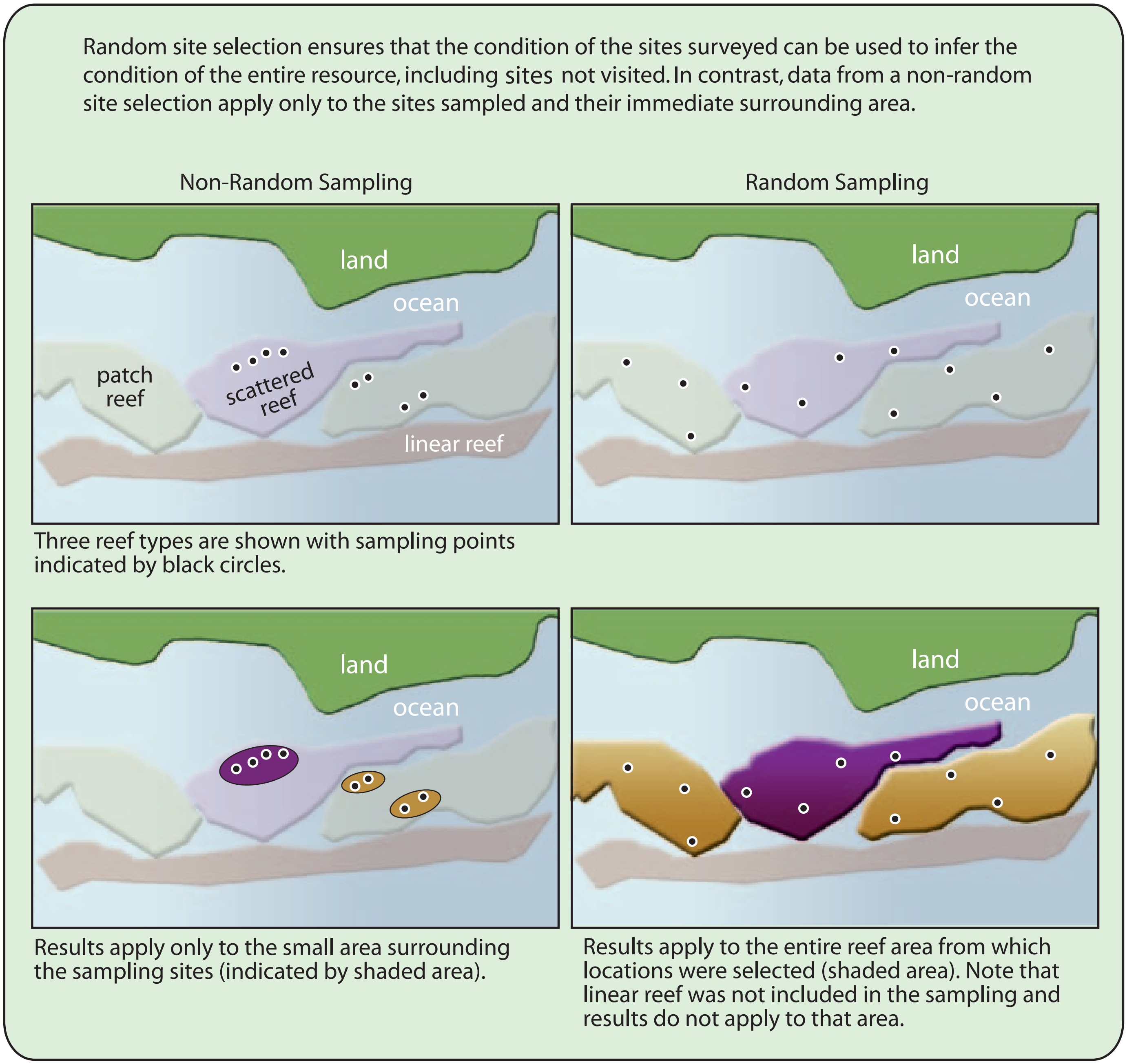



**Figure 5-2** Comparison of random and non-random sampling design (Fore et al. 2006a).

## 5.2 Implementing A Probabilistic Survey

A probabilistic survey selects sampling locations such that the data collected at those sites can be used to estimate condition for the entire area of interest. The primary steps for implementing a probabilistic survey are summarized below, but EPA's Aquatic Resource Monitoring Website should be consulted for greater detail on defining the target population and sampling units, selecting reef locations, and collecting and summarizing data (EPA 2008a). Because the probabilistic survey approach recommended by EPA is more complicated than a simple random survey, EPA has developed open source software that can be used to select sites from digital maps (shape files) and to properly calculate summary statistics and their confidence estimates.

*Define the target population.* Although in biology the term "***population***" typically refers to a single group within a species, in statistics population refers to the complete set of whatever you are sampling. For example, the target population for coral reefs might be defined as "all hardbottom substrate within 1.5 km of shore to a depth of 12 m." Sonar mapping technology cannot reliably distinguish between hardbottom with or without coral, nor can it discern whether the coral are living; therefore, the target habitat is typically referred to collectively as hardbottom substrate. Different shapes and types of hardbottom can be distinguished such as linear reef, spur and groove, or pavement. As a consequence, survey designs can selectively emphasize different types of reef.

**Population:** The entire aggregation of items from which samples can be drawn. Populations may be discrete (made up of separate individuals) or continuous (without break or interruption).

Corals grow at a variety of depths, but if data collection requires SCUBA, restricting the depth of the dives makes a safer, less time-consuming monitoring program that may be easier to implement and sustain over time. In addition, monitoring in the more shallow reefs might detect the first effects of land-based pollution. Thus, the target population of coral reefs for a probabilistic survey may be defined in a variety of ways according to different depths, locations, or distances from shore; however, the key point is that the target population is explicitly defined before sampling begins so that when summary statements about reef condition are made, everyone understands which reefs are being described.

The population to be assessed must be explicitly defined.

*Define the target sampling unit.* Coral reefs are a continuous resource and do not array themselves into convenient patches of standard sizes; therefore, reefs need to be divided into discrete sampling units. For surveys of people, the sampling units are typically easier to define, such as a registered voter. For coral reefs the target population is continuous and must be broken into individual sampling units using some formula.

For a probabilistic survey design, the sampling location is selected randomly, but we must also define the size of the sampling plot around the location. The plot area must be large enough to provide a reliable estimate of resource condition at that location but small enough to complete sampling within a reasonable amount of time. Thus, for a coral reef monitoring program, the size of the plot area should be the smallest area that yields consistent estimates of coral measures. To test whether the plot area was adequate for coral assessment in USVI, a 50 $m^2$ transect area was used (Fore et al. 2006a). All coral colonies within the transect area were identified and measured. During data collection, divers marked their data sheets for each quarter of the area, that is, for each ~12 $m^2$. Coral indicators derived from the smallest areas (~12 $m^2$) were highly variable and did not provide a consistent estimate of coral condition for the site. In contrast, moderate sized transects of 25 $m^2$ area provided estimates of coral condition that were nearly identical to estimate derived from the entire transect. Consequently, for subsequent surveys, a plot size of 25 $m^2$ was used.

For a regional survey design, it is generally true that less information from more places provides a better estimate of resource condition than does more detailed information from a few places. Larger sample sizes yield greater confidence for the results of comparisons as well as tighter confidence intervals around any estimates of resource condition.

*Select a representative sample of reef sites.* A probabilistic survey is intended to characterize the entire population of interest; therefore, the entire target population should be precisely defined and have an equal (or known) chance of being included in the sample. If coral reef sites are selected based on proximity to a harbor or accessibility from a pier, they cannot be used to accurately predict the condition of the entire resource. Similarly, if you polled only your neighbors about their political opinions, you are unlikely to obtain an unbiased prediction for the outcome of a national election.

> We should be able to quantify the probability that a location may be included in a sample. All locations do not need to have an equal probability of inclusion.

The probability of including every possible location does not need to be equal, but it should be specified, or known, for each location. For example, managers may be more interested in the condition of linear reefs because they are the source of the most tourism income; therefore, they might allocate 50% of their annual sampling effort to these habitat types even though linear reefs represent only 10% of the total coral reef area.

*Collect data from sample sites.* Protocols for sites to visit and how to collect data need to be in place before field crews begin to collect data. If methods and locations are carefully defined, agencies can more easily form partnerships to collect the data for a probabilistic survey of coral reef condition. Other groups doing reef studies could collect data if they are near a selected site conducting their own field work. The Florida Reef Resilience Program (FRRP) is a good example of this type of agency cooperation: the standardized data collection protocols have facilitated four years of coral reef survey information from over 600 coral reef sites accomplished by volunteers and partners throughout the region (TNC 2009b).

## 5.3 Trend Detection

The data derived from a probabilistic survey design can be applied in three different ways to detect a trend in coral reef condition through time. First, reef sites can be randomly sampled each year and a biological measure, e.g., coral cover, compared from one year to the next year of sampling. In this case different sites are sampled each year. The advantage of this approach is that new sites are sampled and assessed each year. A second approach also selects new sites each year, but rather than comparing the raw indicator values from the sites, thresholds from biocriteria are applied to the data from each site and the percentage of sites supporting their designated uses is calculated for each year and compared through time. The advantage of this approach is that it accommodates measures of coral condition that are highly variable. In this case, translating indicator values into a binomial response variable (i.e., supports/fails to support) limits the variance and simplifies reporting and comparisons.

For the third approach, a probabilistic design is used to randomly select sites only during the first year. Subsequent years of sampling return to the same sites and the trend analysis compares coral condition at each site to itself through time. The primary advantage of this last approach is that revisiting the same sites through time is the most sensitive design for detecting temporal change in reef condition.

## 5.4 Analyzing Data From A Probabilistic Survey

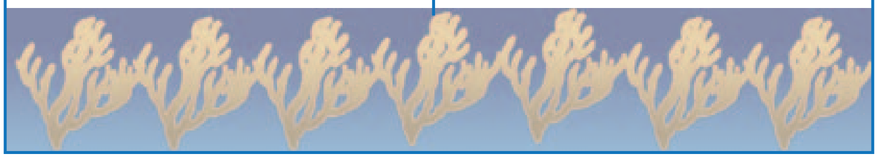
The methods used to calculate summary statistics from a probabilistic survey need to match the survey design used to collect the data. In other words, the survey design and analysis method must be derived from the same statistical mode. The probabilistic survey design recommended by EPA is somewhat complex because 1) the sites are selected from a continuous resource rather than discrete sampling units such as households, and 2) the algorithm used to select sites introduces complexity into the calculations to obtain a more even spread of sites across the landscape. To support states, EPA has developed open source software that can be downloaded from Aquatic Resources Monitoring Website to calculate summary statistics such as the mean and confidence limits for estimates of biological measures (EPA 2008a).

A primary objective of a probabilistic survey is to obtain a representative and unbiased estimate of reef condition and to compare estimates through time to detect trend; but the data derived from a probabilistic survey can be used in a variety of ways, such as, to make regional comparisons of reef condition, to test for correlation between coral reef condition and independent measures of disturbance, or identify unique areas with coral reefs of exceptional quality. If sites are selected for inclusion in a probabilistic survey design with approximately equal probability, most of these analyses do not require any special statistical methods or EPA's analysis software. However, if some areas are surveyed with a much higher intensity, then a subset of sites from these regions should be used for regional analysis and comparisons to avoid biasing the analysis with too many sites from one area. In contrast, estimates of regional condition and trend detection do require some special considerations for statistical analysis.

A clear description of the target population should accompany any summary statistics when results are reported. For example, if a 3% decline in coral cover were observed for the target coral reef population described above, this result would only apply to reefs within 12 m of the surface and within 1.5 km of shore. Conclusions should not be extended to deeper reefs or reefs further off shore. The survey data, with confidence limits to provide an estimate of the uncertainty associated with the statistics and thresholds for biocriteria can be used in determining what percentage of the coral reef waters are supporting their designated uses.

# 6. How Are Reefs Doing?

| Coral Monitoring Programs | Coral Biocriteria Monitoring Programs |
|---|---|
| Are coral reefs improving or declining? | Are coral reefs improving or declining below acceptable levels? |



Once indicators are selected for monitoring reef condition and data have been collected using an appropriate statistical design, decisions need to be made. Results of monitoring guide the next steps of action. What actions should be taken depend on the data. Are the reefs healthy or degraded? If degraded, is the level of degradation acceptable or is restoration needed?

One purpose of biocriteria is to support decisions and actions by U.S. jurisdictions. If the waterbody attains its uses, no action other than reporting is necessary. But if the waterbody is impaired (fails to support its designated uses), the cause of impairment should be determined and restorative actions taken. Simply stated, biocriteria programs use biological monitoring to inform resource managers and stakeholders whether the waterbody is meeting its expectations. Biological information may be useful in distinguishing between different types of impairment.

To make this determination requires standards for comparison. Thresholds must be established to reflect expectations for the waterbody. These thresholds, or criteria, guide decision-making.

Numeric biological criteria are derived from measures of biological condition observed at reference locations. These values become the thresholds for criteria. Numeric criteria are expressed as values of the biological community related to the extent, numbers and kinds of organisms expected in a waterbody. For example, a numeric biological criterion might be expressed as a minimum percentage of coral cover, a minimum number of coral species in a defined region, or a maximum number of nonindigenous fish.

Many challenges remain for insightful definition of impairment thresholds. One is that declining environmental condition (Figure 6-1) is not usually characterized by conspicuous breaks or jumps in indicator values, discontinuities that would clearly identify good and degraded condition. So how do we determine what amount of degradation is too much? Where do we draw the line?

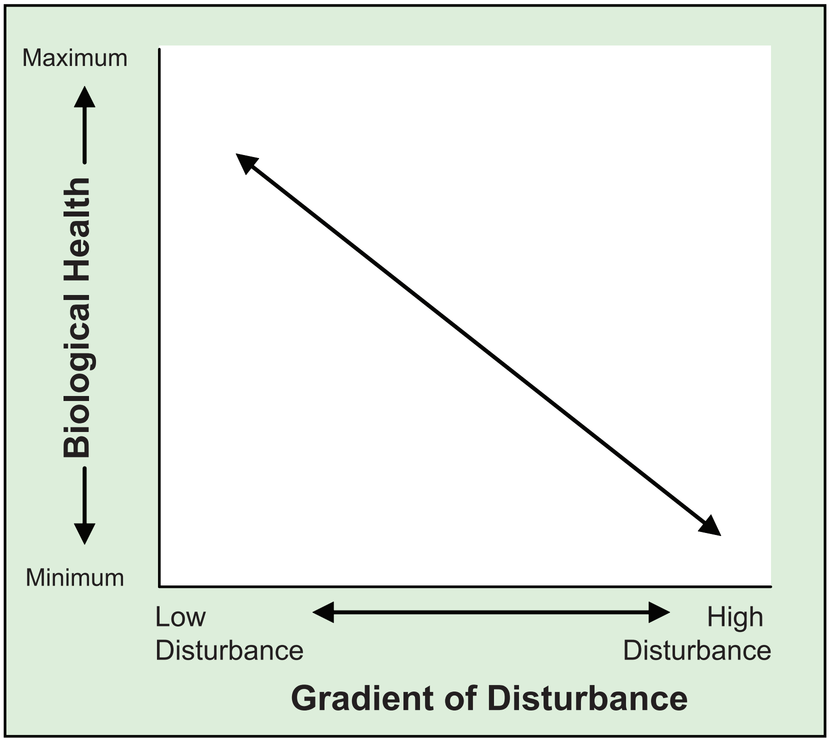



**Figure 6-1.** The challenge of establishing thresholds. How much degradation is too much? Where do we draw the line?

## 6.1 Impairment Thresholds

EPA recommends a reference site approach for setting thresholds that define whether sites in a region support aquatic life uses (EPA 1990). This approach identifies a set of reference sites intended to reflect attainable conditions within the region to describe the biological condition expected for ecologically similar sites (EPA 2006a; EPA 2006b). Sites are selected based on minimal or no human influence within their watershed and coastal zone. If indicator values from other sites fall within an acceptable range of the distribution of reference sites (typically scores above a chosen percentile) then these sites attain their aquatic life designated uses. Other sites that fall below this percentile do not have the same or better condition and likely do not attain their designated uses; these are listed as impaired.

Typically, ***reference condition*** is derived from samples collected from a set of regional locations, or reference sites, with minimal human influence. The set of reference sites is used to approximate the natural condition of a region (EPA 2006; Hughes 1995; Stoddard et al. 2006). To avoid circularity, reference sites are selected based on objective and independent measures of site condition and human influence, not measures of biological condition.

In some areas ***minimally disturbed reference conditions*** no longer exist and may not be achievable. In these situations, states have defined an acceptable condition using ***"least disturbed sites"*** that establish a desired condition based on the best quality sites available. In these cases (least disturbed), a demonstration that the existing biological community structure and function is representative of a sustainable, natural system is necessary. If not, a Use Attainability Analysis (UAA) needs to be conducted to determine whether such a community is achievable under CWA provisions or a lower use is proposed that does not meet the minimum requirements for the CWA.

In heavily disturbed landscapes states may choose a “best potential” condition to establish as restoration goals which may be identified from “the best of what’s left”. Other approaches have used historical data sets to reconstruct a description of biological condition and empirical modeling to extrapolate from existing sites (Hughes 1995).

Measurements of biological condition at reference sites will generate a range of values for each indicator. EPA recommends a state agency define biocriteria for an upper and lower percentile of this distribution of values, e.g., the 75th and 25th percentile. The selection of the upper percentile is intended to protect higher quality aquatic communities and the lower percentile the minimum level to protect the aquatic life use. States may select the upper percentile of this reference site distribution to reflect a refined aquatic life use, such as an exceptional quality use. The specific percentile selected depends on the relative confidence associated with the selection of reference sites. Reference sites can also vary through time; see Chapter 7 for a discussion of the effects of spatial and temporal variability on reference sites.

**Reference condition:** Areas that are undisturbed or minimally disturbed by human activity

**Minimally disturbed condition:** Areas with a minimal amount of human disturbance

**Least disturbed condition:** Areas with the least amount of disturbance in altered landscapes

**Biological condition gradient (BCG):** A scientific model that describes biological response to increasing levels of stressors.

A useful tool to visualize where the reference sites and decision points lay on a scale from pristine to severely degraded is the ***biological condition gradient*** (BCG), which illustrates a range of biological responses that can result from human disturbance (EPA 2005 and Davies and Jackson 2006). The condition of aquatic biological communities typically degrades with increases in the level of human disturbances.

One advantage of the BCG approach is its capacity to incorporate historical and regional data, especially in cases where existing reference sites may already have declined below the conditions desired by the community. The BCG is a conceptual model that assigns the relative health of aquatic communities into one of six categories (Figure 6-2, EPA 2005a), which attempt to characterize what we would expect at a reference site through a progressive loss of structure and function as a result of human disturbance. At some point along this gradient, the designated aquatic life use is no longer supported.

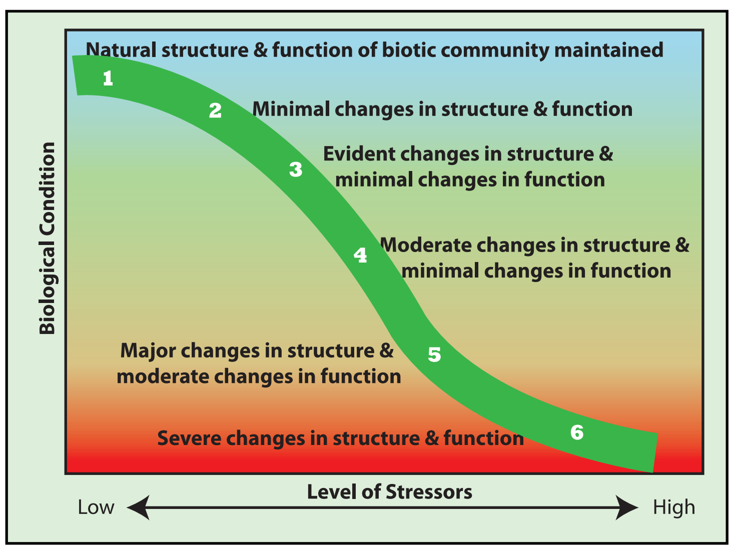



**Figure 6-2.** Biological Condition Gradient (BCG).

Across the range of biological condition, the BCG recognizes ten biological attributes (see text box) of aquatic systems which respond predictably to increasing human disturbance (e.g., pollution, sediment, loss of habitat and overfishing). The attributes of biological systems included in the BCG were developed initially for freshwater systems and though generally applicable to marine systems, may change somewhat when the BCG is applied to coral reefs. The BCG attributes relate to taxa richness of sensitive, rare, tolerant, and non-native taxa, the physical condition of individual organisms, and other measures of ecosystem processes and function. While these ten attributes are measurable, some are not routinely quantified in monitoring programs, but may be inferred via the community composition data. For example, productivity might be inferred from the abundance of taxa that prosper with nutrient enrichment.

The BCG provides a very useful general framework for summarizing and communicating the ecological condition of any aquatic community for any type of waterbody. The BCG for freshwater streams was developed, evaluated and implemented by aquatic biologists during a series of national workshops sponsored by EPA (Davies and Jackson 2006; Stoddard et al. 2006). The framework for the BCG is generally applicable to any biological water resources, but has yet to be applied to coral reefs.

Assigning waterbodies with coral reefs into BCG tiers will help to provide a more refined assessment tool for evaluating and protecting coral reefs. Consideration of biological, physical, chemical, and hydrological data in the context of the BCG allows scientists and managers to strategically address the following questions:

- What is the current condition of this waterbody?
- What is its highest achievable goal condition?
- What are the actions needed to protect/restore it to maintain/attain its goal condition?
- Did the actions taken achieve the desired results, in terms of optimal biological outcome?

Several state freshwater monitoring programs are now based upon sound applications of BCG-based biocriteria. These programs are producing more effective and innovative water resource management approaches to prevent and to solve biological problems (e.g., Best Management Practices to reduce effects of impervious cover; evolution of progressive

**10 Attributes of Biotic Condition**

1. Historically documented, sensitive, long-lived or regionally endemic taxa
2. Sensitive and rare taxa
3. Sensitive but ubiquitous taxa
4. Taxa of intermediate tolerance
5. Tolerant taxa
6. Non-native taxa
7. Organism condition
8. Ecosystem functions
9. Spatial and temporal extent of detrimental effects
10. Ecosystem connectivity

land-use and shoreline protection rules; and tiered aquatic life use (TALU) standards that trigger antidegradation provisions under the CWA). The clarity and simplicity of the BCG facilitates understanding of highly technical biological assessment and stressor information by upper management and the public. The BCG is an invaluable communication and learning resource that adds value to all aspects of the biological management of water quality.

## 6.2 Application of Thresholds

For coral reef communities, thresholds have yet to be defined as biological criteria. For Mesoamerican reefs in the western Caribbean, threshold values were defined for indicators of coral cover, herbivores and algal cover using a reference site approach (HRI 2008). Results were summarized in the style of a regional report card illustrating where reef condition ranges from good to poor condition.

Preliminary results in the U.S. Virgin Islands have identified indicators related to coral and sponge condition that were correlated with independent measures of human disturbance (Figure 6-3). Using the BCG, generalized reef conditions and potentially even thresholds could be derived from these data but would need to be confirmed with data from other regions and vetted by regional coral experts.

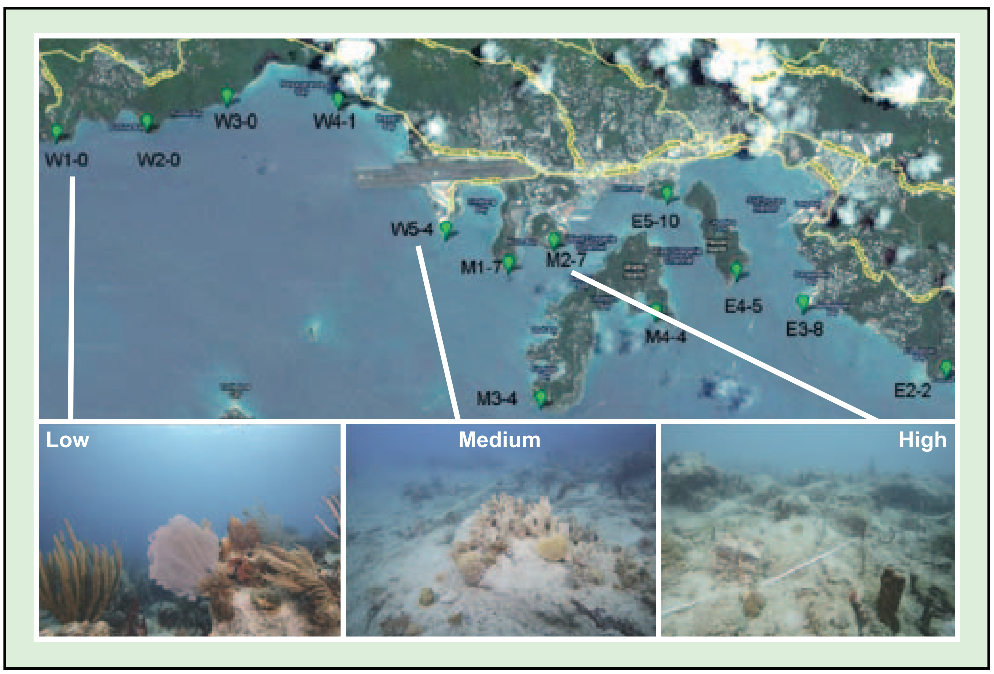



**Figure 6-3.** Human Disturbance Gradient. Human disturbance around St. Thomas Harbor was summarized according to a qualitative description of human disturbance (low, medium and high) related to industrial development, residential development, cruise ship traffic, small boat traffic and roads. Measures of reef cover, stony corals, octocorals, and fish were compared across the gradient. As human disturbance increased, rugosity, stony coral and octocoral cover, stony coral colony size, surface area, live surface area and variability of colony size all declined; the number of sponges increased. In addition the number of colonies of four reef building stony coral species also declined.

Before biocriteria are adopted, they undergo public comment on their scientific merit. Once agreement is reached, then the thresholds can be incorporated into legally-binding water quality standards regulations.

There is potential for confusion around the term *biological criteria*. As a first step toward numeric criteria, states often define narrative criteria to protect aquatic life; but, states still need quantitative thresholds to determine whether designated uses are supported. Typically these are defined in standard operating protocols that may not be part of the of water quality standards. These quantitative thresholds are also referred to as biocriteria even though they are not explicitly documented in water quality standards. Thus, biocriteria may refer to 1) the procedures used to establish benchmarks and determine whether aquatic life designated uses are being met and 2) the numeric criteria in water quality standards. In other words, biological criteria can be used to assess attainment of aquatic life designated uses without being formally adopted into a state water quality standard.

The impairment threshold is particularly important, but the BCG can highlight the need for other thresholds relevant to the third component of state water quality standards, that is, the antidegradation policy. The *antidegradation* policy is intended to ensure:

1. The water quality necessary to support existing uses is maintained.
2. Water quality is maintained and protected wherever water quality exceeds the minimum level necessary to support protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water (“fishable/swimmable”), unless, through a public process, some lowering of water quality is deemed necessary to allow important economic or social development to occur.
3. Water quality is maintained and protected for waterbodies of exceptional recreational or ecological significance (EPA 2009b).

One application of the BCG is to help define high quality and outstanding waters and ensure that they are protected. The BCG can also be used to distinguish between the aquatic life uses that were supported historically but that cannot be attained today. Thus, the BCG provides a framework to evaluate biological assemblages according to six categories of condition ranging from natural condition to severely altered condition and provides a conceptual model to identify different tiers of aquatic life use to set appropriate expectations for protection (Davies and Jackson 2008; EPA 2005).

A state following this independent applicability approach would identify a waterbody as attaining a particular water quality standard only when all of these applicable numeric and narrative criteria (including biocriteria) are in attainment, that is, supporting the designated uses (EPA 2005).

## 6.3 Threshold Trends

The goal of trend monitoring (Section 5.3) is to detect actual change in reef condition throughout the region of interest. Existing monitoring programs sometimes track condition at trend sites that were selected in the past based on best professional judgment or other non-random criteria.

Biocriteria thresholds for water quality standards may be used when reporting the results of trend monitoring. From a probabilistic survey design, the percentage of sites supporting their designated uses can be calculated along with a confidence interval for the percentage. The percentage of sites supporting their designated uses can be compared across years and if the differences exceed the confidence intervals around the percentages, a statistically significant change would be reported.

Monitoring for temporal change requires a long-term commitment to repeat sampling and a specific survey design. At the outset, an estimate is made of the number of sites that can be sampled each year. These sites should be allocated to status, trend and targeted sampling according to agency needs. A rotating panel design is an efficient way to structure monitoring and sampling effort over time (Table 6-1).

**Table 6-1.** Example of a rotating panel design for the U.S. Virgin Islands. The panels represent three subregions of the U.S. Virgin Islands (the larger St. Croix divided in two parts). During the first year, 50 sites would be randomly selected: 10 for trend and 40 for status reporting. During the next 3 years, similar sites would be selected in the remaining subregions. During the 5th year, the first subregion is visited again and the same 10 trend sites are sampled along with 40 new random locations for status monitoring.

| Subregion | Numbers and Types of Stations per Year | | | |
|---|---|---|---|---|
| | Years 1, 5, 9… | Years 2, 6, 10… | Years 3, 7, 11… | Years 4, 8, 12… |
| East St. Croix | 10 trend 40 status | | | |
| West St. Croix | | 10 trend 40 status | | |
| St. Thomas | | | 10 trend 40 status | |
| St. John | | | | 10 trend 40 status |

The area of the target population is first divided into subregions – the "panels." Each year a different panel of sites (subregion) is visited and sampled – the "rotation." Sampling within each subregion saves money by reducing travel time to sampling sites. After a certain number of years, typically three to five, the original panel is visited and sampled again. Sampling the same trend sites every year is inefficient when change occurs slowly. In this design, trend sites are sampled every year, but from different panels. Thus, comparisons occur every fifth year if sites are grouped into four panels.

The key point to a rotating panel survey design is that the same sites on each panel must be sampled during their designated year. If a trend site is lost for any reason, another site cannot simply be substituted. In addition, a panel of sites must be sampled according to the same schedule; sites must not wander from one panel or sampling period to another. The success of any long-term monitoring depends entirely on an adequate data management plan in order to keep the data alive through time. Comparisons may be made 5, 10 or 15 years later; therefore, the data archive must be resilient enough to survive personnel changes and computer upgrades.

# 7. How Do We Account for Reef Variability?

Those familiar with coral reefs know there can be dramatic differences from one reef to the next. Coral communities occur in different locations and are composed of many different organisms living in a variety of physical and chemical environments. Without these differences, reefs would lose much of their value. But variability among reefs can complicate the use of standardized measurements and thresholds. Similarly, changes in reef condition over time create challenges for establishing reference conditions. But spatial and temporal variability are not unique to coral reef ecosystems, and strategies have been developed to account for this variability.

## 7.1 Spatial Variability

Coral reefs vary across locations, even locations that are close to one another. Should we, in spite of this variability, use the same measurements and thresholds for all locations? Or should we develop unique approaches for any locations that differ in substrate, habitat, biota, hydrology or other environmental factors? During the development of biocriteria for freshwater systems, researchers grappled with this issue—how to best minimize the effects of spatial variability on measurements and thresholds. Fortunately, the strategies that were developed can be directly applied to coral reefs. Two strategies relate to the concepts of ***ecoregions*** and ***microhabitats*** (Figure 7-1).

**Ecoregion:** A relatively homogeneous ecological area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables (also known as bioregions).

**Microhabitat:** Small-scale changes in habitat that alter ecosystem structure and function.

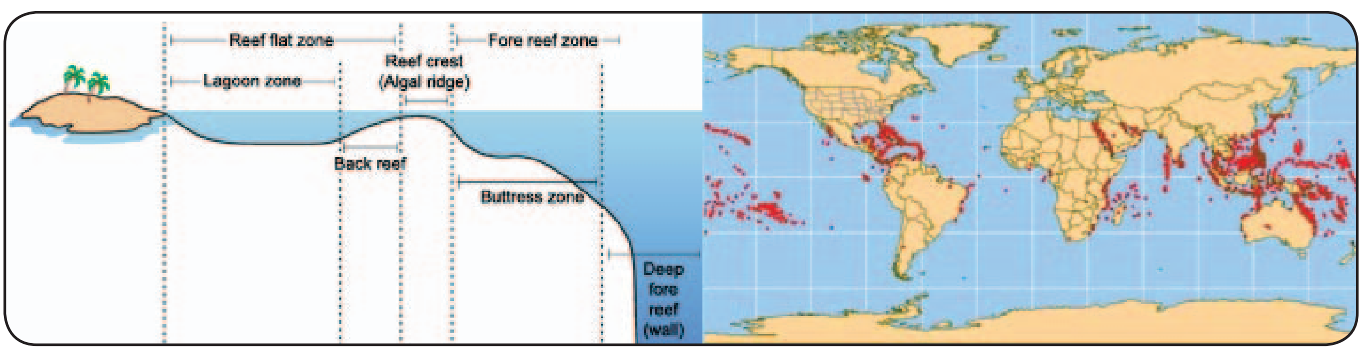



**Figure 7-1.** Scales and coral reef communities. The left graphic shows the microhabitat scale, the right graphic shows the geographic or ecoregion scale (NOAA 2009b).

Fish communities found in streams flowing through forested foothills differ radically from fish communities in streams of plains and deltas. To address this variability, an ecoregion approach has been used to identify unique geographic areas based on geology, soils, geomorphology, dominant land uses, and natural vegetation (Hughes and Larsen 1988). Typically, indicators are tested and selected within an ecoregion. Indicator values from undisturbed sites are compared across ecoregions (and sub-ecoregions if necessary) to determine whether expectations (thresholds) should be raised or lowered. If no differences are found in indicator values, the classification is unnecessary and ecoregions can be combined.

Although ecoregions have not been developed for coral reefs, we know that reefs in the Caribbean and western Atlantic Ocean are substantially different from reefs in the Pacific. These two large geographic areas could be defined as separate ecoregions with different reference conditions, indicators and thresholds. But there could also be finer ecoregion classifications. For example, reefs of the Florida Keys (dominated by large scleractinian corals) differ markedly from reefs of southeast Florida (dominated by gorgonian octocorals). The State of Florida could potentially develop biocriteria that rely on different taxa and region-specific thresholds. Comparisons across regions could be used to determine if this is appropriate or even necessary.

A single standardized protocol for biocriteria is more efficient and makes comparisons and reporting easier, particularly at the national level. EPA recently completed a nationwide survey using standardized data collection and analysis protocols for assessing stream condition (EPA 2006a). Nonetheless, many states still use protocols for bioassessment that are calibrated more specifically to their regional conditions.

Variability also occurs at a smaller scale related to microhabitat differences.

"*Micro*" does not refer to the importance of the differences—the differences can be quite dramatic—but to the spatial scale. For coral reefs, microhabitat differences might be associated with depth or wave energy (Glynn 1976; Grigg 1983). The challenge for biocriteria development is to select measurements and thresholds that are relevant at a regional scale despite microhabitat variability. The best solution is to identify indicators that are immune to microhabitat differences, but this is not always possible. A variety of strategies have been used to address microhabitat differences.

For example, in the Chesapeake Bay benthic invertebrates are collected to assess the biological condition of the estuary. The indicators used to summarize biological condition vary according to salinity of the water and the amount of silt in the sediment. To compensate for these small-scale differences, expectations for benthic invertebrates are defined for seven habitat types: tidal freshwater, oligohaline, low mesohaline, high mesohaline sand, high mesohaline mud, polyhaline sand, and polyhaline mud habitats. The benthic index is scaled for each of these habitat types so that the final index values are comparable for all estuarine sites across the region.

Similar strategies could be used to identify the most important natural features that influence coral reefs. The driver could be habitat type (e.g., fore reef, back reef, patch reef) or underlying physical processes (currents, depth, wave energy). Fisher et al. (2008) identified indicators of stony coral that showed a consistent response to human disturbance despite differences in reef habitat type. However, if greater detection power were needed, data collection might be limited within a region to a single habitat type. Alternatively different expectations of condition could be established for different physical environments. Despite potential strategies and promising indicators, the natural spatial variability of coral reefs is an area where research is still needed (Jameson et al. 2003; Rodgers et al. 2010).

## 7.2 Temporal Variability

The intent of the CWA is to restore and maintain the biological integrity of aquatic resources to a level matching conditions unaffected by human disturbance. Yet finding reference locations with no human impact is unlikely. So, we must decide whether to establish reference conditions from minimally-impacted locations with present-day measurements, or to rely on historical data—and if so, how far back in history should we reach?

Historic conditions, especially those that preceded human activity, would be rated high on the BCG. Setting expectations at historic levels of biological integrity would certainly be protective; however, defining historic conditions requires historic reef assessments that are both scientifically defensible and provide a reasonable characterization of biological condition for the region. Rarely are such data available.

Historic data for coral reef ecosystems is scarce because they could not be widely studied until the late 20th century when diving equipment became available. Relevant data on conditions prior to human influences are rare, although a few studies provide valuable insights to previous, if not historic, condition (Dustan 1977; Dustan and Halas 1987; Porter and Meier 1992).

Consequently, coral reef biocriteria may have to rely on reference conditions derived from present day reef assessments, which are unlikely to represent the biological integrity typical of historic condition. Loss of integrity over time can result in a shifting baseline, that is, a lowering of our expectations for what good conditions should look like (Pauly 1995; Sheppard 1995; Knowlton and Jackson 2008; Sandin et al. 2008).

Use of the BCG addresses the complexity of temporal variability and changing reference conditions by placing contemporary measurements within a context of regional potential. Historic data, empirical models and expert consensus have been used to develop BCGs for highly disturbed resource types, e.g., streams in the agricultural plains. For this type of situation, the BCG provides a framework to compare current biological conditions to natural (historic) conditions and develop reasonable expectations for restoration and protection (Herlihy et al. 2008).

Table 7-1 shows various ways to establish reference condition, and the strengths and weaknesses of each approach.

**Table 7-1.** Comparison of approaches for defining reference condition (Stoddard et al. 2006).

| | Historical Data | Present-Day Biology | Predictive Methods | Best Professional Judgment |
|---|---|---|---|---|
| Strengths | • Uses available data<br>• Provides a permanent benchmark<br>• Only generate once<br>• Compelling vision for stakeholders<br>• Rare or extirpated species can be included | • Realistic description of current best condition<br>• Based on current sampling methods<br>• Any assemblages or communities can be used | • Uses existing data, avoids expensive sampling<br>• Results can be extended to areas without data | • Perspective and experience of professionals with specific ecological knowledge of the specific region is valuable<br>• Could apply expert consensus rules for reference conditions |
| Weaknesses | • Data may be limited<br>• Studies likely were designed for different purposes<br>• Human impacts in historic times were sometimes severe | • Even best available sites have experienced human influence<br>• Potential for shifting baselines | • Inference beyond existing data is risky<br>• Can be subjective when data are unavailable | • May be qualitative description of “ideal” communities<br>• Experts might be biased |

## 7.3 Climate Change Variability

Global climate change introduces a high degree of variability into coral reef ecosystems and has generated new challenges for biocriteria development. Reefs are protected by the CWA from anthropogenic degradation, not natural changes. Historically, most anthropogenic degradation was believed to have a local origin. Regional and global factors, such as climate, currents, ocean temperatures, storm events and wind patterns, were generally perceived to be natural and outside the authority of the CWA. Yet many of these global factors, particularly elevated sea temperatures and ocean acidification (See Appendix F), are now recognized as the result of human activities.

The issue for biocriteria arises from the need to define expectations. Should a state set its goals to attain conditions that existed prior to climate change effects, even though it has no management control over climate change? Or should it tie expectations to the control of local activities only, essentially ignoring global change effects?

There are at least two unwanted consequences of setting expectations that ignore climate change effects. The first is that coral reefs will not be adequately protected from human disturbance. The second is that the public may be misled. One of the most influential parts of the CWA is reporting under Section 303(d), which alerts the public and Congress as to whether state waterbodies support designated uses. If climate change effects are not considered, stakeholders might infer that coral reefs are in acceptable condition. This incorrect message will stymie efforts to control the root causes of climate change.

But if waterbodies are impaired by global pollution that cannot be controlled by a state, what good does it do to list them? Biocriteria are, first and foremost, a reporting mechanism. The greatest purpose for biocriteria is to identify and report impairment, even if causes are unknown. A similar situation existed with acid rain. Coal-fired power plants in the Midwest U.S. caused acidic rainfall in the northeast which affected the biota of lakes and streams. Despite the fact that impacted states had no control over the emissions, documentation of stream and lake impairment alerted officials and the public and supported regulatory actions taken under the Clean Air Act (Menz and Seip 2004). Similar legal documentation of declining coral reef condition may also serve to alert officials at regional, national and even international levels to the growing global crisis for coral reefs.

# 8. What Is Causing Reefs to Change?

> *"It is a curious situation that the sea, from which life first arose, should now be threatened by the activities of one form of that life."*
>
> *~Rachel Carson, 1960*

When the biological condition of reef sites falls below the criteria for support of designated uses, the reasons for impairment must be determined before the sites can be protected or restored. In order to reverse declining trends in coral reef condition, we need to know which human actions are most damaging to coral reefs. Reducing known sources of impairment before damage occurs may provide the best protection.

The probabilistic survey design that detected a loss or change in the biological condition of a reef area is unlikely to provide the type of information that will identify the cause. Identification of the sources and causes of biological degradation at specific locations may require different types of data collected at specific targeted sites.

While probabilistic design works well to estimate condition, targeted monitoring is needed to identify the causes and sources of impairment.

A particular challenge is to distinguish local stresses from global and regional stresses. Biological impairment resulting from global and regional stressors should be reported, but local management actions can do little to reduce these threats. Nonetheless, resource managers need to identify sources and causes of degradation that can be eliminated through local management practices.

Even a single human activity can have multiple effects on a coral reef, and that activity may be anywhere in the watershed. Human activities can affect coral reefs through changes in water quality (increased sediment), habitat structure (construction of docks), flow regime (freshwater releases from upstream dams), food sources (loss of prey from shoreline armoring) and biotic interactions (fishing). The relative risk to coral reef ecosystems associated with different stressors (e.g., toxic chemicals vs. sediment) is not known, but synergistic effects of multiple stressors from across the watershed is likely.

Stressor identification is an emerging field; it is made difficult by the fact that the variety of human actions that degrade coral reefs rarely occur independently (Figure 8-1). If each watershed had only one human activity, direct connections could be made between specific stressors and changes in coral reefs, but most watersheds contain a mix of activities and stressors. All these influences are then further mixed by ocean currents.

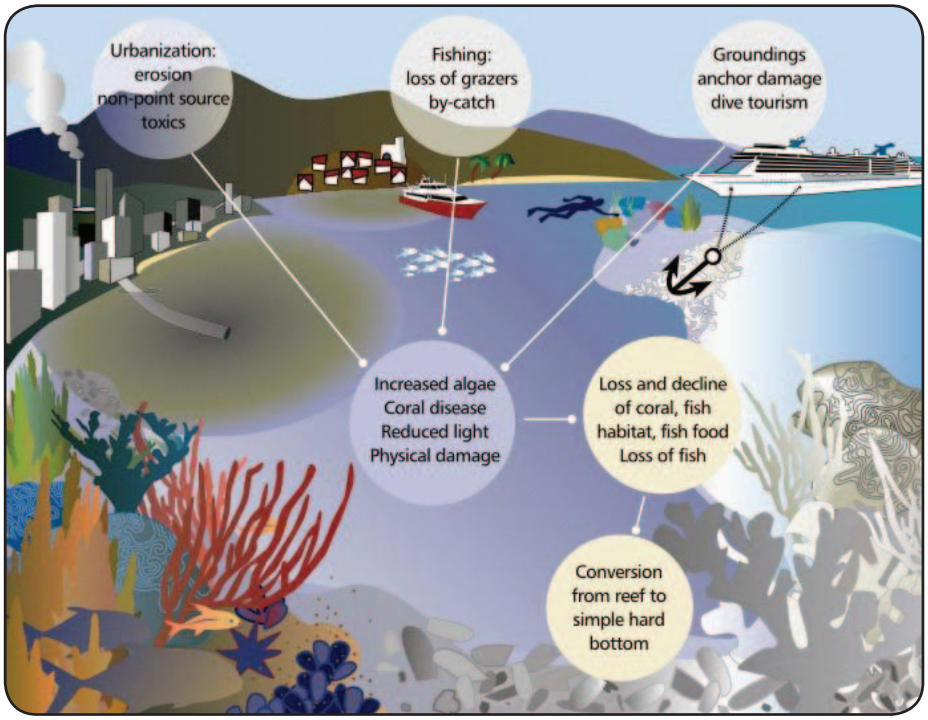


**Figure 8-1.** Conceptual model of stressors impacting a coral reef.

Causal analysis and stressor identification cannot be accomplished with a simple statistical test or a single process model. Although discussion of potential approaches is beyond the scope of this manual, EPA guidance (EPA 2007a) recommends a qualitative and logical approach to diagnosis. Causal analysis should start with a candidate list of causes and the ecological theory supporting those candidates, in other words, scientific studies that support the proposed causal relationship. Next, available data from the impaired sites are considered along with maps and other supporting material. Perhaps there has been recent suburban growth into forested areas; or, a new chemical plant has gone on-line in the near-coastal watershed. Data from other studies or similar sites should also be considered. The final step, deciding the cause of the impairment, relies on a careful examination of the evidence and well-reasoned discussion regarding the probable cause of the impairment in biological condition.

Although unique biological indicators have not been identified for all the stressors that affect coral reefs, some relationships are emerging (Table 8-1 for examples). Coral bleaching has increased dramatically in recent years in response to elevated sea temperatures, particularly for *Acropora* and *Pocillopora* species; however, bleaching is also a sign of excessive sediment as well as other stressors. Nonetheless, the pattern and timing of bleaching, as well as the species that bleach, could be used to characterize the influence of different stressors.

**Table 8-1.** Examples of commonly observed biological responses characteristic for particular coral reef stressors.

| Stressor | Biological response |
|---|---|
| Global climate change | • Coral bleaching, loss of *Acropora* spp. |
| Ocean acidification | • Decrease in calcification rates; decreased coral growth |
| Coral disease | • Lesions, banding, or bleaching |
| Fishing | • Reduced herbivores and large predators<br>• Increased growth of macro-algae<br>• Loss of appropriate substrate for coral recruitment |
| Land-based pollutants | • Loss of coral cover and increased macroalgae cover due to nutrients<br>• Loss of appropriate substrate for coral recruitment and reduction of growth in large colonies due to sediments<br>• Increased coral mucus associated with sewage outfalls and sediment<br>• Inhibition of photosynthesis and metamorphosis of coral larvae due to herbicides<br>• Altered genetic expression due to heavy metals<br>• Elevated RNA/DNA ratio related to turbidity |
| Boating and shipping | • Broken colonies, marine debris, dredged channels |
| Invasive species | • Loss of fish taxa richness due to predation by lion fish |
| Tourism & recreation | • Broken colonies, anchor damage |

A key point is that managers should not wait to report the extent of coral reef loss until the causes of the problem has been identified. The purpose of CWA Section 305(b) reporting and 303(d) listing of reef sites is to document that problems exist. After listing, other processes are used to evaluate the causes and sources of impairment within the context of stressor identification.

# 9. What Can We Do to Protect Reefs?

> *"The problem is not to manage the reefs but to manage human population and their activities."*
> *— Bernard Salvat, 1995*

Coral reef ecosystems not only fall under the states' jurisdictions, but also under the jurisdiction of the National Oceanic and Atmospheric Administration (NOAA), National Park Service (NPS), and Fish and Wildlife Service (FWS). Each agency has its own mandates and legislative purview. Consequently there are diverse legislative actions and initiatives to protect reefs. Recent declines in reef health have been met with legislation to promote interagency cooperation and collaboration. An Executive Order issued by President Clinton in 1998 (EO 13089 1998, Coral Reef Protection) established the interagency U.S. Coral Reef Task Force to enhance reef conservation and stewardship. In the Coral Reef Conservation Act of 2000 (16 USC § 6401 2000), Congress authorized the Secretary of Commerce to establish a national monitoring program to promote the understanding, conservation, and sustainable use of coral reef ecosystems.

Less auspicious but highly significant was submission of the President's Ocean Action Plan (The White House 2004) to Congress in 2004. Under this plan, the U.S. EPA was directed to develop biocriteria and assessment methods for states and territories to evaluate the condition of coral reefs and surrounding marine water quality. Biocriteria can be used to establish acceptable thresholds of biological condition, effectively integrate the cumulative effects of human influence (Karr and Yoder 2004), and are easy for the public to understand and support because they focus on benefits to society.

Perhaps less obvious is that the process of developing biocriteria, summarized in this manual, is a legally defensible means to translate scientific understanding into legal and regulatory authority. Because of these characteristics, biocriteria and the process to develop biocriteria support and complement a variety of existing management and regulatory programs (Figure 9-1), some of which fall within the aegis of other federal agencies.

In particular, the process for developing biocriteria compels states to engage stakeholders to determine what should be protected (what has societal value) and at what level (thresholds). Biocriteria also require defensible assessment methods. Bioassessments for coral reef condition are required for many different management and regulatory actions. Thresholds, codified as biocriteria, can be applied to determine high-quality waters for greater protection and to gauge the effectiveness of management actions. Biocriteria should not be considered a stand-alone CWA regulatory tool, but rather a legally defensible method to support biological integrity goals for many different authorities and legislations.

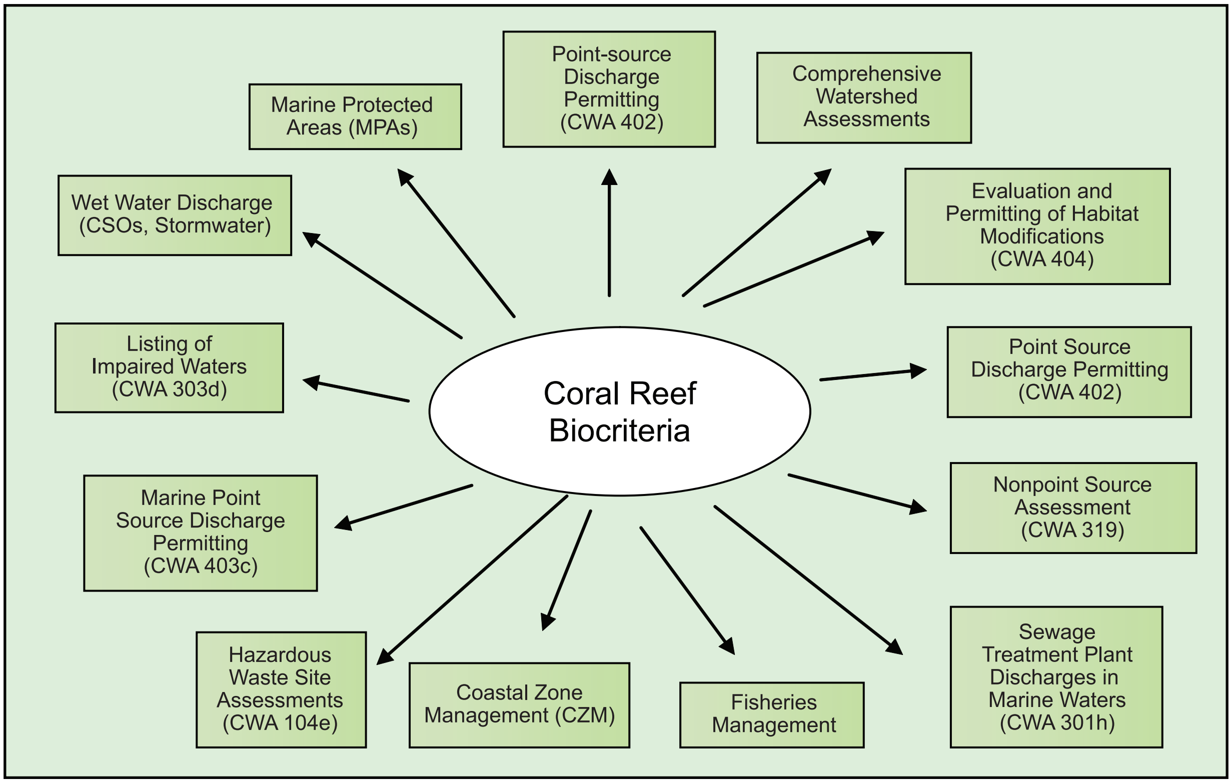



**Figure 9-1.** Examples of coral reef management programs that may be supported by biocriteria.

## 9.1 CWA and Existing Coral Reef Management Programs

Dodge et al. (2008) outlines a series of actions needed to reverse the decline of coral reefs (Table 9-1). Their list highlights the inability of existing watershed and coastal management practices to protect coral reefs from land-based activities or other threats that originate outside their boundaries.

Several commonly-used management approaches for coral reef resources can be advanced by application of CWA methods for development of biocriteria, including designated uses, bioassessment procedures, biological condition gradient (BCG), and thresholds (criteria) to protect designated uses. The process of developing biocriteria includes community decisions to be made on what to protect and at what level, and provides an easy mechanism to identify high-quality waters and gauge management success. Some of the programs that can benefit from biocriteria are characterized below. They are also summarized in Appendix G.

**Marine Protected Area (MPA):** Any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein (EO 2000).

**Marine Protected Areas (MPA).** Among the most used management tools for coral reefs is the Marine Protected Area. Creation of MPAs is one of nine actions recommended by Dodge et al. (2008) to reverse the decline of coral reefs. There are many types of MPAs, including national marine sanctuaries,

**Table 9-1.** Biocriteria can be used to identify waterbody impairments for coral reefs (Fore et al. 2009) and the U.S. Clean Water Act can be used to address many of them.

| Actions of Dodge et al. (2008) | Addressed by CWA? |
|---|---|
| (i) Cut $CO_2$ emissions | Yes; possible precedent with acid rain in northeastern states |
| (ii) Eliminate open-access fisheries in coral reef ecosystems and establish and enforce sustainable fisheries regulations. | CWA protects water quality suitable for protection and propagation of fish, shellfish and wildlife; other laws manage fisheries |
| (iii) Ban the harvest of coral reef herbivores, including parrotfish. | CWA protects water quality suitable for protection and propagation of fish, shellfish and wildlife; other laws manage fisheries |
| (iv) Establish and enforce Marine Protected Areas that include No-Take Areas. | No |
| (v) Effectively manage the waters in between Marine Protected Areas. | Yes; all waters of the territorial seas are required to have designated uses and standards to protect uses |
| (vi) Maintain connectivity between coral reefs and associated habitats such as mangroves, sea grass beds, and lagoons. | Yes; authority to set water quality standards in all types of habitats within the territorial seas |
| (vii) Report regularly and publicly on the health of local coral reefs. | Yes; mandate for states and territories to report biological condition of water resources (305b) |
| (viii) Recognize the links between what we do on land and how it affects the ocean. | Yes; authority to regulate terrestrial pollutants |
| (ix) Bring together industry, civil society, local government, and the scientific community to develop a vision of healthy reefs. | Yes; long history of examples |

national parks and wildlife refuges, state parks and conservation areas, and a variety of fishery management closures. MPAs vary in what is protected, the size of the area protected and the form of enforcement. The United States has developed a national system of MPAs to advance the conservation and sustainable use of the nation’s vital natural and cultural marine resources (NOAA 2009c). Specifically for coral reefs, the U.S. Coral Reef Task Force (USCRTF) has developed a strategy for building a national network of marine protected areas, and has published “Coral Reef Protected Areas: A Guide for Management” to assist those involved in planning and managing programs for coral reef protected areas (16 USC § 6401 2000). Biocriteria can be used to identify waters with outstanding biological condition, establish desired thresholds for reef condition and to gauge effectiveness of the MPA. Also, biocriteria can be used to manage waters between MPAs, either by protecting connectivity and resilience or by protecting organisms inhabiting interstitial areas.

**Managing Fisheries.** Fishing regulations are designed and implemented to enforce sustainable fisheries. These actions can also protect coral reef ecosystems. Basic fisheries management practices include restricting the numbers of people or number of boats fishing, the time allowed for fishing, the fishing area, type of gear or technology, and the species and sizes that can be harvested (ISRS 2004). Fisheries management could incorporate biocriteria to establish size class and abundance minima for harvested species to protect the fishery ("fishable" waters). Declines below these thresholds would trigger changes in fishery practices and regulations. In a related example, the Supreme Court blocked construction of the Dosewallips River Dam (Washington) to protect the state's CWA designated use for migration, rearing and spawning of salmonids (Ransel 1995).

**Managing Tourism.** The unique and diverse biota of coral reefs provide many attractions for tourists. However, tourism development projects and the behavior of tourists themselves can contribute to significant reef losses and coral reef degradation (GEF 1996). Some jurisdictions have implemented management practices that regulate tourism and tourist activities. Practices include placement of mooring buoys to limit anchor damage, permits for diving, fishing, and boating, user fees, and navigational aids such as buoys to mark reef locations and documenting reef locations on international nautical charts. Biocriteria can be used to identify waters of outstanding biological condition and evaluate the success of tourism management practices. Development of a BCG, driven by expert analysis, can be useful for determining acceptable levels of tourism (Figure 9-2).

**Figure 9-2.** Managing tourism. Jurisdictions implement a variety of approaches to manage tourists, including mooring buoys and use permits.

**Managing Endangered Species.** The Endangered Species Act (ESA) (16 USC §1531 et seq. 1973) provides a program for conserving threatened and endangered plants and animals and their habitats. A species is considered endangered if it is in danger of extinction throughout all or a significant portion of its range. A species is considered threatened if it is likely to become an endangered species within the foreseeable future. The listing of a species as endangered makes it illegal to "take" (harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect) that species. In May 2006, FWS listed *Acropora palmata* (elkhorn coral) and *Acropora cervicornis* (staghorn coral) as vulnerable under the ESA because of widespread decline throughout their Caribbean range. More recently, the Center for Biological Diversity filed a formal petition seeking to protect an additional 83 imperiled coral species under the ESA. The corals occur in both Atlantic/Caribbean and Pacific waters and face a growing threat of extinction from rising ocean temperatures and ocean acidification. Biocriteria can be applied to specifically protect ESA species; this normally would require that a state cites protection of that species or any endangered species as a designated waterbody use. Biocriteria in combination with a BCG can be used to gauge the effectiveness of the protective measures and can also be used to determine the point at which a coral species has recovered and no longer requires protection of the ESA.

**Coastal Zone Management (CZM).** A partnership between the federal government and U.S. coastal states was authorized by the Coastal Zone Management Act of 1972 (CZMA) (16 USC §1451 1972). The CZMA encourages states to preserve, protect, develop, and where possible, restore or enhance valuable natural coastal resources (Figure 9-3) such as wetlands, floodplains, estuaries, beaches, dunes, barrier islands, and coral reefs, as well as the fish and wildlife using those habitats. To encourage states to participate, the act makes federal financial assistance available to any coastal state that is willing to develop and implement a comprehensive coastal management plan (CCMP). NOAA administers the program at the federal level and works with coastal states to develop and implement their coastal zone management plans. In the Coastal Zone Act Reauthorization Amendments of 1990 (CZARA), Congress added Section 6217, which calls upon states with federally approved coastal zone management programs to develop and implement coastal nonpoint pollution control programs. The section 6217 program is administered at the federal level jointly by EPA and NOAA (NOAA 2009d; EPA 1993). Biocriteria have an opportune role to reinforce the integrated and comprehensive nature of CZMA and CZARA. The CZMA provides umbrella coverage across all aquatic resources, not just coral reefs, so biocriteria and physical/chemical water quality standards can be used to protect the entire ecological system that comprises coral and its associated habitats. A CCMP can employ biocriteria to establish valued attributes (designated uses) and derive acceptable thresholds for different organisms, habitats and ecosystems. Attaining biocriteria goals is a quantitative reflection on the success of the management plan.

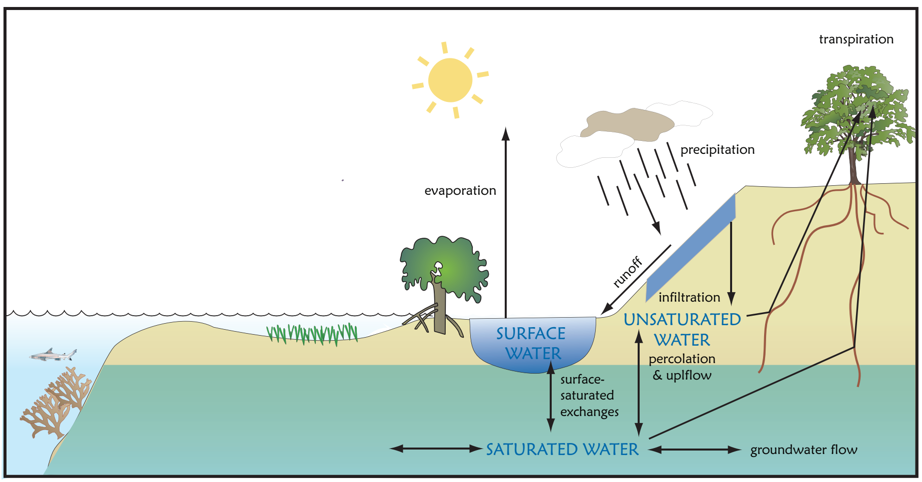



**Figure 9-3.** The coastal watershed. Water enters the watershed through precipitation, and then travels throughout the watershed in myriad ways including runoff to creeks, streams, and rivers, making its way to lower elevations, and eventually to the coastal waters and coral reefs.

**Watershed Management.** A watershed is the area of land from which rainfall drains into a single point. Watersheds are also sometimes referred to as drainage basins or drainage areas. Ridges of higher ground generally form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

A watershed management plan usually considers the entire watershed with a goal to protect and restore an environmentally and economically healthy watershed that benefits all stakeholders. This generally means to sustain and enhance watershed functions that affect the plant, animal, and human communities within a watershed boundary. Agencies manage activities in the watershed such as water supply, water quality, drainage, stormwater runoff, water rights, and the overall planning and utilization of watersheds (EPA 2008b). Biocriteria can be developed and implemented for any lake, river, stream and estuary in a U.S. watershed. This serves to protect downstream resources as well, such as coral reefs. Likewise, biocriteria for protection of coral reefs can benefit upstream resources. An integrated plan to employ biocriteria for valued populations and ecosystems throughout the watershed can work interactively to protect resources and identify sources of pollution that are causing impairment.

**Damage Assessment and Restoration.** Seagrasses, mangroves and coral reefs that are physically damaged by human actions are addressed through a process that allows resource managers to identify injured resources, recover damages from responsible parties, restore habitats and resources to pre-injury/pre-exposure conditions, and compensate the public for the loss of ecological and visitor use services. Some restoration activities now underway include active propagation and selection of stress-resistant colonies (e.g., staghorn coral restoration by The Nature Conservancy, www.nature.org). Development of a BCG can assist in the identification of pre-injury/pre-exposure conditions. Biocriteria can be used to establish thresholds to measure the effectiveness of restoration efforts.

**National Environmental Policy Act (NEPA).** Federal agencies are required under the National Environmental Policy Act (NEPA) to integrate environmental values into decision-making by considering the environmental impacts of proposed actions and possible alternatives. The Act requires preparation of Environmental Impact Statements (EIS), which are full disclosure documents detailing the developmental process for federal projects. The EIS describes existing resources and environmental condition, including the social, economic and ecological settings surrounding the project and any environmentally sensitive features that may be impacted. An EIS also describes the environmental impacts of project alternatives and potential measures that could be taken to mitigate these impacts. Biocriteria can be used to describe and compare the condition of resources to be impacted under the alternatives. Biocriteria and a BCG can also be used to determine whether the project has complied with the approved EIS and associated project permits and is protecting the natural resources that were identified.

## 9.2 Biocriteria and Other CWA Programs

One strength of the CWA is that it provides multiple ways to protect biological integrity of the Nation's waters. Chapter 4 provided an overview of water quality standards (designated uses, water quality standards [including biocriteria], and antidegradation) described in Sections 303, 304 and 305 of the CWA. Other sections establish a variety of other programs to achieve CWA goals. Biocriteria and bioassessment methods, in ways similar to those described above, can work interactively with other CWA programs to protect coral reefs.

**CWA Section 104(b)(3): Wetlands Program Development Grants.** EPA is authorized to provide federal assistance to states (including territories, the District of Columbia), Indian Tribes, and local governments to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution. Coral reefs, mangroves, and seagrasses are considered special aquatic sites and wetlands under CWA 404, and Section 104(b)(3) grants can directly fund monitoring and assessment of coral reefs and development of biocriteria for coral reefs. EPA Region 9 has awarded Wetlands Program Development Grants to support coral reef biocriteria development for Hawaii and CNMI.

**CWA Section 106: Grants for Pollution Control Programs.** EPA is authorized to provide federal assistance to states (including territories, the District of Columbia) and Indian Tribes and interstate agencies to establish and implement ongoing water pollution control programs. These grants may be used to fund a wide range of water quality activities including: water quality planning and assessments; development of water quality standards; ambient monitoring; development of total maximum daily loads (TMDLs); issuing permits; ground water and wetland protection; compliance and enforcement activities; non-point source control activities (including non-point source assessment and management plans); and Unified Watershed Assessments (UWA) under the Clean Water Action Plan (CWAP). EPA Region 10, in a 2009 Request for Initial Proposals for TMDL Grants, explicitly mentioned the application of biological monitoring protocols and biocriteria (including narrative biocriteria) that lead to improved TMDLs.

**CWA Sections 205(j) and 604(b): Water Quality Management Planning Grants.** EPA is authorized to provide grants to assist state water quality management agencies and others in carrying out water quality management planning. State agencies are encouraged to give priority to watershed restoration planning. Comprehensive water quality management programs include development and implementation of biocriteria, the development of which can be supported under these grants.

**CWA Section 301(h): Effluent Limitations.** The CWA provides an opportunity for a variance from technology-based secondary treatment standards for publicly owned treatment works discharging into marine waters, provided that the applicant demonstrates that, among other things, the discharge subject to the variance would not adversely affect biological communities. To obtain this variance, extensive biological monitoring is required to detect any potential effects on the biological communities. Biocriteria and a BCG can be used to demonstrate a no-effect threshold. In one example, EPA determined in 2009 that the discharges from two Honolulu wastewater treatment plants did not meet all applicable water quality standards. Discharges from both plants failed to protect recreational use or marine life in the vicinity of the ocean outfalls.

**CWA Section 312: Marine Sanitation Devices.** The CWA mandates the use of marine sanitation devices (MSDs), on-board equipment for treating and discharging or storing sewage, on all commercial and recreational vessels that are equipped with installed toilets. It also mandates the development of MSD standards and regulations to implement the requirements of the statute. Under CWA Section 312, EPA or states may establish “no-discharge zones” for sewage from vessels. State water quality standards, including biocriteria, can be applied to identify appropriate locations for no-discharge zones, and biocriteria can be used to identify locations with outstanding biological condition that would benefit from a no-discharge zone status. Biocriteria can also be used to establish thresholds to gauge the effectiveness of no-discharge zones.

**CWA Section 319: Nonpoint Source Program (NPS).** A voluntary non-point source control program allows states to control the impacts of watershed runoff. Since 1990, Congress has annually appropriated grant funds to states for a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific nonpoint source implementation projects. Biocriteria can be used to assess the impacts of nonpoint source pollution and to determine the effectiveness of nonpoint source controls. An example of successful use of biocriteria in managing nonpoint source pollution is the American Samoa Piggery Compliance Program. Six coral reef habitats were assessed on Tutuila to characterize the relationship between NPS pollution and coral reef habitat (Houk and Musberger 2007; Houk and Musberger 2008). Five of the six habitats were found to only partially support aquatic life uses and one was not supporting. Because it was a baseline study, the results did not draw any direct links to NPS pollution. Nonetheless, the degraded condition of coral reefs was used to more strongly enforce compliance for pig facilities (i.e., remove illegal piggery discharges). The American Samoa EPA Piggery Compliance Team has recently reduced nutrient loads to nearby waters by more than 5000 kg of nitrogen and 1800 kg of phosphorus.

**CWA Section 320: National Estuary Program (NEP).** A CWA program to identify, restore and protect nationally significant estuaries was established in 1987 by amendments to the CWA. EPA administers the National Estuary Program (NEP), but program decisions and activities are conducted by committees of local government officials, private citizens, and representatives from other federal agencies, academic institutions, industry, and estuary user-groups. When an estuary is admitted into the program, a management conference is convened to characterize the environmental issues, including relationships between pollutant loading and impacts on living resources, and to develop a comprehensive plan to resolve priority problems. EPA is authorized to award grants for development of the management plan and implementation projects. The intent of NEP management plans is to restore and protect water quality (as defined by the CWA); this translates to restoring and protecting the chemical, physical and biological integrity of the estuary. Biocriteria establish thresholds for biological integrity and can be developed as an integral part of the management plan. There is currently only one NEP with corals – the San Juan Estuary in Puerto Rico.

**CWA Section 401: State Water Quality Certification.** Any activity that requires a federal license or permit that may result in a discharge to waters of the U.S. must first obtain a CWA Section 401 water quality certification from the relevant state or territorial water quality agency to ensure the project will comply with applicable water quality standards. Federal Energy Regulatory Commission hydro licenses and U.S. Army Corps of Engineers (Corps) dredge and fill permits, for example, trigger the requirement for CWA Section 401 certification. For example, when offshore projects are under construction in Florida, the Florida Department of Environmental Protection requires that procedures are employed to protect water quality and potential sedimentation on the reefs. Biological monitoring is necessary to document the effects of construction projects on natural resources. Biocriteria can be used to provide a threshold to estimate dredge and fill impacts on biological communities. Biocriteria can also be helpful in evaluating a range of alternatives for dredge and fill activities and for identifying the least damaging alternative, as required by CWA Section 404.

**CWA Section 402: National Pollutant Discharge Elimination System (NPDES).** It is illegal under the CWA to discharge any pollutant to waters of the United States from a ***point source*** unless authorized by a National Pollutant Discharge Elimination System (NPDES) permit. Typical point sources regulated under the NPDES program include: municipal wastewater systems, municipal and industrial storm water systems, industries and commercial facilities, Concentrated Animal Feeding Operations (CAFOs), and large aquaculture facilities.

> **Point source** is defined by the CWA as "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or floating craft, from which pollutants are or may be discharged." This includes certain municipal, industrial, and construction site discharges of storm water.

An NPDES permit limitation is required in any case where a discharge is expected to have the reasonable potential to cause, or contribute to non-attainment of a water quality standard, including biological impairments. NPDES permits establish pollutant discharge limits based on treatment technology performance, the quality of the water into which pollutants are discharged, and the potential adverse impact of the discharge on water quality standards. EPA oversees the NPDES program and also approves submissions by states to administer state NPDES permitting programs in lieu of EPA administration. EPA is promoting a watershed-based NPDES permitting that emphasizes consideration of all stressors within a hydrologically-defined drainage basin rather than individual pollutants on a discharge-by-discharge basis (EPA 2009c). Watershed-based permitting can encompass a variety of activities ranging from synchronizing permits within a basin to developing water quality-based effluent limits using a multiple discharger modeling analysis. Biocriteria have several applications in NPDES programs. Biocriteria can be used in determining the condition of a waterbody prior to issuance of a permit and during discharge to ensure that state water quality standards are being met. They can also be used to evaluate the effectiveness of any controls implemented by the discharger. Florida uses freshwater biocriteria to identify "hot spots" and evaluate the effectiveness of NPDES stormwater management programs on stream biota.

**CWA Section 403(c): Ocean Discharge Program.** There are special requirements applicable to NPDES permits for discharges into the ocean, including three different ocean regions defined in the CWA (i.e., a three mile territorial sea, a 12-mile contiguous zone, and waters beyond the 12-mile zone). The permitting process requires that the permitting agency determine for any permitted ocean dischargers that the discharge will not cause an unacceptable degradation of the marine environment, including the biological community in the area surrounding the discharge. Biocriteria provide defensible measures of biological communities and thresholds to estimate the impact of ocean discharge on biological communities.

**CWA Section 404: Permits for Dredged and Fill Material.** Establishes a permit program to regulate the discharge of dredged and fill material into waters of the United States, including a three mile territorial sea. Dredge and fill discharge permits are jointly administered by the U.S. Army Corps of Engineers and EPA, but permits are issued by the Army Corps. The FWS and National Marine Fisheries Service (NOAA) play special advisory roles because of their expertise in wildlife habitat and endangered species. EPA issues certain rules and guidelines to guide Corps permit decisions. EPA can veto a permit issued by the Corps. Biocriteria can provide methods and thresholds to identify high value areas for protection to determine dredged and fill discharge impacts on biological communities. When marine projects are under construction in Florida, the Department of Environmental Protection ensures that methods are implemented to protect water quality and potential sedimentation on the reefs. Biocriteria and a BCG can also be used to identify acceptable sites for disposal of dredged and fill material.

**CWA Section 603: Clean Water State Revolving Fund (CWSRF).** Capitalization grants are made available to each state for the purpose of establishing a Clean Water State Revolving Fund (CWSRF) to provide independent and permanent sources of low-cost financing for (1) construction of publicly owned wastewater treatment works, (2) implementing nonpoint source management activities included in State Plans developed pursuant to Section 319, and (3) developing and implementing an estuary conservation and management plan under Section 320. Today, all 50 states and Puerto Rico are operating successful CWSRF programs. Funds to establish or capitalize the CWSRF programs are provided through federal government grants and state matching funds. In recent years EPA has provided more than $5 billion annually to fund a variety of water quality projects. Total funds available to the program since its inception exceed $70 billion. Biocriteria can provide a threshold to measure the degree to which water quality projects reduce human impacts on biological communities.

A table summarizing these CWA sections can be found in Appendix H.

## 9.3 Biocriteria Can Link CWA and CAA to Address Ocean Acidification

Ocean acidification is a major threat to coral reefs. The cause of ocean acidification, high levels of carbon dioxide ($CO_2$) in the atmosphere, is an air quality issue over which states have little influence. Even though each state has contributed to ocean acidification, emissions of $CO_2$ are worldwide. At first glance it doesn't appear that the CWA has any role in resolving this issue, even though coral reefs are among those highly threatened by $CO_2$ emissions. Yet, past experience has shown that the CWA can complement the Clean Air Act (CAA), which regulates all forms of air pollution, including $CO_2$ emissions. The CWA can be used to assess waterbody impairment caused by ocean acidification, which can trigger action under the CAA. A similar approach was applied in the 1980s with creation of the Acid Rain Program. Streams in the northeastern U.S. were becoming increasingly acidic and stream biota were adversely impacted. Listing streams on the 303(d) impaired waters list triggered regulatory action under the CAA at the national level.

# 10. Do Our Efforts Protect Reefs?

For all the effort that goes into protecting coral reefs, we must always ask whether or not we are making a difference. How do we know that our policies and management strategies are protecting reefs? The most reliable answer to this question would come from trend monitoring stations. If, over time, repeat sampling indicates an upward trend in coral reef condition, we would have a positive answer that, yes, our efforts are working. This is called effectiveness monitoring. Given the scale of protection and restoration efforts compared to the magnitude of environmental change associated with modern human life, a measurable improvement at the regional scale may be an unlikely outcome. Unfortunately, rather than a measurable improvement, it may be in some cases that our efforts can only slow the decline of coral reefs.

It's more difficult to quantify but very important to understand how much damage to coral reefs has been avoided by past and existing management efforts. Reefs were in some measure spared when a toxic effluent was not released, when soil was not eroded, and young fish were not harvested. We don't typically measure or report damage that was avoided, even though it is an important outcome of conservation practices. This is sometimes called silent evidence (Taleb 2007). Our inability to measure how much worse the environmental condition would have been if we had done nothing is a difficult concept to quantify and can be a source of frustration for resource managers.

The best opportunity to see measurable improvement in resource condition is at a relatively small spatial scale. For example, some marine protected areas have shown an increase in fish species or other measures of biological condition within the boundaries of marine protected areas (Halpern 2003). Nonetheless, the initial hope that protected areas would adequately support biota in the unprotected areas has faded somewhat (Kareiva 2006).

In the Florida Keys National Marine Sanctuary (FKNMS), over 300 mooring buoys have been placed throughout the park to reduce anchor damage from recreational boats. Sanctuary scientists and managers also defined zones for shipping to prevent groundings by large vessels. A dramatic drop in the number of groundings resulted. We can assume that if the changes were not made, the rate of coral loss would have continued and the "savings" in coral reef can be calculated.

Other FKNMS programs are not as easily evaluated. Sanctuary managers have worked to eliminate the discharge of untreated sewage to meet a 2010 deadline set by EPA. They have implemented wastewater treatment, injection wells to replace ocean outfalls, eliminated septic systems, repaired leaky wastewater systems, and established no-discharge zones for cruise ships and other vessels. How can we tell if these nutrient reduction projects have improved reef condition?

There are multiple approaches to evaluate the success of these efforts. First, was untreated sewage eliminated? At a local scale, the success of this program has been measured in terms of fewer exceedances for fecal coliform and enterococcus bacteria and reduced beach closures.

Local jurisdictions were found to be in compliance with the new requirements, so there was successful implementation. These types of summary statistics represent compliance monitoring, that is, tracking whether the mandated changes were accomplished. For reduction of sewage discharge in FKNMS, the answer seems to be yes.

Connecting changes in nutrient concentration at a larger spatial scale is more challenging. Beginning in 1995, a regional water quality monitoring program was implemented to collect water samples from 154 locations located offshore of south Florida, in Florida Bay, and around the Florida Keys (Boyer and Briceno 2006). Natural variability and other larger sources of nutrients, such as those originating from Florida Bay, have made it difficult to detect changes in nutrient levels related to human sources and natural processes (Lirman and Fong 2007). The answer to whether the projects have reduced nutrient concentrations is therefore largely unanswered.

The most challenging question is, do these changes protect coral reefs? Elimination of sewage reduces nutrients and pathogens that threaten corals and other biota. Nonetheless, during this same period of increased efforts to improve water quality, coral cover has been in a steep decline. For Florida reefs, from 1996 to 2006 coral cover has declined from 12% to 6%, a 50% loss (Callahan et al. 2007). Similarly the number of coral taxa typically found in a standard transect has declined by a total of 4 taxa from an expected number of about 17. The continued decline of coral reefs doesn't mean that the sewage treatment efforts were not successful, because we don't know how many fish or corals were actually protected. What we know is that in spite of our efforts, coral reefs are still declining. That means that we are not controlling other important stressors unrelated to nutrient and contaminant pollution.

How can we be more effective? Resource managers responsible for coral condition probably need more help because the problem is bigger than we initially realized. One way to get more attention on the problem and more help is through reporting. The Clean Water Act provides a formal reporting mechanism to report to Congress, stakeholders, and local jurisdictions the condition of coral reefs, e.g., "30% of coral reef area fails to support aquatic life use." The key to effective protection and restoration is to measure and report on the water resources we truly care about. In this case, nutrient reduction was identified as a threat to corals, but it wasn't the only threat. Work and research remains to determine the risks associated with different human activities and to prioritize our efforts to reduce those threats.

Effectiveness monitoring takes people and dollars, resources that may be subtracted from more or better conservation and restoration programs. A good argument can be made for both needs. Evidence of a significant difference resulting from a management practice may take very intensive sampling, but it is hard to keep implementing programs if you don't know they are working. One approach is to perform effectiveness monitoring at a small spatial scale and then decide whether any changes are enough to mandate a program at a larger regional scale. Modeling represents a way to evaluate the potential regional effect if the management program were implemented across a larger area (Zitello et al. 2008).

The outlook for coral reefs is potentially grim, but protection and restoration can arise from multiple sources. A broader recognition of regulatory and legal actions, such as the Clean Water Act (and many other state and federal laws), that are available to protect water and reef resources is a good start. Along with understanding the regulatory options, there must be a will to use these instruments to their full capability. Another approach involves fostering a more widespread understanding that economic prosperity is founded on natural capital, such as the natural resources associated with coral reefs (MEA 2003).

A different perspective is gained when we think about the problem of resource degradation as a society. In the early years of the Clean Water Act, the focus was on “polluters” and efforts were directed toward eliminating industrial sources. In recent years, the balance has shifted and we know that much of the damage to water resources derives from the cumulative effects of average citizens living their everyday lives (NRC 2008). This is a profound shift. Individual citizens and independent groups around the world recognize that the responsibility for the natural world is not just the government’s job, but a responsibility shared by all (Hawken 2007).

# Appendix A: Acronyms and Abbreviations

| | |
|---|---|
| BCG | Biological Condition Gradient |
| BMP | Best Management Practices |
| CAA | Clean Air Act |
| CCMP | Comprehensive Conservation & Management Plans |
| CFR | Code of Federal Regulations |
| CNMI | Commonwealth of the Northern Mariana Islands |
| $CO_2$ | Carbon Dioxide |
| CREMP | Coral Reef Ecosystem Monitoring Program (EPA & FKNMS) |
| CWA | Clean Water Act |
| CWSRF | Clean Water State Revolving Fund |
| DEP | Department of Environmental Protection (Florida) |
| DO | Dissolved Oxygen |
| DOH | Department of Health (Hawaii) |
| DOI | Department of the Interior |
| DPNR | Department of Planning and Natural Resources (USVI) |
| DPSIR | Driving Forces, Pressures, State, Impacts, and Response |
| EO | Executive Order |
| EPA | U.S. Environmental Protection Agency |
| ESRP | Ecosystem Services Research Program |
| FKNMS | Florida Keys National Marine Sanctuary (NOAA) |
| FL | Florida |
| FRRP | Florida Reef Resilience Program (TNC) |
| FWS | Fish & Wildlife Service |
| LDI | Landscape Development Intensity Index |
| MPA | Marine Protected Area |
| NEP | National Estuary Program |
| NEPA | National Environmental Policy Act |
| NMSA | National Marine Sanctuaries Act |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NPS | National Park Service (U.S. Department of the Interior) |
| NPS | Non-Point Source |
| ONRW | Outstanding National Resource Waters |
| POTWs | Publicly Owned Treatment Works |

| | |
|---|---|
| SCUBA | Self-Contained Underwater Breathing Apparatus |
| TMDL | Total Maximum Daily Load |
| TNC | The Nature Conservancy |
| UAA | Use Attainability Analysis |
| USCRTF | U.S. Coral Reef Task Force |
| USVI | U.S. Virgin Islands |
| WQ | Water Quality |
| WQC | Water Quality Criteria |
| WQS | Water Quality Standards |

# Appendix B: Glossary

**106.** The section of the Clean Water Act that authorizes the USEPA to provide federal assistance to states (including territories, the District of Columbia, and Indian tribes) and interstate agencies to establish and implement ongoing water pollution control programs. Prevention and control measures supported by state water quality management programs include permitting, pollution control activities, surveillance, monitoring, and enforcement; advice and assistance to local agencies; and the provision of training and public information.

**301.** The section of the Clean Water Act that establishes the national policy regarding discharge of pollutants from a point source to waters of USA, shorelines and waters of contiguous zones.

**303(d).** The section of the Clean Water Act that requires a listing by states, territories, and authorized tribes of impaired waters, which do not meet the water quality standards that states, territories, and authorized tribes have set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology.

**304.** The section of the Clean Water Act that authorizes EPA to develop criteria for water quality that accurately reflects the latest scientific knowledge. These criteria are based solely on data and scientific judgments on pollutant concentrations and environmental or human health effects. Section 304(a) also provides guidance to states and tribes in adopting water quality standards. Criteria are developed for the protection of aquatic life as well as for human health.

**305(b).** The section of the Clean Water Act that requires EPA to assemble and submit a report to Congress on the condition of all waterbodies across the country as determined by a biennial collection of data and other information by states and tribes.

**312.** The section of the Clean Water Act that regulates vessel sewage discharge through the mandatory use of marine sanitation devices (on-board equipment for treating and discharging or storing sewage) on all commercial and recreational vessels that are equipped with installed toilets. Under Section 312 states may request a No-Discharge Zone (NDZ) designation that prohibits the discharge of sewage from all vessels into defined waters.

**319.** The section of the Clean Water Act that authorizes EPA to provide federal funding to states, territories, and Indian tribes to help focus state and local nonpoint source efforts. Funding can be received for a wide variety of activities including technical assistance, financial assistance, education, training, technology transfer, demonstration projects, and monitoring to assess the success of specific nonpoint source implementation projects.

**320.** The section of the Clean Water Act that directs EPA to develop plans for attaining or maintaining water quality in estuaries that are part of the National Estuary Program. This includes protection of public water supplies and the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife, and allows recreational activities, in and on water, and requires the control of point and non-point sources of pollution to supplement existing controls of pollution. Each National Estuary Program establishes a Comprehensive Conservation and Management Plan to meet the goals of Section 320. Section 320 also allows a state to use the Clean Water State Revolving Fund (CWSRF) to fund publicly and privately owned projects as long as the project is part of the state's Comprehensive Conservation and Management Plan (CCMP) and is sanctioned in the plan.

**401.** The section of the Clean Water Act that requires an applicant for a federal license or permit to obtain a certification that any discharges from the facility will comply with state laws, including water quality standards.

**402.** The section of the Clean Water Act that specifically required EPA to develop and implement the NPDES program. The CWA allowed EPA to authorize the NPDES Permit Program to state governments, enabling states to perform many of the permitting, administrative, and enforcement aspects of the NPDES Program. In states that have been authorized to implement CWA programs, EPA still retains oversight responsibilities. NPDES is not delegated to Guam, Commonwealth of the Northern Mariana Islands, American Samoa or Puerto Rico. Florida, Hawaii, and the USVI have delegated authority from EPA.

**403.** The section of the Clean Water Act that specifically required EPA to promulgate ocean discharge guidelines for determining the degradation of the waters of the territorial seas, the contiguous zone, and the oceans. The ocean discharge criteria must become a part of any National Pollutant Discharge Elimination System (NPDES) permit that EPA or a state issues for discharges of pollutants into ocean and coastal waters. Section 403 requirements are intended to ensure that no unreasonable degradation of the marine environment will occur as a result of the discharge and to ensure that sensitive ecological communities are protected.

**404.** The section of the Clean Water Act that authorizes EPA to restrict or prohibit the use of an area as a disposal site for dredged or fill material if the discharge will have unacceptable adverse effects on municipal water supplies, shellfish beds and fishery areas, wildlife or recreational areas. Along with wetlands, coral reefs are designated as "special aquatic sites" and afforded special protection under CWA 404. In 1999, EPA and the Army Corps jointly issued guidance to emphasize the protection afforded the Nation's valuable coral reef ecosystems under the Clean Water Act (CWA) Section 404 regulatory program (EPA and ACOE 1999).

**603.** The section of the Clean Water Act that allows the use of state revolving funds to assist municipalities to construct publicly owned treatment works and to implement a nonpoint source pollution management plan as provided for in Section 319 of the Clean Water Act.

**abiotic.** Non-living components of the environment, including chemicals in the air, water and soil, and the level and variability of solar radiation and other aspects of the climate.

**acid rain.** A complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in wet form.

***Acropora cervicornis* (aka Staghorn coral)**. This species of coral has cylindrical branches ranging from a few centimeters to over two meters in length and height. It occurs in back reef and fore reef environments from 0 to 30 m depth. Staghorn coral is found throughout the Florida Keys, the Bahamas, and the Caribbean islands. The northern limit is on the east coast of Florida, near Boca Raton. Since 1980, populations have collapsed throughout their range from disease outbreaks, with losses compounded locally by hurricanes, increased predation, bleaching, and other factors. This species is also particularly susceptible to damage from sedimentation and sensitive to temperature and salinity variation. Populations have declined by up to 98% throughout the range, and localized extirpations have occurred. On May 4, 2006, Staghorn coral was recognized as a threatened species and placed on the Endangered Species List (71 Federal Register 89 2006).

***Acropora palmata* (aka Elkhorn coral).** This species of coral is structurally complex with many large branches. These branches create habitats for many other reef species such as lobsters, parrot-fish, snappers, and other reef fish. Elkhorn coral was once one of the most abundant species of coral in the Caribbean and the Florida Keys. Since 1980 it has been estimated that 90-95% of Elkhorn coral has been lost. Threats to Elkhorn coral include disease, coral bleaching, predation, climate change, storm damage, and human activity. All of these factors have created a synergistic affect that greatly diminishes the survival and reproductive success of Elkhorn coral. Natural recovery of coral is a slow process and may never occur with this species because there are so many threats to its survival. On May 4, 2006 Elkhorn coral was recognized as a threatened species and placed on the Endangered Species List (71 Federal Register 89 2006).

**algae.** Any of various primitive, chiefly aquatic, one- or multi-celled, nonflowering plants that lack true stems, roots, and leaves, but usually contain chlorophyll. Algae convert carbon dioxide and inorganic nutrients, such as nitrogen and phosphorus, into organic matter through photosynthesis and form the basis of the marine food chain. Common algae include dinoflagellates, diatoms, seaweeds, and kelp.

**algorithm.** A precise rule (or set of rules) specifying how to solve some problem.

**ambient.** Enveloping or surrounding.

**anemone.** A solitary soft-bodied marine animal belonging to Phylum Cnidaria.

**anthropogenic.** Originating from man, not naturally occurring.

**antidegradation.** An integral part of state water quality standards designed to help protect existing and designated uses, to maintain that quality which is better than the applicable criteria, and to protect Outstanding National Resource Waters.

**aquatic community.** Association of interacting assemblages in a given waterbody, the biotic component of an ecosystem (see also aquatic assemblage).

**Aquatic Life Use (ALU).** A beneficial use designation in which the waterbody provides suitable habitat for survival and reproduction of desirable fish, shellfish, and other aquatic organisms (EPA 2009a).

**aquatic.** Living in the water.

**assemblage.** An association of interacting populations of organisms in a given waterbody.

**attribute.** A measurable component of a biological system (Karr and Chu 1999).

**back reef.** The landward side of a reef between the reef crest and the land.

**ballast water.** Fresh or salt water, sometimes containing sediments, held in tanks and cargo holds of ships to increase stability and maneuverability during transit. This water can be pumped on or off a ship.

**benthic macroinvertebrates.** Animals without backbones, living in or on the sediments, a size large enough to be seen by the unaided eye, and which can be retained by a U.S. Standard No. 30 sieve (28 openings/inch, 0.595-mm openings). Also referred to as benthic macroinvertebrates, infauna, or macrobenthos (EPA 2009a).

**benthic.** Living in or on the bottom of a body of water.

**best management practices (BMPs).** Management practices (such as nutrient management) or structural practices (such as terraces) designed to reduce the quantities of pollutants — such as sediment, nitrogen, phosphorus, and animal wastes — that are washed by rain from farms into nearby receiving waters, such as lakes, creeks, streams, rivers, estuaries, and ground water.

**bias.** Systematic error in a data set due to approaches and methods and their application in sampling, investigation, measurement, classification, or analysis (MEA 2009).

**binomial.** Having two possible values, in general x and y. A coin toss may come down only heads (H) or tails (T), and is thus binomial.

**bioerosion.** The erosion of undersea rock or coral reefs by mollusks and other organisms.

**biogeography.** The study of living systems and their distribution to understand where and why animals and plants live in certain places.

**biological assessments (bioassessments).** Evaluation of the biological condition of a waterbody using biological surveys and other direct measurements of resident biota in surface waters (EPA 2009a).

**biological condition gradient (BCG).** A scientific model that describes biological response to increasing levels of stressors.

**biological criteria (biocriteria).** Narrative expressions or numeric values that describe the biological condition (structure and function) of aquatic communities inhabiting waters of a designated aquatic life use. Biocriteria are based on the numbers and kinds of organisms present and are regulatory-based biological measurements (EPA 2009a).

**biological diversity (biodiversity).** The variability among living organisms from all sources including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within and among species and diversity within and among ecosystems (MEA 2009).

**biological integrity.** The ability of an aquatic ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region (Karr and Dudley 1981).

**biological monitoring.** Use of a biological entity as a detector and its response as a measure to determine environmental conditions. Toxicity tests and ambient biological surveys are common biological monitoring methods (EPA 2009a).

**biomass.** The mass of living tissues in either an individual or cumulatively across organisms in a population or ecosystem (MEA 2009).

**biota.** The animal and plant life of a given region.

**biotic.** A term applied to the living components of an area.

**bivalves.** Marine or freshwater mollusks having a soft body with plate like gills enclosed within two shells hinged together (e.g., mussels, clams, oysters).

**bleaching.** The loss of symbiotic zooanthellae from corals. Bleaching is usually caused by elevated sea surface temperatures, but it can also be caused by sedimentation, salinity variation, or bacterial infection.

**bryozoans.** Aquatic animals forming mossy colonies of small polyps each having a curved or circular ridge bearing tentacles; attach to stones or seaweed and reproduce by budding.

**calcification.** The deposition of calcium carbonate skeletons by aquatic plants or animals. In reef-building corals, calcium is deposited in its aragonitic mineral form.

**carbon dioxide ($CO_2$).** A heavy odorless colorless gas formed during respiration and by the decomposition of organic substances; absorbed from the air by plants in photosynthesis. It is also a by-product of burning fossil fuels and biomass, as well as land-use changes and other industrial processes. It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance.

**carbon footprint.** The total amount of greenhouse gas emissions produced by a person, organization or state in a given time. For simplicity of reporting, it is often expressed in terms of the amount of carbon dioxide emitted.

**census.** Sampling every member of the population, i.e., every site on every coral reef.

**Clean Water Act (CWA).** An act passed by the U.S. Congress to control water pollution (also known as the Federal Water Pollution Control Act (33 U.S.C. 1251 et seq.) [As Amended Through P.L. 107–303, November 27, 2002] (EPA 2009a).

**climate change** (also referred to as "global climate change"). The term "climate change" is sometimes used to refer to all forms of climatic inconsistency, but because the Earth's climate is never static, the term is more properly used to imply a significant change from one climatic condition to another. In some cases, "climate change" has been used synonymously with the term, “global warming”; scientists however, tend to use the term in the wider sense to also include natural changes in climate (EPA 2010).

**commonwealth.** An organized United States insular area, which has established with the Federal Government, a more highly developed relationship, usually embodied in a written mutual agreement. Currently, two United States insular areas are commonwealths, the Northern Mariana Islands and Puerto Rico. A United States insular area from April 11, 1899, the Philippine Islands achieved commonwealth status on March 24, 1934 (Public Law 73-127), and remained as such until the United States recognized the Philippine Islands’ independence and sovereignty as of July 4, 1946 (DOI 2009).

**community.** All the groups of organisms living together in the same area, usually interacting or depending on each other for existence (EPA 2009a).

**composition.** The species found in a particular area.

**concentration.** The relative amount of a substance in a given medium.

**condition.** The relative ability of an aquatic resource to support and maintain a community of organisms having a species composition, diversity, and functional organization comparable to reference aquatic resources in the region.

**connectivity.** A topological property relating to how geographical features are attached to one another functionally, spatially, or logically.

**contaminant.** A substance that is not naturally present in the environment or is present in amounts that can, in sufficient concentration, adversely affect the environment.

**continuous.** Without break or interruption.

**coral.** The term “coral” means species of the phylum Cnidaria, including-- (A) all species of the orders Antipatharia (black corals), Scleractinia (stony corals), Gorgonacea (horny corals), Stolonifera (organpipe corals and others), Alcyanacea (soft corals), and Coenothecalia (blue coral), of the class Anthozoa; and (B) all species of the order Hydrocorallina (fire corals and hydrocorals) of the class Hydrozoa (16 U.S.C. 6401 et seq 2000).

**coral cover.** The covering of the sea floor by coral. It can be measured in square miles/kilometers or as a percent of area with cover.

**coral reef.** The term “coral reef” means any reefs or shoals composed primarily of corals.

**coral reef ecosystem.** Coral and other species of reef organisms (including reef plants) associated with coral reefs, and the nonliving environmental factors that directly affect coral reefs, that together function as an ecological unit in nature.

**coral reef managers.** Coral reef managers work for many different organizations both within government (at the federal, state, and local levels) and for non-profit organizations. While they all have a general responsibility to protect coral reefs, their authorities and roles can be quite varied, including: pollution prevention, including various permitting authorities; coral reef protection; coral reef restoration; fisheries management; and park/sanctuary management.

**coral reef restoration.** The process of replacing damaged and disturbed reefs with fully functional, restored ecosystems. Ideally restoration is accomplished by restoring conditions such as water and substrate quality that allow natural recruitment and growth. Most coral reef restoration programs have been focused on repairing reef frameworks damaged by vessel groundings to avoid continued loss of habitat associated with erosion. They also may involve the reattachment or transplantation of corals and other organisms to restore community composition and accelerate recovery of the habitat. New coral reef restoration approaches include efforts to restore trophic structure through reintroductions of key missing links or removal of pest species.

**criteria.** Statements of the conditions presumed to support or protect the designated use or uses of a waterbody. Criteria may be narrative or numeric (EPA 2009a).

**designated use.** Classification specified in water quality standards for each waterbody or segment describing the level of protection from perturbation afforded by the regulatory programs. The designated aquatic life uses established by the state or authorized tribes set forth the goals for restoration and/or baseline conditions for maintenance and prevention from future degradation of the aquatic life in specific waterbodies (EPA 2009a).

**diatoms.** Microscopic algae with cell walls made of silicon and have two separating halves.

**direct use values.** Economic values derived from direct use or interaction with a biological resource or resource system.

**discrete.** Made up of separate individuals.

**disease.** An abnormal condition of an organism that impairs physiological function. Disease may be caused by external factors, such as infectious disease or exposure to toxicants, or by internal dysfunctions that may come from nutritional or genetic abnormalities. Coral bleaching, though not usually caused by an infectious agent, can be considered a disease.

**dissolved oxygen.** Oxygen that is dissolved in water and therefore available for use by plants (phytoplankton), shellfish, fish, and other animals. If the amount of oxygen is too low, aquatic plants and animals may die. In addition, aquatic populations exposed to low dissolved oxygen concentration may be more susceptible to adverse effects of other stressors (e.g., disease, toxic substances). Wastewater and naturally occurring organic matter contain oxygen-demanding substances that, when decomposing, consume dissolved oxygen.

**DPSIR.** A decision support framework for capturing the physical and human processes in a decision process; it includes the identification of the Drivers (socioeconomic sectors that drive human activities), Pressures (human activities that stress the environment), resulting environmental and ecological States (reflect condition of the natural and living phenomena), Impacts on services and values (effects of environmental degradation of ecological attributes and ecosystem services), and Responses to those impacts (policies and responses).

**driving force.** A "driving force" is a need. Examples of primary driving forces for an individual are the need for shelter, food and water, while examples of secondary driving forces are the need for mobility, entertainment and culture. For an industrial sector, a driving force could be the need to be profitable and to produce at low costs, while for a nation a driving force could be the need to keep unemployment levels low.

**ecological indicator.** A characteristic of an ecosystem that can provide quantitative information on ecological structure and function. An indicator can contribute to a measure of integrity and sustainability.

**ecological integrity.** The condition of an unimpaired ecosystem as measured by combined chemical, physical (including physical habitat), and biological attributes (Karr and Dudley 1999).

**ecology.** The scientific study of relationships between organisms and their environment.

**ecoregion.** A relatively homogeneous ecological area defined by similarity of climate, landform, soil, potential natural vegetation, hydrology, or other ecologically relevant variables (also known as bioregions).

**ecosystem.** A dynamic complex of plant, animal, and microorganism communities and their nonliving environment interacting as a functional unit (MEA 2009).

**ecosystem functions.** Physical, chemical, and biological processes that occur in ecosystems.

**ecosystem services.** Benefits that human populations receive from ecosystems.

**ecosystem structure.** The individuals and communities of plants and animals of which an ecosystem is composed, their age and spatial distribution, and the non-living natural resources present. The elements of ecosystem structure interact to create ecosystem functions.

**effluent.** The discharge to a body of water from a defined or point source, generally consisting of a mixture of waste and water from industrial or municipal facilities.

**empirical.** Derived from experiment and observation rather than theory.

**endangered species.** Animals, birds, fish, plants, or other living organisms threatened with imminent extinction and officially declared as "endangered" under the Endangered Species Act.

**environment.** The complete range of external conditions, physical and biological, that affect a particular organism or community.

**Environmental Impact Statement (EIS).** A document required of federal agencies by the National Environmental Policy Act for major projects or legislative proposals significantly affecting the environment. A tool for decision making, it describes the positive and negative effects of the undertaking and cites alternative actions (EPA 2010).

**erosion.** Wearing away of rock or soil by the gradual detachment of soil or rock fragments by water, wind, ice, and other mechanical, chemical, or biological forces.

**estuary.** A coastal water resource where fresh water from rivers mixes with salt water from the ocean.

**extent.** The length or area over which observations were made or for which an assessment was made or over which a process is expressed (MEA 2009).

**fauna.** Animal life, especially the animals characteristic of a region, period, or special environment.

**fecundity.** Reproduction potential. Fecundity is usually measured by the number of eggs a female produces.

**fixed stations.** A type of monitoring approach where the same sites are repeatedly sampled at regular time intervals over a long period of time. Fixed station designs are used to estimate temporal variance and monitor trends.

**flora.** Plant life, especially the plants characteristic of a region, period or special environment.

**foraminiferans.** Shelled amoeboid protozoans, very small one-celled animals. Primarily marine although a few live in freshwater or in brackish conditions.

**fore reef.** The seaward edge of a reef that is fairly steep and slopes down to deeper water.

**functions.** The physical, chemical, and biological processes that occur in ecosystems.

**global climate change.** Refers to a suite of changes in the Earth's climate, including phenomena such as global warming, severe storm frequency and intensity, and glacial melting. Increasingly, scientists believe that global climate change is being accelerated by anthropogenic inputs of $CO_2$.

**gorgonians.** Corals having a horny or calcareous branching skeleton (e.g., Sea Fans).

**habitat.** A place where the physical and biological elements of ecosystems provide a suitable environment including the food, cover, and space resources needed for plant and animal livelihood (EPA 2009a).

**hardbottom.** Shallow and deep-water habitats with solid floor that can provide an attachment surface for sessile organisms such as corals.

**health.** Health is the general condition of a person in all aspects, including physical and mental. The term health is also sometimes used to represent condition of other organisms and even ecosystems, ecosystem health being synonymous with ecosystem integrity. Organism and ecosystem health usually implies a functioning system absent of disease.

**heavy metals.** Metallic elements with high atomic weights (e.g., mercury, chromium, cadmium, arsenic, and lead); can damage living things at low concentrations and tend to accumulate in the food chain (EPA 2010).

**herbicides.** Chemicals used to destroy or inhibit the growth of undesirable vegetation.

**herbivores.** An animal that feeds on plants (EPA 2010).

**historical data.** Data sets from previous studies, which can range from handwritten field notes to published journal articles (EPA 2009a).

**Human Disturbance Gradient (HDG).** A model that documents the level of human induced impacts on the biological, chemical, and physical processes of surrounding lands or waters along a gradient from high to low. Methods can range from a single measurement (e.g., percent of impervious surface) to the Landscape Development Intensity Index (LDI) that uses land use data and a development-intensity measure derived from energy use per unit area.

**impact.** An adverse effect.

**impaired waters.** Surface and ground waters that are negatively impacted by pollution resulting in water quality that prevents attainment of the designated use.

**impairment.** Detrimental effect on the biological integrity of a waterbody caused by an impact that prevents attainment of the designated use (EPA 2009a).

**impervious cover.** Surfaces where the infiltration of water is impossible, including roads, sidewalks, driveways, parking lots, swimming pools, and buildings.

**index.** A usually dimensionless numeric combination of scores derived from biological measures called metrics (EPA 2000).

**indicator.** Information based on measured data used to represent a particular attribute, characteristic, or property of a system (MEA 2009).

**indirect use values.** The regulating services that control water or air quality that can be estimated from how we behave as consumers. For example, although we might not pay for the maintenance of a healthy coral reef, we may be willing to pay a higher price for a house near such a coral reef or to drive longer to dive or snorkel this coral reef.

**institutions.** The rules that guide how people within societies live, work, and interact with each other. Formal institutions are written or codified rules. Examples of formal institutions would be the constitution, the judiciary laws, the organized market, and property rights. Informal institutions are rules governed by social and behavioral norms of the society, family, or community (MEA 2009).

**insular area.** A jurisdiction that is neither a part of one of the several states nor a federal district. This is the current generic term to refer to any commonwealth, freely associated state, possession or territory and from July 18, 1947, until October 1, 1994, the Trust Territory of the Pacific Islands. Unmodified, it may refer not only to a jurisdiction which is under United States sovereignty but also to one which is not, i.e., a freely associated state or, 1947-94, the Trust Territory of the Pacific Islands or one of the districts of the Trust Territory of the Pacific Islands (DOI 2009).

**integrity.** The extent to which all parts or elements of a system (e.g., an aquatic ecosystem) are present and functioning.

**landscape.** An area of land that contains a mosaic of ecosystems, including human-dominated ecosystems. The term cultural landscape is often used when referring to landscapes containing significant human populations (MEA 2009).

**land-use.** The way land is developed and used in terms of the kinds of anthropogenic activities that occur (e.g., agriculture, residential areas, industrial areas).

**league.** An obsolete unit of distance of variable length (usually 3 miles).

**least disturbed condition.** Areas with the least amount of disturbance in altered landscapes.

**macroalgae.** Non-rooted aquatic plants commonly referred to as seaweed.

**macroinvertebrates.** Animals without backbones of a size large enough to be seen by the unaided eye and which can be retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595 mm openings) (EPA 2009a).

**macrophytes.** Large aquatic plants that may be rooted, non-rooted, vascular or algiform (such as kelp); including submerged aquatic vegetation, emergent aquatic vegetation, and floating aquatic vegetation (EPA 2000).

**mangroves.** Salt-tolerant woody plants that grow in muddy swamps inundated by tides. Mangrove plants form communities that help stabilize banks and coastlines (Conservation International 2009).

**marine ecosystems.** The complex of living organisms in the ocean environment. They include oceans, salt marshes, estuaries, lagoons, mangroves, and coral reefs.

**Marine Protected Area (MPA).** Any area of the marine environment that has been reserved by federal, state, tribal, territorial, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein (EO 13158 2000).

**marine sanitation devices (MSDs).** Any equipment or process installed on board a vessel to receive, retain, treat, or discharge sewage.

**measurement error.** The extent to which there are discrepancies between survey results and the true value of what the survey researcher is attempting to measure.

**Mesoamerica.** Mexico and Central America.

**mesohaline.** Waters having salinity between 5 and 18 ppt (EPA 2000).

**metamorphosis.** A biological process by which an animal physically develops after birth or hatching, involving a conspicuous and relatively abrupt change in the animal's body structure through cell growth and differentiation. Some insects, amphibians, mollusks, crustaceans, Cnidarians, echinoderms and tunicates undergo metamorphosis, which is usually (but not always) accompanied by a change of habitat or behavior.

**metric.** A calculated term or enumeration representing some aspect of biological assemblage, function, or other measurable aspect and is a characteristic of the biota that changes in some predictable way with increased human influence. A multimetric approach involves combinations of metrics to provide an integrative assessment of the status of aquatic resources (Karr and Chu 1999).

**microhabitat.** A small area with physical and ecological characteristics that distinguish it from its immediate surrounding area.

**minimally disturbed condition.** Areas with a minimal amount of human disturbance.

**minimally impaired.** Sites or conditions with slight anthropogenic perturbation relative to the overall region of the study (EPA 2009a).

**model.** A physical, mathematical, or logical representation of a system of entities, phenomena, or processes; i.e., a simplified abstract view of the complex reality. For example, meteorologists use models to predict the weather.

**monitoring.** A periodic or continuous measurement of the properties or conditions of something, such as a waterbody.

**multimetric.** Analysis techniques using several measurable characteristics of a biological assemblage (Karr and Chu 1999).

**multimetric index.** A combination of several measurable characteristics of the biological assemblage to provide an assessment of the status of water resources (EPA 2000).

**multiplier.** How many times money spent on an activity circulates through an economy. For example, money spent on recreational diving helps create jobs directly in the dive company, but it also creates jobs indirectly elsewhere in the economy. The dive company, for example, has to buy gasoline from the marina, which may spend some of this money on food or boating supplies.

**narrative biological criteria.** General statements of conditions of biological integrity and water quality for a given designated aquatic life use (EPA 2009a).

**narrative criteria.** Part of water quality standards that addresses pollutants, such as color and odor, that can't be measured with numeric criteria. Narrative criteria are statements that describe a desired water quality goal, such as waters being "free from" pollutants such as oil and scum, color and odor, and other substances that can harm people, fish, and other coral reef biota.

**National Pollutant Discharge Elimination System (NPDES).** A national program established by the Clean Water Act for permitting point sources of pollution. Discharge of pollution from point sources is not allowed without a permit. EPA has delegated NPDES authority to some states and territories.

**no-discharge zone.** An area where the discharge of polluting materials is not permitted.

**non-indigenous.** Species that have become able to survive and reproduce outside the habitats where they evolved or spread naturally. Other names for these species include alien, exotic, injurious, introduced, invasive, and non-native.

**nonpoint source (NPS) pollution.** Any source of water pollution that does not meet the legal definition of "point source" in section 502(14) of the Clean Water Act. NPS pollution is widespread because it can occur any time activities disturb the land or water. Agriculture, forestry, grazing, septic systems, recreational boating, urban runoff, construction, physical changes to stream channels, and habitat degradation are potential sources of NPS pollution. NPS pollution includes adverse changes to the vegetation, shape, and flow of streams and other aquatic systems.

NPS pollution also results from land runoff, precipitation, atmospheric deposition, drainage, seepage or hydrologic modification that can pick up pollutants, and deposit them into rivers, lakes and coastal waters or introduces them into ground water. NPS sources are automobile emissions, road dirt and grit, and runoff from parking lots; runoff and leachate from agricultural fields, barnyards, feedlots, lawns, home gardens and failing on-site wastewater treatment systems; and runoff and leachate from construction, mining and logging operations. Most NPS pollutants fall into six major categories: sediment, nutrients, acid and salts, heavy metals, toxic chemicals and pathogens. The cumulative impact of nonpoint source pollution is significant.

**nonpoint source controls.** General phrase used to refer to all methods employed to control or reduce nonpoint source pollution. NPDES. National Pollutant Discharge Elimination System (EPA 2009a).

**non-random sampling design.** A sample that is not random. Some examples of non-random samples are convenience samples and best professional judgment samples.

**numeric biocriteria.** Numerical indices that describe expected attainable community attributes for different designated aquatic life uses (EPA 2009a).

**nudibranch.** A mollusk that has no protective covering as an adult. Gills or other projections on the dorsal surface carry on respiration.

**numeric criteria.** Values in water quality standards that should rarely be exceeded if beneficial uses are to be supported. Individual criteria are based on specific data and scientific assessment of adverse effects. Numeric guidelines assign numbers that represent limits and/or ranges of chemical concentrations, like oxygen, or physical conditions, like water temperature.

**nutrients.** Chemicals that are needed by plants and animals for growth (e.g., nitrogen, phosphorus). In water resources, if other physical and chemical conditions are optimal, excessive amounts of nutrients can lead to degradation of water quality by promoting excessive growth, accumulation, and subsequent decay of plants, especially algae. Some nutrients can be toxic to animals at high concentrations.

**ocean acidification.** The decrease in the pH of the Earth's oceans caused by the uptake of carbon dioxide ($CO_2$) from the atmosphere. When atmospheric carbon dioxide dissolves in seawater it produces carbonic acid, which subsequently lowers pH of surrounding seawater, decreases the availability of carbonate ions, and lowers the saturation state of the major shell-forming carbonate minerals. Current research indicates the impact of ocean acidification on marine organisms will largely be negative, and the impacts may differ from one life stage to another.

**octocorals.** Water-based organisms formed of colonial polyps with 8-fold symmetry.

**oligohaline**. Waters having salinity less than 5 ppt (EPA 2000).

**open source software.** Software available free of charge as an alternative to conventional commercial models. Open source software can be used and disseminated at will, and the source code is open and can be changed as required. The only condition is that the user make such changes known and pass this information on to others. Open source software is the shared intellectual property of all developers and users and, thanks to the collaboration, achieves a higher level of quality than software produced using conventional means. The best-known example of open source software is the Linux operating system.

**option values.** The value placed upon goods and services for their potential to be available in the future.

**organic matter.** Natural or synthetic substances based on carbon.

**ostracods.** Tiny marine and freshwater crustaceans with a shrimp-like body enclosed in a bivalve shell.

**Outstanding Natural Resource Waters (ONRW).** Outstanding National Resource Waters (ONRW) designations offer special protection (i.e., no degradation) for designated waters. These are areas of exceptional water quality or recreational/ecological significance.

**over-fishing.** Occurs when fishing activities reduce fish stocks below a level that is biologically or economically sustainable.

**patch reef.** Small circular or irregular reefs that arise from the floor of lagoons, behind barrier reefs, or within an atoll.

**pathogen.** An agent of disease. A disease producer. The term pathogen most commonly is used to refer to infectious organisms. These include bacteria (such as staphylococcus), viruses (such as HIV), and fungi (such as yeast). Less commonly, pathogen refers to a noninfectious agent of disease such as a chemical (MedicineNet.com 2010).

**pesticide.** Any substance that is intended to prevent, destroy, repel, or mitigate any pest.

**pH.** The negative log of the hydrogen ion concentration. It is a measure of the acidity or basicity of a solution. Water ranges from very acid (pH=1) to very alkaline (pH=14). A pH of 7 is neutral. EPA recommends the range of pH 6.5 to 8.5 for coral reefs.

**pharmaceuticals.** Man-made and natural drugs used to treat diseases, disorders, and illnesses.

**phosphorus.** An element essential to the growth and development of plants, but which, in excess, can cause unhealthy conditions that threaten aquatic animals in surface waters.

**photosynthesis.** The manufacture by plants of carbohydrates and oxygen from carbon dioxide mediated by chlorophyll in the presence of sunlight (EPA 2010).

**phylum.** A taxonomic rank below Kingdom and above Class.

**phytoplankton.** Minute plant life usually containing chlorophyll, that passively drifts or weakly swims in a water body.

**plot (sampling plot).** Plot sampling is most often used to intensively study a small portion of the system in question in order to obtain a representative sample.

**point source.** Any confined and discrete conveyance from which pollutants are or may be discharged. These include pipes, ditches, channels, tunnels, conduits, wells, containers, and concentrated animal feeding operations.

**point source pollution.** Water pollution that is discharged from a discrete location such as a pipe, tank, pit, or ditch.

**pollutant.** Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water (CWA §502 (6)). The term includes nutrients, sediment, pathogens, toxic metals, carcinogens, oxygen-demanding materials, and all other harmful substances. Pollutants adversely alter the physical, chemical, or biological properties of the environment

**pollution.** The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water (CWA §502 (19)).

**polychaetes.** A class of annelid worms, generally marine. Each body segment has a pair of fleshy protrusions that bear many bristles made of chitin. Polychaetes are sometimes referred to as bristle worms.

**polyhaline.** Waters having salinity greater than 18 ppt.

**population.** The entire aggregation of items from which samples can be drawn. Populations may be discrete (made up of separate individuals) or continuous (without interruption).

**precision.** The ability of a measurement to be consistently reproduced.

**predation.** The consumption of animals by other animals (MEA 2009).

**prediction (or forecast).** The result of an attempt to produce a most likely description or estimate of the actual evolution of a variable or system in the future. See also projection and scenario (MEA 2009).

**pressures on the environment.** Human activities exert "pressures" on the environment, as a result of production or consumption processes, which can be divided into three main types: (i) excessive use of environmental resources, (ii) changes in land use, and (iii) emissions (of chemicals, waste, radiation, noise) to air, water and soil.

**primary contact recreation.** A beneficial use as defined in water quality standards. Applies to waters where people engage in activities that involve immersion in, and likely ingestion of, water, such as swimming and water skiing.

**primary production.** The production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis.

**probabilistic sampling.** A type of random sampling that yields a spatially balanced subset of sites, and avoids the clumping associated with simple random sampling.

**propagation.** The act of multiplication by a plant or animal by any process of natural reproduction from the parent stock.

**qualitative.** Descriptive of kind, type, or direction.

**quantitative.** Descriptive of size, magnitude, or degree.

**random sampling.** Selects a subset of all coral reef sites to ensure that the sample is "representative" of all coral reefs and the estimate condition is unbiased.

**reef mooring buoys.** Mooring buoys are used to keep one end of a mooring cable or chain on the water's surface so that ships or boats can tie on to it. Mooring buoys have proven to be an effective tool around the world in reducing the damage to coral reefs caused by anchors. They eliminate the need to drop anchor on coral reefs by providing boaters with a convenient means of securing their boats.

**reference condition.** The chemical, physical and biological condition expected to be found in unimpaired waterbodies of a similar type. This can be determined by sampling at unimpaired or minimally impaired reference sites, from historical data and information, or through modeling and estimations.

**reference site.** Specific locality on a waterbody which is unimpaired or minimally impaired and is representative of the expected biological integrity of other localities on the same waterbody or nearby waterbodies (EPA 2009a).

**refugia.** An area or refuge where biota can live and breed without the worry of predation from other organisms.

**replicate.** Taking more than one sample or performing more than one analysis (EPA 2000).

**representative sample.** A portion of material or water that is as similar in content and consistency as possible to that in the larger body of material or water being sampled.

**resilience.** The ability of a system to absorb or recover from disturbance and change, while maintaining its functions and services (Carpenter et al. 2001). For example a coral reef's ability to recover from a bleaching event.

**responses.** The term "response" is used in two contexts in this report: 1) Human actions, including policies, strategies, and interventions, to address specific issues, needs, opportunities, or problems. In the context of ecosystem management, responses may be of legal, technical, institutional, economic, and behavioral nature and may operate at local or micro, regional, national, or international level and at various time scales (MEA 2009). 2) Ecosystem processes occurring due to the effect of some stressor or combination of stressors.

**rugosity.** A measure of small-scale variations or amplitude in the height of a surface. In coral biology, high rugosity is often an indication of the presence of coral, which creates a complex surface as it grows. A rugose seafloor's tendency to generate turbulence is understood to promote the growth of coral and coralline algae by delivering nutrient-rich water after the organisms have depleted the nutrients from the envelope of water immediately surrounding their tissues (Wikipedia 2009).

**salinity.** A measurement of the amount of salt in water. Generally reported as “parts per thousand” (i.e., grams of salt per 1,000 grams of water) and abbreviated as “ppt” or ‰.

**scale.** The physical dimensions, in either space or time, of phenomena or observations (source: MEA). There is no single natural scale at which ecological phenomena should be studied; systems generally show characteristic variability on a range of spatial, temporal, and organizational scales (Levin 1992).

**scenarios.** A coherent, internally consistent, plausible description of a possible future state of the world. Scenarios are used in assessments to provide alternative views of future conditions considered likely to influence a given system or activity.

**scleractinians.** Corals that have a hard limestone skeleton and belong to the order Scleractinia.

**scuba.** An apparatus carried by a diver, which includes a tank holding a mixture of oxygen and other gases, used for breathing underwater.

**seagrasses.** Flowering plants from one of four plant families (Posidoniaceae, Zosteraceae, Hydrocharitaceae, or Cyomodoceaceae), all in the order Alismatales (in the class of monocotyledons), which grow in marine, fully-saline environments (Wikipedia 2009).

**secondary production.** The generation of biomass through the transfer of organic material between trophic levels.

**sediment.** Particles and/or clumps of particles of sand, clay, silt, and plant or animal matter that are suspended in, transported by, and eventually deposited by water or air.

**sedimentation.** The removal, transport, and deposition of detached soil particles by flowing water or wind.

**services.** The benefits that human populations receive from functions that occur in ecosystems.

**shapefile.** A data storage format for storing the location, shape, and attributes of geographic features.

**shifting baseline.** A term used to describe the way significant changes to a system are measured against previous baselines, which themselves may represent significant changes from the original state of the system (Wikipedia 2009).

**ship grounding.** A type of marine accident that involves the impact of a ship on the seabed. Can cause damage to both the ship and the sea bottom including the resident biota (seagrasses and coral reefs).

**soft corals.** A term often used to describe a group of coral species (octocorals, Alconyonaria) that actually include soft coral, blue coral, sea pens and gorgonians (sea fans and sea whips). Octocorals are generally thick and fleshy and resemble stony corals in polyp size. Because they lack a calcium carbonate skeleton, octocorals move with ocean currents.

**sovereign.** An independent or non-independent jurisdiction which itself possesses or whose people possess in their own right the jurisdiction's supreme authority, regardless of the jurisdiction's or people's current ability to exercise that authority (DOI 2009).

**species.** A category of taxonomic classification, ranking below a genus or subgenus and consisting of related organisms capable of interbreeding. Also refers to an organism belonging to such a category.

**sponge.** A primitive multi-cellular marine animal whose porous body is supported by a fibrous skeletal framework; usually occurs in sessile colonies.

**spur and groove reef.** A reef formation where the barrier reef parallel to shore puts off intermittent ridges which grow away from shore. These ridges, or spurs, alternate with grooves, where the sandy bottom lies in view 30 to 60 feet (10-20 meters) below.

**stakeholder.** Someone having a stake or interest in a physical resource, ecosystem service, institution, or social system, or someone who is or may be affected by a public policy (MEA 2009). All citizens of the nation are stakeholders, including residents of local communities adjacent to coral reefs, tourists and the tourism industry, fishermen and other marine-based industries, land-based industries, conservation and environmental groups, research organizations, and educational institutions.

**stony corals.** A group of coral species known as hard coral that form the hard, calcium carbonate skeleton. Such types include the brain corals, fungus or mushroom corals, Staghorn and Elkhorn corals, table corals, flower pot corals, bubble corals and lettuce corals.

**stormwater.** Water from rain that flows over the ground surface and is subsequently collected by natural channels or artificial conveyance systems, and also includes water that has infiltrated into the ground but nonetheless reaches a stream channel relatively rapidly and that contributes to the increased stream discharge that commonly accompanies almost any rainfall event in a human-disturbed watershed.

**stressors.** Physical, chemical and biological factors that adversely affect aquatic organisms (EPA 2009a).

**subsistence fishing.** Fishing for food (consumed by the local group of people who do the fishing), not for commercial sale.

**sustainability.** A characteristic or state whereby the needs of the present and local population can be met without compromising the ability of future generations or populations in other locations to meet their needs (MEA 2009).

**substrate.** A surface on which a plant or animal grows or is attached.

**surface water.** Water found over the land surface in rivers, streams, creeks, lakes, ponds, marshes, or oceans.

**targeted sampling.** Targeted sampling may also be referred to as judgment sampling and selects sites according to a particular condition or to test a scientific hypothesis. Most non-random sampling plans would probably be included in this category. Targeted sampling is the best approach when a specific question is being evaluated, e.g., the effect of restoration or best management practices on stream condition.

**taxa.** Nested groups of species that reflect similarity. Familiar taxa are birds (which belong to the class Aves) and fig trees (which belong to the genus Ficus) (MEA 2009).

**taxonomic.** Referring to the science of hierarchically classifying animals by categories (phylum (pl. phyla), class, order, family, genus (pl. genera), species and subspecies) that share common features and are thought to have a common evolutionary descent.

**technology based standards.** Industry-specific effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water-quality effects (EPA 2010).

**territorial seas.** Defined in section 502(8) of the Clean Water Act to be the belt of the seas measured from the line of ordinary low water along that portion of the coast which is in direct contact with the open sea and the line marking the seaward limit of inland waters, and extending seaward a distance of 3 nautical miles.

**territory.** Under Article IV of the U.S. Constitution, territory is subject to and belongs to the United States (but not necessarily within the national boundaries or any individual state). This includes tracts of land or water not included within the limits of any state and not admitted as a state into the Union. U.S. territories with coral reefs include American Samoa, Commonwealth of the Northern Mariana Islands (CNMI), Guam, Puerto Rico, and the U.S. Virgin Islands (USVI).

**threatened species.** Species, determined by the U.S. Fish and Wildlife Service, that are likely to become endangered within the foreseeable future throughout all or a significant portion of their range.

**threshold.** Numeric standards and guidelines to determine whether a waterbody supports its designated use.

**tidal freshwater.** Freshwater (0-0.5 ppt) that is tidally influenced.

**Tiered Aquatic Life Use (TALU).** A conceptual model predicting the response of aquatic communities to increasing human disturbance. It is a draft framework for using biological assessment information to refine designated aquatic life uses.

**topography.** The physical features of a surface area including relative elevations and the position of natural and man-made (anthropogenic) features.

**Total Maximum Daily Load (TMDL).** A water quality improvement plan. A TMDL is the calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards and an allocation of that amount to the pollutant's source (EPA 2009a).

**toxic pollutants.** Pollutants that are poisonous, carcinogenic, or otherwise directly harmful to plants and animals.

**toxics.** Any chemical listed in EPA rules as “Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986” (EPA 2010).

**transect.** A path along which one records and counts occurrences of the phenomena of study (e.g., corals, noting each instance).

**trophic.** Describing the relationships between the feeding habits of organisms in a food chain.

**turbidity.** The amount of solid particles that are suspended in water and that cause light rays shining through the water to scatter. Thus, turbidity makes the water cloudy or even opaque in extreme cases. High levels of turbidity are harmful to aquatic life.

**Unified Watershed Assessment (UWA).** A cooperative approach promoted by EPA to restoring and protecting water quality in which state, federal, tribal, and local governments work with stakeholders and interested citizens to (1) identify watersheds not meeting clean water and other natural resource goals and (2) work cooperatively to focus resources and implement effective strategies to solve these problems.

**Use Attainability Analysis (UAA).** A structured scientific assessment of the factors affecting the attainment of uses specified in Section 101(a)(2) of the Clean Water Act (the so-called “fishable/swimmable” uses). The factors to be considered in such an analysis include the physical, chemical, biological, and economic use removal criteria described in EPA’ s water quality standards regulation (40 CFR 131.10(g)(1)-(6)).

**U.S. jurisdictions.** In the context of this document, we mean the states, territories and commonwealths with coral reef ecosystems.

**valuation.** The process of expressing a value for a particular good or service in a certain context (e.g., of decision-making) usually in terms of something that can be counted, often money, but also through methods and measures from other disciplines (e.g., sociology and ecology) (MEA 2009).

**value.** The quality of a thing according to which it is thought of as being more or less desirable, useful, estimable or important. Using this definition the value of an ecosystem might be defined in terms of its beauty, its uniqueness, its irreplaceability, its contribution to life support functions or commercial or recreational opportunities, or its role in supporting wildlife or reducing environmental or human health risks, or providing many other services that benefit humans (Ecosystem Valuation 2009).

**wastewater treatment plant.** A facility containing a series of tanks, screens, filters and other processes by which pollutants are removed from water.

**wastewater treatment system.** A system for disposing of wastewater. There are generally two types of systems: centralized and decentralized. Centralized systems are “public sewer systems” and usually serve established towns and transport wastewater to a central location for treatment. Decentralized systems are systems that do not connect to a public sewer system. They may treat wastewater on-site or may discharge to a private treatment plant.

**wastewater.** Spent or used water, such as from households and businesses that contains enough harmful material to damage the water's quality. Every building with running water generates some sort of wastewater.

**waterbody.** A stream, river, lake, estuary, coastline, or other water feature, or portion thereof.

**Water Pollution Control State Revolving Loan Fund.** A fund to provide below-market-rate interest loans to help build new or repair existing wastewater treatment facilities. Eligible facilities include treatment plants, interceptor sewers, and collector sewers.

**water pollution.** The man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water.

**water quality.** A term for the combined biological, chemical, and physical characteristics of water with respect to its suitability for a designated use.

**water quality assessment.** An evaluation of the condition of a waterbody using biological surveys, chemical-specific analyses of pollutants in waterbodies, and toxicity tests.

**water quality criteria.** Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use (40 CFR 131.3).

**water quality standards.** Provisions of state or federal law which consist of a designated use or uses for the waters of the United States, water quality criteria for such waters based upon such uses. Water quality standards are to protect public health or welfare, enhance the quality of the water and serve the purposes of the Act (40 CFR 131.3).

**watershed.** The area of land from which rainfall drains into a single point. Watersheds are also sometimes referred to as drainage basins or drainage areas. Ridges of higher ground generally form the boundaries between watersheds. At these boundaries, rain falling on one side flows toward the low point of one watershed, while rain falling on the other side of the boundary flows toward the low point of a different watershed.

**wetlands.** A type of ecosystem, generally occurring between upland and deepwater areas, that provides many important functions including fish and wildlife habitat, flood protection, erosion control, water quality maintenance, and recreational opportunities. A wetland is an area that is covered by water or has water-saturated soil during a portion of the growing season. In general, it is often considered the transitional area between permanently wet and dry environments. The Ramsar Convention on Wetlands identifies the following Marine/Coastal wetlands: permanent shallow marine waters; marine sub-tidal aquatic beds (kelp beds, sea-grass beds, tropical marine meadows); coral reefs; rocky marine shores (including rocky offshore islands and sea cliffs); sand, shingle or pebble shores; estuarine waters; intertidal mud, sand or salt flats; intertidal marshes (includes salt marshes, salt meadows, saltings, raised salt marshes); intertidal forested wetlands (includes mangrove swamps, nipah swamps, and freshwater tidal brackish and freshwater marshes); coastal brackish/saline lagoons; coastal freshwater lagoons; and marine and coastal karst and other subterranean hydrological systems (UN 2001).

**zooplankton.** Free-floating or drifting animals with movements determined by the motion of the water (EPA 2000).

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# Appendix D: Common Questions and Their Answers

### Q. Isn't the Clean Water Act only about clean water?

A. In the early days of implementing the act, what was most obvious was the pollution from point sources. The thought was that once the end-of-pipe effluent was cleaned up, the waters would be restored. Today we have a more complete understanding of the diversity of point source and non-point source pollution that degrades water resources. Although the goal of the act is to protect "physical, chemical and biological integrity," early emphasis on chemical measurements may have reflected the naïve hope that clean up of industrial users was all that was needed. Since that time our appreciation of the primary importance of living, biological systems has supplemented the narrow focus on chemical water quality. If our goal is to protect and restore the biota, clean water is not enough. We must also address human-induced changes related to hydrology, habitat, food and energy sources, and biological interactions.

### Q. How will implementing biological criteria benefit state water quality programs?

A. State water quality programs could benefit from biological criteria because they:

a) directly assess impairments in ambient biota from adverse impacts on the environment;
b) are defensible and quantifiable;
c) document improvements in water quality resulting from agency action;
d) reduce the likelihood of false positives (i.e., a conclusion that attainment is achieved when it is not);
e) provide information on the integrity of biological systems that is compelling to the public.

### Q. Should biocriteria be able to identify or characterize the sources of impairment?

A. No, while advantageous, this is not necessary for biocriteria. Biocriteria have the sole purpose of determining whether a waterbody has achieved its biological condition as defined by designated uses.

### Q. Can biocriteria trigger actions unrelated to the regulatory authority of the Clean Water Act?

A. Yes. Once biocriteria have been used to determine impairment, jurisdictions can use any of the authorities available to them to respond to the impairment. Chapter 9 includes a discussion of how biocriteria can be used in support of various programs and legislative authorities.

### Q. How will biological criteria be used in a permit program?

A. When permits are renewed, records from chemical analyses and biological assessments are used to determine if the permit has effectively prevented degradation and led to improvement. The purpose for this evaluation is to determine whether applicable water quality standards were achieved under the expiring permit and to decide if changes are needed. Biological surveys and criteria are particularly effective for determining the quality of waters subject to permitted discharges. Because biosurveys provide both integrative evaluations of current biological condition and the information needed to determine if that condition diverges from the biological integrity goal, permit writers can make informed decisions on whether to maintain or modify permits.

### Q. What expertise and staff will be needed to implement a biological criteria program?

A. Staff with sound knowledge of state aquatic biology and scientific protocol are needed to coordinate a biological criteria program. Actual field monitoring could be accomplished by summer-hire biologists led by permanent staff aquatic biologists. Most states employ aquatic biologists for monitoring trends or issuing site-specific permits.

### Q. Which management personnel should be involved in a biologically-based approach?

A. Management personnel from each area within the standards and monitoring programs should be involved in this approach, including permit engineers, resource managers, and field personnel.

### Q. How much will this approach cost?

A. The cost of developing biological criteria is a State-specific question depending upon many variables. However, states that have implemented a biological criteria program have found it to be cost effective. Biological criteria provide an integrative assessment over time. Biota reflect multiple impacts. Testing for impairment of resident aquatic communities can actually require less monitoring than would be required to detect many impacts using more traditional methods (e.g., chemical testing for episodic events).

### Q. What are some concerns of dischargers?

A. Dischargers are concerned that biological criteria will identify impairments that may be erroneously attributed to a discharger who is not responsible. This is a legitimate concern that the discharger and state must address with careful evaluations and diagnosis of cause of impairment. However, it is particularly important to ensure that waters used for the reference condition are not already impaired. Although a discharger may be contributing to surface water degradation, it may be hard to detect using biosurvey methods if the waterbody is also impaired from other sources. This can be evaluated by testing the possible toxicity of effluent-free reference waters on sensitive organisms. Dischargers are also concerned that current permit limits may become more stringent if it is determined that meeting chemical and whole-effluent permit limits are not sufficient to protect aquatic life from discharger activities. Alternative forms of regulation may be needed; these are not necessarily financially burdensome but could involve additional expense. Burdensome monitoring requirements are additional concerns. With new rapid bioassessment protocols available for stony corals, and under development for other coral reef biota (e.g., fish, soft corals and sponges), monitoring resident biota is becoming more straightforward. Since resident biota provide an integrative measure of environmental impacts over time, the need for continual biomonitoring is actually lower than chemical analyses and generally less expensive. Guidance is being developed to establish acceptable research protocols, quality assurance/quality control programs and training opportunities to ensure that adequate guidance is available.

### Q. What are the concerns of environmentalists?

A. Environmentalists are concerned that biological criteria could be used to alter restrictions on dischargers if biosurvey data indicate attainment of a designated use even though chemical criteria and/or whole-effluent toxicity evaluations predict impairment. Evidence suggests that this occurs infrequently (e.g., in Ohio, 6 percent of 431 sites evaluated using chemical-specific criteria and biosurveys resulted in this disagreement). In those cases where evidence suggests more than one conclusion, independent application applies. If biological criteria suggest impairment but chemical-specific and/or whole-effluent toxicity implies attainment of the use, the cause for impairment of the biota is to be evaluated and, where appropriate, regulated. If whole effluent and/or chemical-specific criteria imply impairment but no impairment is found in resident biota, the whole-effluent and/or chemical-specific criteria provide the basis for regulation.

### Q. Do biological criteria have to be codified in state regulations?

A. State water quality standards require three components: (1) designated uses, (2) protective criteria, and (3) an antidegradation policy and implementation procedures. Criteria may be codified in regulations. Codification could involve general narrative statements of biological criteria, numeric criteria, and/or criteria accompanied by specific testing procedures. Codifying general narratives provides the most flexibility for incorporating new data and improving data gathering methods as the biological criteria program develops. States should carefully consider how and when to codify these criteria.

### Q. How will biocriteria fit into the agency's method of implementing standards?

A. Resident biota integrate multiple impacts over time and can detect impairment from known and unknown causes. Biocriteria can be used to verify improvement in water quality in response to regulatory efforts and detect continuing degradation of waters. They provide a framework for developing improved best management practices for nonpoint source impacts. Numeric criteria can provide effective monitoring criteria for inclusion in permits.

### Q. Who determines the values for biological criteria and decides whether a waterbody meets the criteria?

A. The process of developing biological criteria, including refined use classes, narrative criteria, and numeric criteria, must include agency managers, staff biologists, and the public through public hearings and comment. Once criteria are established, determining attainment/nonattainment of a use requires biological and statistical evaluation based on established protocols. Changes in the criteria would require the same steps as the initial criteria: technical modifications by biologists, goal clarification by agency managers, and public hearings. The key to criteria development and revision is a clear statement of measurable objectives.

# Appendix E: DPSIR Framework

DPSIR is a general framework for organizing information about state of the environment. This framework was adopted by the European Environmental Agency (RIVM 1995; UNEP/RIVM 1994) and has been used by the United Nations to organize information about the state of the environment in relation to human activities (UNEP 2007). It is a human-centric framework, focused on human activities that affect the environment and the consequences of those activities.

EPA's Coral Reefs Ecosystem Services Research Program (ESRP) has adopted the DPSIR framework to show the broad array of human interactions with coral reefs, and for examining consequences (e.g., changes in benefits, costs and sustainable delivery of ecosystem services) across ecological and multiple socioeconomic sectors. The utility of a DPSIR framework lies in its transparency (readily obvious to coral reef managers and stakeholders) and its capacity to isolate particular linkages and interactions while retaining conceptual relevance to the larger system. The framework does not capture every situation perfectly, but is a reasonable means to organize the many social, economic and ecological interactions.

The framework assumes cause-effect relationships between interacting components of social, economic, and environmental systems (Pierce 1998; Smeets and Weterings 1999), which are:

- **D**riving forces: Socio-economic sectors that describe basic needs of human society such as food, water, fuel and shelter, and secondary needs such as recreation, cultural heritage and sense of place
- **P**ressures: Driver-generated human activities that affect the environment
- **S**tate: status of the environment and ecological resources, including attributes that provide services; state is altered by changes in pressure
- **I**mpacts: changes in coral reef persistence and delivery of services as a consequence of changes in ecological state
- **R**esponse: societal reactions to changes in ecosystem services, values and sustainability

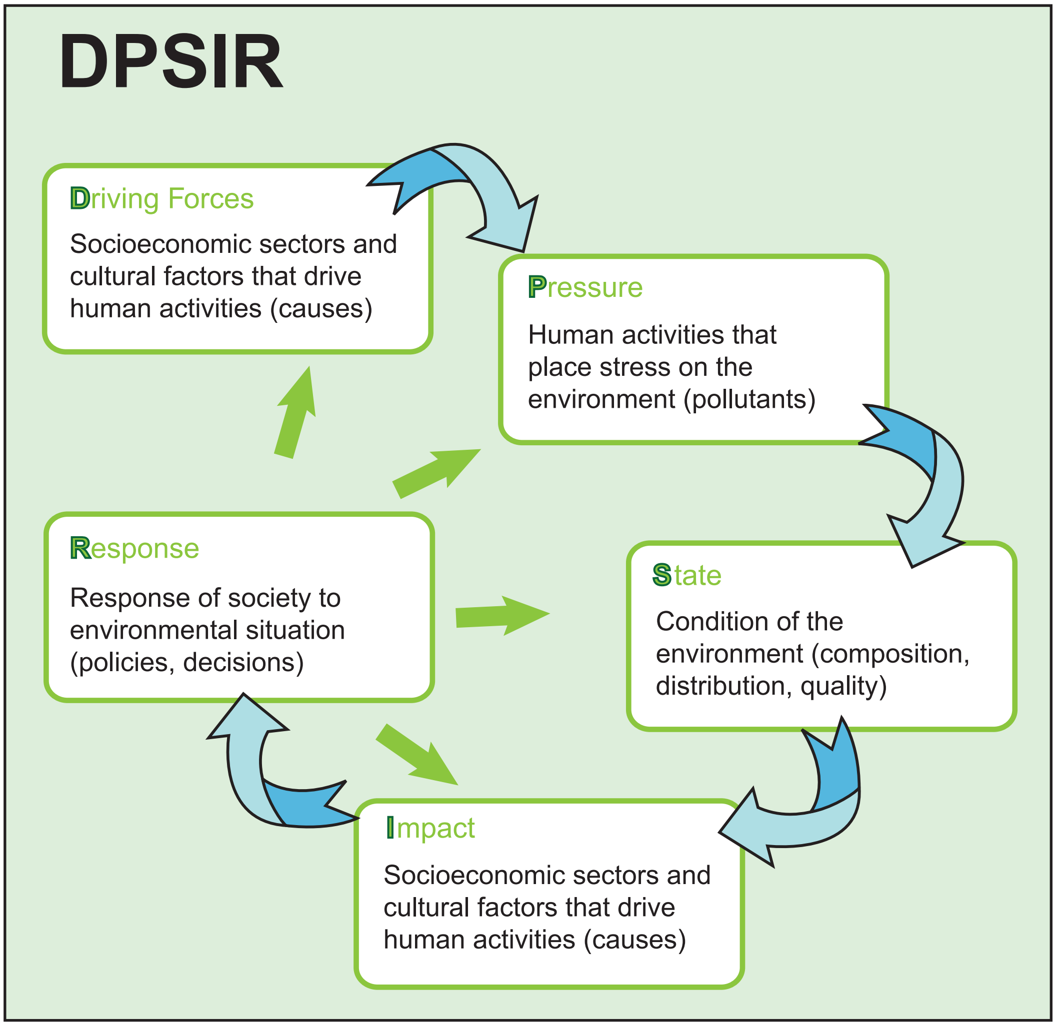


**Figure E-1.** Conceptual relationships among DPSIR sectors

Generation of a comprehensive framework to link ecological and socioeconomic factors, even an introductory version, is significant because it has never been attempted for coral reefs. For decades scientists have conducted research to assess and understand the ecological phenomena of coral reefs around the world. While the body of information is extensive, it is unevenly distributed across disciplines, times and places. Consequently, the information has not been effectively used to identify gaps and prioritize research; nor has it been easily synthesized into concepts and tools for conservation that resonate with stakeholders and influence management. This situation is not unique to coral reefs. Curran (2009) suggests that there are no programs capable of delivering overall support (including social and economic perspectives) to environmental decision-making. Curran also emphasizes the need for further research on viable decision-support frameworks.

Application of the DPSIR framework will better ensure that we do not overlook critical relationships and that we recognize the full consequence of a decision to related parts of the larger system (O'Connor and McDermott 1997). It is anticipated that the DPSIR framework will be ultimately expanded into a human-inclusive ecosystem model.

# Appendix F: Ocean Acidification

Since the Industrial Age began, burning of fossil fuels has added significant amounts of carbon dioxide ($CO_2$) into the atmosphere. Concentrations have risen from 280 ppm in the atmosphere to today's level of 387 ppm (Feely et al. 2004). About a third of atmospheric $CO_2$, approximately 22 million tons per day, is absorbed into oceans. The estimated time lag for absorption is at least 10 years, meaning that today's level of atmospheric $CO_2$ will still influence ocean chemistry a decade from now (Veron et al. 2009). Once dissolved, $CO_2$ reacts with the seawater to form carbonic acid, which dissociates into hydrogen and bicarbonate and decreases ocean pH. During the last 250 years, oceans have become more acidic by 0.1 pH units (Feely et al. 2004). This may at first seem small but the pH scale is logarithmic so this represents a 30% increase in acidity. Models forecast continued acidification—another 0.3 to 0.4 pH units—by the end of this century.

Oceanic absorption of atmospheric $CO_2$ mitigates some climate change impacts, but may generate others. Increased absorption has led to a decline in ocean saturation state for aragonite and calcite, forms of calcium carbonate incorporated into shells and skeletons of many marine organisms (Kleypas et al. 1999). Reduced saturation states reduce the ability to form shells and tests, and consequently reduce the growth of organisms such as corals, mussels, oysters, snails, sea urchins, and a wide variety of microscopic plants and animals. Many other physiological effects on marine life may result from changes in ocean chemistry from $CO_2$ absorption. Overall, little is known about the effects on particular species or on population and community interactions.

The Center for Biological Diversity has petitioned EPA to tighten water quality standards to no observable change in pH for marine coastal waters (see Craig 2009). This raises several questions: Is there evidence that slight changes in pH are affecting designated uses? Are states responsible for global atmospheric $CO_2$? Can pH be effectively monitored across spatial and temporal scales? Since few of the answers to these questions are known, EPA issued a Notice of Data Availability (NODA) to solicit additional pertinent data or scientific information that may be useful in addressing ocean acidification (EPA 2009d).

Specifically, EPA solicited information on measurement of ocean acidification in marine coastal waters, on effects of ocean acidification on marine biota, and scientific views of current knowledge and literature. EPA also asked for information and views on EPA's current CWA Section 304(a) recommended pH criterion for marine waters, on implementation of the current recommended pH criterion, and on potential implementation of a new criterion based on information related to ocean acidification. Finally, EPA solicited information that could help develop strategies for coordinated state and federal data collection and information that could be used to develop guidance for information pursuant to Clean Water Act Section 304(a)(2) for states and the public on ocean acidification. EPA expects to make a decision by November 15, 2010, on how to proceed with regard to the interplay between ocean acidification and the 303(d) program based on information from the NODA as well as other ongoing federal efforts.

# Appendix G: CWA and Existing Coral Reef Management Programs

| Management Area | Description | Application of Biocriteria |
|---|---|---|
| Marine Protected Areas (MPAs) | Selecting MPA Sites | • To identify waterbodies that have outstanding biological condition and require protection |
| | Managing MPAs | • To establish thresholds against which to measure effectiveness of MPAs |
| | Effectively manage the waters between MPAs | • With establishment of designated uses, to protect those uses (i.e., connectivity) |
| Managing Fisheries | Eliminate open-access fisheries in coral reef ecosystems and establish sustainable fisheries regulations | • To establish levels (e.g., taxa richness, abundance) expected to sustain reef fisheries<br>• Degradation can trigger changes in fishery practices and regulations |
| | Restricting the species being selected (e.g., coral reef herbivores, including parrotfish) | • To establish expected or desired levels of individual species (e.g., abundance, biomass)<br>• Degradation can trigger changes in fishery practices and regulations |
| Managing Tourism | Mooring Buoys | • To identify locations with outstanding biological condition that would benefit from the protection of mooring buoys |
| | Permits – diving, fishing, boating | • With establishment of designated uses, to protect those uses |
| Watershed Management | Regulating activities in the watershed | • To establish thresholds against which to measure effectiveness of permits |
| Coastal Zone Management | Regulating Coastal Development | • To support setting goals for watershed and regional planning<br>• To prioritize watershed goals and actions<br>• To develop management plans |
| | Maintain connectivity between coral reefs and associated habitats such as mangroves, sea grass beds, and lagoons | • All nearshore environments are protected by the CWA<br>• Coral reefs, mangroves, sea grass beds, and lagoons can be specifically protected when they are identified in water quality standards |

| Management Area | Description | Application of Biocriteria |
|---|---|---|
| Damage Assessment and Restoration | Restoring coral reefs or seagrass meadows damaged by boats and anchors | • To establish thresholds against which to measure effectiveness of restoration efforts. |
| Managing Endangered Species (Endangered Species Act) | Protecting rare, threatened and endangered species | • To establish expected or desired levels of individual species (e.g., abundance, biomass).<br>• To establish thresholds against which to measure effectiveness of legal protection. |
| National Environmental Policy Act (NEPA) of 1969 | Environmental Impact Statements | • To identify where site-specific criteria modifications may be needed to effectively protect a waterbody.<br>• To assess the overall ecological effects of regulatory actions. |

# Appendix H: Biocriteria and Other CWA Programs

| Program | Title | Description | Biocriteria Use(s) |
|---|---|---|---|
| 104(b)(3) | Wetlands Program Development Grants | Authorizes grants to states[1], and local governments to conduct projects that promote the coordination and acceleration of research, investigations, experiments, training, demonstrations, surveys, and studies relating to the causes, effects, extent, prevention, reduction, and elimination of water pollution. Coral reefs, mangroves, and seagrasses are considered special aquatic sites and wetlands under CWA 404, and Section 104(b)(3) grants can directly fund monitoring and assessment of coral reefs and development of biocriteria for coral reefs. | • Providing a threshold against which to measure detrimental effects on biological communities.<br>• EPA Region 9 has awarded Wetlands Program Development Grants to support coral reef biocriteria development for Hawaii and CNMI. |
| 106 | Grants for Pollution Control Programs | Authorizes federal grants to states[1] to support the development and operation of state programs implementing the CWA. | • In 2009, EPA Region 10 explicitly mentioned the application of biological monitoring and biocriteria that lead to improved TMDLs in their Request for Initial Proposals. |
| 205(j) and 604(b) | Water Quality Management Planning | Authorizes grants to states[1] and funding for substate agencies for water quality planning. | • To develop water quality criteria, including biocriteria. |
| 301(h) | Effluent Limitations | Waiver to defer secondary treatment if discharge does not adversely affect biological communities. | • Providing a threshold against which to measure detrimental effects on biological communities. |
| 312 | Marine Sanitation Devices | No discharge zones. | • To identify appropriate locations for no-discharge zones.<br>• To identify locations with outstanding biological integrity that would benefit from a no-discharge zone status.<br>• To establish thresholds to gauge the effectiveness of no-discharge zones. |
| 319 | Nonpoint Source Program (NPS) | Every 5 years, states report to EPA on their NPS pollution problems, including categories of NPS pollution and measures used to reduce that pollution. | • Assessing impacts of NPS pollution.<br>• Determining effectiveness of NPS controls.<br>• Site-specific assessment of BMPs for NPS. |
| 320 | National Estuary Program (NEP) | Authorizes grants to states[1] for development of NEP management plans and implementation projects. | • To establish thresholds for biological integrity as part of the management plan. |

1 When the term “states” is used, it implies “states, territories and tribes”

| Program | Title | Description | Biocriteria Use(s) |
|---|---|---|---|
| 401 | State Water Quality Certification | Requires that before issuing a license or permit that may result in any discharge to waters of the United States, a federal agency must obtain from the state in which the proposed project is located, a certification that the discharge is consistent with the CWA, including attainment of applicable state ambient water quality standards. | • Providing a threshold against which to measure dredge/ fill impacts on biological communities.<br>• Identify acceptable sites for disposal of dredge and fill material. |
| 402 | National Pollutant Discharge Elimination System (NPDES) | The CWA makes it illegal to discharge pollutants from a point source to the waters of the United States. Point sources must obtain a discharge permit from the proper authority (usually a state, sometimes EPA, a tribe, or a territory). The permits set the limit on the amounts of various pollutants that a given source can discharge in a given time. | • Determining condition of a waterbody prior to issuance of a permit.<br>• Providing a threshold against which to measure discharger impacts on biological communities.<br>• Evaluating effectiveness of implemented controls.<br>• Helping to verify that NPDES permit limits are resulting in achievement of state water quality standard. |
| 403 | Ocean Discharge Program | Establishes special requirements for point source permits for discharges into all three ocean regions defined in the CWA (e.g., the territorial sea, the contiguous zone and the ocean) | • Providing a threshold against which to measure discharger impacts on biological communities. |
| 404 | Permits for Dredged or Fill Material | Establishes a permit program to regulate the discharge of dredged and fill material into waters of the U.S. Jointly managed by EPA and U.S. Army Corps of Engineers. The Corps handles the actual issuance of permits (both individual and general); it also determines whether a particular plot of land is a wetland or water of the United States. The U.S. Fish and Wildlife Service and National Marine Fisheries Service play special advisory roles because of their expertise regarding wildlife habitat. EPA issues certain guidelines and policies, including methods for determining whether a particular tract is a wetland. EPA can actually veto a Corps-issued permit (a step rarely taken). EPA is also responsible for determining whether portions of the 404 program should be turned over to a state. | • Providing g a threshold against which to measure dredge/ fill impacts on biological communities.<br>• Identify acceptable sites for disposal of dredge and fill material.<br>• Determine the effects of the disposal. |
| 603 | Clean Water State Revolving Fund (CWSRF) | Authorizes annual capitalization grants to States[1] who in turn provide low interest loans for a wide variety of water quality projects. | • To provide a threshold to measure the degree to which water quality projects reduce human impacts on biological communities. |

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