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Development and implementation of coral reef biocriteria in U.S. jurisdictions

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Abstract Coral reefs worldwide are declining at an alarming rate and are under continuous threat from both natural and anthropogenic environmental stressors. Warmer sea temperatures attributed to global climate change and numerous human activities at local scales place these valuable ecosystems at risk. Reefs provide numerous services, including shoreline protection, fishing, tourism and biological diversity, which are lost through physical damage, overfishing, and pollution. Pollution can be controlled under provisions of the Clean Water Act, but these options have not been fully employed to protect coral reefs. No U.S. jurisdiction has implemented coral reef biocriteria, which are narrative or quantitative water quality standards based on the condition of a biological resource or assemblage. The President's Ocean Action Plan directs the U.S. Environmental Protection Agency (EPA) to develop biological assessment methods and biological criteria for evaluating and maintaining the health of coral reef ecosystems. EPA has formed the Coral Reef Biocriteria Working Group (CRBWG) to foster development of coral reef biocriteria through

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focused research, evaluation and communication among Agency partners and U.S. jurisdictions. Ongoing CRBWG activities include development and evaluation of a rapid bioassessment protocol for application in biocriteria programs; development of a survey design and monitoring strategy for the U.S. Virgin Islands; comprehensive reviews of biocriteria approaches proposed by states and territories; and assembly of data from a variety of monitoring programs for additional metrics. Guidance documents are being prepared to assist U.S. jurisdictions in reaching protective and defensible biocriteria.

Keywords Bioassessment · Biocriteria · Clean Water Act · Coral reefs · Coral reef ecosystems · Rapid bioassessment protocol · RBP · Stony corals · U.S. EPA

Coral reef ecosystems

Coral reefs are the most biologically diverse marine ecosystems on earth, and rivaled only by tropical rainforests on land (Sebens 1994; Odum 1997). The delicately balanced marine environment of the coral reef relies on the interaction of many species, including hard and soft corals, marine invertebrates and fish.

Hard and soft corals provide structural habitat for this high abundance and diversity. The habitat supports harvestable fish species and attracts tourists. Scleractinian (stony) corals provide shoreline protection from erosion by physically blocking current and wave energy (Wilkinson 1996). The Nature Conservancy estimates that 500 million people rely on reefs for food and income (TNC 2006). These collective benefits, known as ecosystem services (ESA 2000), are valued at over $30 billion annually (Cesar et al. 2003). In the United States, coral reef ecosystems support millions of dollars worth of goods and services annually (Davidson et al. 2003; Johns et al. 2001).

Yet, coral reefs are sensitive to relatively small changes in the environment (Richmond 1993). Corals are generally found in clear, shallow tropical oceans and their growth is limited by temperature, salinity, light intensity, water clarity, and other chemical and water quality characteristics (Wells 1957; Brown and Howard 1985; Odum 1997; Hubbard 1997; Ogden 1997; Hoegh-Guldberg 1999). Because these conditions are usually constant in most marine environments, change in environmental condition can acutely affect coral biology, particularly the delicate balance of coral polyps with symbiotic algae. This lack of resilience to environmental change has led some to regard coral reefs as sentinels of oceanic environmental quality (Hatcher et al. 1987; Andrews and Pickard 1990; Barber et al. 2001).

Extensive human populations, nearly 500 million people, live within 100 km of coral reefs (Bryant et al. 1998). Coral reefs are 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. Reef ecosystems are declining worldwide, including those in the U.S. While Pacific reefs have not been as severely affected, reefs in the U.S. Caribbean and Florida have declined from 50% to less than 10% coral cover in just 25 years (Wilkinson 2004).

U.S. coral reef management

The United States, in cooperation with various local governments, has stewardship of extensive shallow-water coral reef ecosystems, including reefs in Florida, Hawai'i, and U.S. territories in the Caribbean and Pacific. Areal extent estimates range from 6,800 km^2 (Boesch et al. 2000; Turgeon et al. 2002), to 36,816 km^2 in waters less than 18 m deep and an estimated 143,058 km^2 in waters less than 183 m deep (Rohmann et al. 2005; Waddell 2005).

The United States has taken numerous actions in response to the documented decline of coral reef ecosystems. In 1998, President Clinton issued Executive Order 13089: Coral Reef Protection (E.O. 13089), which enhanced the role of Federal Agencies in coral reef conservation and established the U.S. Coral Reef Task Force. In 2000, the U.S. Congress enacted the Coral Reef Conservation Act of 2000 (CRCA 2000), which authorized the Secretary of Commerce to establish a

national monitoring program and conduct activities benefiting the understanding, sustainable use, and long-term conservation of coral reef ecosystems. In December 2004, President Bush submitted the U.S. Ocean Action Plan to Congress, which directed EPA to develop biological assessment methods and biological criteria for states and territories to evaluate the health of coral reefs and associated water quality.

In the U.S., coral reefs fall under the jurisdiction of multiple entities. The National Oceanic and Atmospheric Administration (NOAA), the National Park Service (NPS) and U.S. Fish and Wildlife Service (FWS) function as natural resource custodians. EPA has a regulatory role, focused primarily on control of pollution, which is any addition to a water body of sediment, nutrients, contaminants or microorganisms from human activity. The states and territories have both regulatory and custodial responsibilities. Some stressors (e.g., vessel groundings, harvesting or damaging coral, and alteration of the seabed), fall within the jurisdiction of the natural resource custodians,while others (e.g., land-based sources of pollution from point and non-point sources) fall under EPA. To fully protect the coral reef resource, the federal and state agencies must work together, each fulfilling their respective responsibilities.

EPA, by authority of the Clean Water Act, is committed to providing technical and regulatory guidance to states and territories for control of pollution in water bodies and adjacent watersheds. The Clean Water Act (CWA) provides several different regulatory vehicles to curb pollution, and these indirectly protect coral reefs. But Section 303(d) provides direct protection to coral reefs and any other valued biological resource or assemblage. This Section requires that states and territories prepare and submit lists of specific waterbodies that currently violate or have the potential to violate water quality standards, including designated uses and *numeric or narrative biocriteria.* Biocriteria are benchmark, guideline or threshold values that describe the expected (or desired) biological integrity of a waterbody. Biological criteria are adopted into state, tribal, or territorial water quality standards to describe expected condition for aquatic life in waters with a designated aquatic life use. As with any water quality standard, when biological condition does not meet the criterion, the waterbody is impaired and will require a total maximum daily load (TMDL) designation. It is a clear benefit of a biocriteria program that, once established, each monitoring cycle automatically triggers a regulatory decision.

Biocriteria and several other aspects of the CWA rely on biological assessments (bioassessments). These directly measure the condition of one or more taxonomic assemblages (e.g., corals, fish) and the chemical and physical attributes that support those assemblages. Since the community of plants and animals reflect the underlying health of the waterbody in which they live, assessments of species richness, species composition, population size, and trophic composition of resident biota are the most direct measures of biological integrity (Karr 1993). Many bioassessment protocols emphasize the interaction and association of species and the structure and function of resident aquatic communities (Karr 1995). Importantly, bioassessments measure the integrated and cumulative effects of water quality on the biota. Using only chemical criteria for water quality regulation may underestimate the accumulation of multiple stressors over time.

Whereas technical guidance has been provided for several other ecosystems, no bioassessment procedures and regulatory biomonitoring programs have yet been developed or recommended for protection of coral reefs. Regardless, there is a great potential for such programs—previous work in biocriteria development has laid a solid foundation, coral reef research has generated a variety of useful indicators, and resource managers are quite familiar with approaches to environmental monitoring.

Implementing biocriteria

Because there are currently no coral reef biocriteria used in U.S. jurisdictions and because the 2004 President's Ocean Action Plan directed EPA to develop biological assessment methods and biological criteria for coral reefs, EPA has formed a Coral Reef Biocriteria Working Group

(CRBWG). The CRBWG membership spans several Program Offices and Regions throughout EPA with the purpose of fostering coral reef biocriteria through focused research, evaluation, and communication within the Agency for interactive implementation with U.S. jurisdictions.

The principal stakeholders for development and implementation of coral reef bioassessment methods and biocriteria are U.S. jurisdictions with coral reef ecosystems, including:

- Puerto Rico and U.S. Virgin Islands (within EPA Region 2),
- Florida, including Florida Keys National Marine Sanctuary and Dry Tortugas National Park (within EPA Region 4),
- Flower Garden Banks National Marine Sanctuary (within EPA Region 6), and
- Hawai'i, including Papahanaumokuakea Marine National Monument, Northwestern Hawai'ian Islands National Marine Sanctuary, American Samoa, Guam, Commonwealth of the Northern Mariana Islands (within EPA Region 9).

Members of the CRBWG recognize that success will require simultaneous progress in refinement and validation of biological assessment and monitoring methods, evaluation of available data and different biocriteria approaches, and interactive communication and sharing of information with resource managers in all coral reef jurisdictions.

Coral reef biocriteria research and development

EPA's Office of Research and Development (ORD) has the responsibility within EPA for developing biological assessment methods and monitoring strategies. Numerous workshops and publications have addressed methods to measure coral reef condition, usually with a focus on development of rapid, reliable, low-cost monitoring (UNESCO 1984; Aronson et al. 1994; Rogers et al. 1994; Crosby et al. 1996; Bruckner and Burrows 2005). The methods have varied in approach, scope, and purpose, so comparisons across spatial scales, reef habitats, and geographic zones have been uncertain at best. While development of coral reef biocriteria will not require a 'standard' protocol applied across all jurisdictions, retention of some basic components will allow complementary development.

Recently, ORD consolidated and integrated two of the most effective coral assessment methods (a colony-based and a surface-area method) into a single protocol. It was intended for application at a variety of scales and for flexibility of purpose, but most importantly for application in regulatory monitoring. Effectiveness in regulatory monitoring requires that results from a survey address issues that are relevant to the assessment, scientifically defensible, responsive to human activities, and transparent to stakeholders (Jackson et al. 2000).

The EPA protocol, *Stony Coral Rapid Bioassessment Protocol* (RBP, Fisher 2007), measures assessment endpoints highly relevant to ecosystem services: stony corals provide fish and invertebrate habitat, shoreline protection, carbon sequestration, primary production, sand and construction material, and the building blocks of an ecosystem recognized as a high-end tourist destination. The procedures are technically feasible (only three underwater observations on each coral colony), are transparent and easily transferred to managers and stakeholders alike, and provide multiple indicators that are relevant to ecosystem services.

Initial development of the RBP was conducted in Florida coral reefs. EPA scientists, in collaboration with NOAA, the Florida Keys National Marine Sanctuary, and NPS, collected field data, developed the RBP techniques, and refined the monitoring design in the Florida Keys National Marine Sanctuary during 2003 and 2004 (Fisher et al. 2007). The purpose of the pilot studies was to demonstrate that both colony-based data (e.g. species, number, density) and surface-area data (e.g., coral cover, percent living) could be rapidly obtained in the field and could distinguish differences among stations. This pilot study provided reliable, repeatable estimates of coral condition and good statistical precision for detecting change through time (Fore et al. 2006a). These data demonstrated that the protocol was scientifically defensible. Moreover, the protocol incorporated for the first time calculation of three-dimensional colony surface area using conversion

factors derived from colony height, diameter and width (Courtney et al. 2007).

In 2006, the protocol was tested at St. Croix, U.S. Virgin Islands, to determine how responsive RBP indicators were to human disturbances, a requisite for regulatory application. When monitored along a disturbance gradient, indicators related to taxa richness, total coral surface area, living surface area, and average colony size demonstrated a consistent and logical change with distance from the center of disturbance (Fore et al. 2006b). These indicators are now considered candidate metrics because they detected effects of human activity over natural environmental factors (Karr and Chu 1999).

The U.S. Virgin Islands and EPA Region 2 are engaged in the development of stronger CWA tools for addressing degrading coral conditions, including scientifically defensible coral reef biocriteria. Because the RBP provided indicators that distinguished condition among stations and were responsive to human activity, the next step is to generate a practical long-term monitoring program that addresses local as well as regional needs. It is recommended that water quality evaluations under the CWA employ probability-based (spatially balanced random) monitoring designs. Consequently, the RBP was applied in a probability-based survey design at St. Croix in 2007. When analyzed, results will characterize reef status and will set the stage for determining reference conditions and biocriteria thresholds. A needs-assessment workshop, assembled by U.S. Virgin Islands, ORD and EPA's Office of Environmental Information (OEI), was convened with local resource managers to evaluate different local and regional needs that should be addressed by a long-term coral reef monitoring program. ORD is developing a rotating panel design to provide a balance of status, trend and targeted sampling stations spread across multiple monitoring years.

The RBP, which considers only stony corals, will eventually be integrated with indicators for other members of the reef community (e.g., soft corals, fish, invertebrates) and indicators of ecosystem function to provide a more robust assessment. Many successful biocriteria have been developed that focus on changes in indicators of community composition, such as an index of biotic integrity (Karr 1991; Jameson et al. 2001). New approaches provided by researchers in the Commonwealth of Northern Mariana Islands and American Samoa (Houk et al. 2005) and Hawai'i (Jokiel et al. 2004) are being examined for potential integration with the RBP.

Coral reefs, especially stony corals, are highly sensitive to elevated temperatures and solar radiation associated with global climate change (Shick et al. 1996; Wilkinson 1996; Barber et al. 2001). Other large-scale mechanisms may also be contributing to coral reef degradation (Barber et al. 2001). Biocriteria are most effective when the indicators are able to differentiate stressors caused by local human activities from those caused by larger-scale or natural mechanisms. These indicators, or metrics (Karr and Chu 1999), are directly applicable to monitoring for the CWA, which regulates primarily human impacts on water quality. Because large-scale and natural mechanisms also affect the condition of coral reefs, ORD has begun to examine potential effects of these drivers on reference conditions and biocriteria metrics.

Evaluation and analysis

States and territories have the primary responsibility for establishing, reviewing, revising, and enforcing water quality standards, while EPA develops regulations, policies, and guidance to support them. 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. This process is unique to each jurisdiction, and the CRBWG is working collaboratively with the states and territories to develop efficient and scientifically defensible processes for developing biocriteria.

Coral reef biocriteria must be specifically applicable to each water body. Due to the heterogeneous nature of coral reefs (Boesch et al. 2000), some metrics developed for Caribbean reefs may not be applicable in Pacific Region reefs, and vice-versa. Each jurisdiction must test candidate metrics for their ability to detect change across a human disturbance gradient—an ability that could vary with reef type, stressor type and hydrogeography. While continuing work in the U.S.

Virgin Islands, ORD will collaborate with the Regions and other territories and states to evaluate the RBP in other geographic regions and under various environmental conditions (beginning with Florida and Puerto Rico in summer 2008).

There are existing coral reef monitoring programs that collect measurements comparable to the RBP metrics. Similar data from other programs can be analyzed for RBP metrics with certain conversions and assumptions. It may also be possible through comparative testing to generate conversion factors that estimate RBP values from historical data. If so, historical values could be used for trend analysis and reference condition development.

Analysis of ongoing reef monitoring programs is particularly important because of the value of long-term datasets and the resources already committed. Ideally, ongoing programs will be able to incorporate RBP procedures without losing their historical links. Datasets to be evaluated include The Nature Conservancy's Florida Reef Resilience Program (FRRP) (TNC 2006), Florida's Coral Reef Evaluation and Monitoring Program (CREMP) (FWC 2005), and Hawai'i's Coral Reef Assessment and Monitoring Program (CRAMP) (Jokiel and Brown 2000). The FRRP database is not publicly available. Select datasets for CREMP can be accessed at http://ocean.floridamarine.org/fknms_wqpp/pages/cremp.html. The CRAMP data is available in NOAA's Coral Reef Information System (CORIS) at www.coris.noaa.gov.

Another important analytical effort is the evaluation of potential assemblage indicators. Most biocriteria are based on community assemblages, but the RBP measures only populations of stony coral. The on-line searchable database will be used to identify those methods that provide assemblage information. This information will be summarized and evaluated for the potential to develop assemblage indicators for research, analysis and use in EPA national reports on environmental condition. Evaluations will include analysis of an assemblage indicator recently proposed from a dataset provided to ORD by the Atlantic and Gulf Rapid Reef Assessment Program (Meng and Helyer. A provisional index of biotic integrity for coral reefs (in preparation)).

The Commonwealth of Northern Mariana Islands, American Samoa and Hawai'i are developing proposals for coral reef biocriteria. The CRBWG members will provide technical assistance and facilitate incorporating standardized methods (such as core measures of the RBP) for shared use and comparison. As other jurisdictions begin to develop biocriteria, the CRBWG will provide similar support and assistance.

In collaboration with states and territories, the CRBWG will continue to provide assistance on the use of biocriteria toward improving monitoring, assessment and interpretation of coral reef condition. Different jurisdictions have different needs for reef protection, but many processes for implementing biocriteria will be similar.

Communication and access

Activities, results and recommendations of the CRBWG must be conveyed to stakeholders and other resource managers, collaborators, monitoring program personnel, and scientists in the coral reef community to better support the development and understanding of biocriteria and the regulatory potential of the CWA. The concepts of regulatory bioassessment protocols and biocriteria are not well known to many coral reef managers. The members of the CRBWG are working together to develop guidance on protocols, monitoring strategies, and procedures to develop and implement coral reef biocriteria and to make these accessible to states and territories.

EPA's Office of Environmental Information (OEI) has developed a Coral Reef Biocriteria website (http://www.epa.gov/bioindicators/coral/index.html) that provides information about coral reefs and EPA efforts to protect them. The website includes downloadable EPA documents and publications, and links to related websites. OEI's future plans for the website include adding an online version of the comparative database for RBP data, examples of approved coral biocriteria, and methodological information such as conversion tools to obtain three-dimensional coral colony surface area (3DCSA) from two-dimensional colony data.

OEI will also build a tool kit for coral reef protection under the CWA. The first step will be a report evaluating available tools (see Section "U.S. Coral Reef Management"). A user-friendly, web-based version will be developed to describe and incorporate the analytical approaches required for development and implementation of coral reef biocriteria. The tool kit will anticipate and respond to many of the questions and situations that arise as jurisdictions begin the process of biocriteria development.

EPA periodically publishes a national Report on the Environment (ROE) (http://www.epa.gov/roe), but past ROEs do not include any indicators for assessment of coral reef condition (USEPA 2007). While numerous assessment procedures exist, there are wide discrepancies in methodology and reporting. This lack of standardization has hampered efforts to validate indicators for regulatory uses. The various evaluations of the RBP described earlier will help identify appropriate indicators for use in future ROEs.

Use of the CWA for coral reef protection must be developed in concert with other federal agencies with similar missions. EPA is a member of the U.S. Coral Reef Task Force, to which the Assistant Administrator for EPA's Office of Water provides bi-annual updates on EPA activities. As a member of the coral reef scientific and management community, the EPA assisted with the local organization and support of 2008 International Year of the Reef events. The CRBWG communicated the need for coral reef monitoring, assessment and biocriteria through presentations and participation at the 2008 International Coral Reef Symposium in Florida, a unique opportunity afforded only rarely in the U.S.

Conclusions

Coral resource managers in the U.S. and throughout the world are faced with increasing reports of coral decline, but are using few regulatory tools to reverse the trend. However, regulatory mechanisms are available under the CWA. Local resource managers, with limited personnel, limited funds and wide environmental responsibilities, have expressed a strong desire to implement CWA tools and have requested EPA support to develop bioassessment methods and criteria. EPA is committed to providing technical and regulatory guidance to states and territories on development and implementation of biocriteria for coral reefs. Assistance includes the development of bioassessment methods to identify reefs at risk (impaired water bodies), application of regulatory actions as needed, and evaluation of restoration efforts. In accordance with the President's Ocean Action Plan, EPA is working collaboratively with coral reef managers, scientists, and stakeholders to develop bioassessment and biocriteria tools that protect U.S. coral reef ecosystems.

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