The Healthy Mesoamerican Reef Ecosystem Initiative: a conceptual framework for evaluating reef ecosystem health

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Abstract The Healthy Mesoamerican Reef Ecosystem Initiative seeks to build consensus on what can be characterized as a modern day healthy reef for the Mesoamerican Reef Ecoregion. The Initiative aims to: (i) develop a quantitative framework for evaluating reef health and (ii) make the information readily available to practitioners, scientists, the public, and decision makers. A common understanding of reef health provides clarity and cohesiveness to the many conservation efforts in the region. In addition, a shared analysis framework aids interpretation of monitoring data being collected within the ecoregion. To this end, we have identified 16 key structural attributes, functional attributes, human threats and social issues that provide the framework for this analysis. We have also identified more than 50 potential indicators that are being tested to evaluate those attributes/threats/issues. For each indicator, information has been compiled (where available) on current and historical status and known Caribbean end-points. An expert panel assisted with the establishment of threshold values for each indicator, providing our yardsticks for interpretation. It is only through the difficult and imperfect task of establishing these quantified interpretive frameworks for each indicator that we can maximize their utility and relevance for management and conservation decisions. This Initiative aims to develop a range of communication and decision-support tools aimed at galvanizing public and political support for reef conservation.

Keywords: Mesoamerican Reef, coral reef, indicators, socioeconomic, health, management

Introduction

The Mesoamerican Reef Ecoregion (MAR) extends approximately 1,000 Km from the northern tip of Mexico's Yucatan Peninsula southward to Belize, Guatemala, and the Bay Islands off the Honduran coast. This biologically rich and threatened Ecoregion encompasses barrier, fringe, patch, and atoll coral reefs, as well as associated coastal mangroves, lagoons and seagrass beds. More than one million people directly depend on the integrity and health of the Mesoamerican Reef for their livelihood, and the national economies of the four countries substantially benefit from the reef's appeal as an international tourist destination. In response to the escalating degradation of the Mesoamerican Reef in recent years (e.g., Aronson et al. 2000; Kramer et al. 2000; McField 2002; Alamada-Villela et al. 2002), an increasing number of institutions are dedicating substantial resources to address the main issues that jeopardize the long-term integrity and health of this Ecoregion. Important efforts are underway in the Wider Caribbean and in the Mesoamerican Reef Ecoregion to collect data on the condition of coral reefs and associated ecosystems. However, we remain challenged on how to collectively evaluate how healthy -- or unhealthy – the reef ecosystem is at this time and equally, how effective have our conservation efforts been.

The Healthy Mesoamerican Reef Ecosystem (HMRE) Initiative is an international, multi-institutional effort that tracks the health of the Mesoamerican Reef, the human choices that shape it and our progress in ensuring its long-term resiliency and sustainability. We hope that the Initiative (HMRE) - a joint effort of the Global Environment Facility/World Bank Mesoamerican Reef System (MBRS) Project with the Central American Commission on Environment and Development, the World Wildlife Fund (WWF), The World Bank, and The Summit Foundation - will spark the interest of additional institutions and enhance science-based management decisions throughout the region. The Initiative builds on existing monitoring efforts and seeks to aid interpretation of monitoring data through the development of quantitative yet practical indicators to provide context and meaning to monitoring data and serve as the foundation for measuring our collective conservation success in the Mesoamerican Reef. More specifically, the main goals of the HMRE are to: (i) develop a shared definition of reef health specific to the Mesoamerican Reef (ii) develop practical analytical tools for evaluating reef health on an ecoregional scale, and (iii) generate communication tools including annual Report Cards, biennial State of the Reef reports, and symposia to publicize the results.

Thus far, the Initiative has completed the conceptual framework to define reef health including key ecological structural and functional attributes and human stressors, and has identified a suite of associated strategic indicators. A consultation workshop was held in Miami

in June 2004, where a panel of more than 25 experts evaluated the effectiveness of these indicators and established baseline and target values. Currently, the Initiative is focused on the identification and selection of socio-economic indicators most relevant to reef health and quality of life, including their associated benchmarks and target values. End-product communication tools are being designed to assist practitioners and managers who need effective tools to interpret their monitoring data and better understand the status of their reefs in relation to the wider region. The products also aim to encourage broad consensus regarding what can be characterized as a healthy reef under present-day levels of natural and human-induced stresses in order to maximize the relevance, synthesis and applicability of monitoring data to management and conservation decisions.

What is Healthy?

Most reef scientists, conservationists and local stakeholders in the Caribbean agree there has been a decline in the health of coral reef ecosystems. Coral populations -- the critical ecosystem engineers -- have suffered dramatic and unprecedented declines in condition and abundance. Moreover, the complex and not fully understood trophic relationships and critical natural processes (such as herbivory) have been severely disrupted due to human overexploitation of highly sought-after species. Although numerous reports have documented the decline of coral reefs (e.g., Jackson et al. 2001) some variation exists, particularly in the Mesoamerican reef where some reefs show mixed signals such as a relatively high abundance of predatory fish (i.e., indicating good health) but a low density of coral recruits or coral cover (i.e., indicating ill health). Given the complexity of reef ecosystems, what constitutes a decline often varies from reef to reef depending upon such factors as past disturbance history, reef type, level of current threat, or the baseline to which the decline is compared. Over the past year when we asked various audiences "What should a healthy reef look like?", the answers varied depending upon the audience or person asked (i.e., the presence of key indicator species or vital processes like coral recruitment/herbivory or like it did prior to the Acroporid or *Diadema* die-off). A comprehensive, synthesized definition of coral reef health that includes an identification of the important biotic and abiotic structures and processes necessary to maintain reef integrity is greatly needed.

A definition of a healthy reef is especially needed to improve our conservation and management efforts in the MAR. The growing interest in conservation science in general, and reef conservation in particular, is creating a plethora of ecological buzzwords that are loosely defined or have inherently different meanings. Large global and national conservation initiatives, policy instruments and even some laws are requiring the preservation of biological integrity or ecosystem health, although the criteria for defining or measuring integrity are rarely included. Such generalizations can lead to less effective conservation planning and management interventions.

The HMRE chose the term health as an easily understood 'bridging concept' connecting two different worlds - natural systems and humans (Ehrenfeld 1993) and is based on the principle of ecosystem health, which recognizes humans are an integral part of the ecosystem (e.g., Costanza et al. 1992; Rapport et al. 1998; Sherman 2000, yet see Suter 1993; Callicott 1995). For the MAR, we hope the idea of reef ecosystem health can enrich scientific understanding while creating an understandable dialogue that will increase human awareness, responsibility, and ultimately concern to take action.

Efforts to determine coral reef health, particularly on larger regional scales have been challenging due to a lack of data, different terminology or sampling methods, focus on small scales, and the failure to integrate human activities (e.g., Gardner 2003; Kramer 2003). Existing indicators of coral reef health have primarily included measurements of either biological structure (e.g., coral cover, species diversity) or environmental conditions (e.g., temperature, nutrients), with only a few measuring vital ecological processes (e.g., recruitment, herbivory) (Jameson et al. 1998; Linton and Warner 2003), socioeconomic concerns (Bunce et al. 2003), or the effectiveness of management actions (Pomeroy et al. 2004). Exciting new diagnostic indicators, such as molecular biomarkers, are now being developed that can identify precise stressors and their sources (Jameson et al. 2001; Downs et al. 2002). A benefit of using indicators to understand reef health is that it allows managers and the public to interpret complex scientific data as useable information. However, selecting indicators requires a commitment to collecting and managing scientific data to justify indicators, identifying and using selection criteria, evaluating indicators for their efficacy, and recognizing scale and scope considerations (Karr and Chu 1999). A challenge for the HMRE is to identify specific, strategic indicators that characterize reef health and are useful in improving our conservation and management efforts in the MAR.

Defining a Healthy Mesoamerican Reef Ecosystem

In order to fully understand and assess MAR reef health, we are developing a practical, quantifiable interpretive framework by defining measurable criteria and indicators of health and developing effective tools for assessment and communication. We recognize the strong linkages between reef health and human health (e.g., Patil et al. 2001; Knapp et al. 2002) and the need to improve our understanding of how humans impact the reef ecosystem and conversely, how the condition of the reef ecosystem may be influencing local people and their livelihoods. The HMRE framework (Fig. 1) is grounded in the fundamental elements of ecosystem structure and function, while integrating human stressors and social issues, and includes the following main components:

1. **Structural Attributes** include the key structural components of a reef ecosystem, including abiotic (e.g., salinity, temperature) and biotic (abundance/distribution of organisms) attributes.

These components contribute to biodiversity by providing different organization of organisms and habitats. Reef structure plays an important role in determining the way reef ecosystems function.

2. **Functional Attributes** include key ecological and evolutionary processes (e.g., mortality, recruitment, herbivory). They are the processes required to sustain biodiversity and they influence how structural components interact.

3. **Threat Issues** include anthropogenic or natural characteristics that directly or indirectly cause degradation of reef health and integrity by disrupting the natural structure and functioning of reefs. Conservation efforts are usually directed at reducing these threats.

4. **Social Issues** include economic, human health, cultural, and policy/legal issues that affect or are affected by the condition of the reef.

For each of these components we have identified several potential indicators, for which quantitative baselines, benchmarks and target values were reviewed and evaluated at an expert's workshop in Miami. Since a list of 50 or more indicators may be more comprehensive than practical to those working in the field, our expert review panel also assisted by selecting the following top-ten list of most useful indicators for management (Table 1). They evaluated each indicator by ranking four criteria: 1) Ecological Significance (i.e., is it relevant to the key structures and processes affecting MAR ecosystem health?), 2) Feasibility (i.e., are data collection methods realistic for the MAR given spatial scope and monitoring constraints), 3) Limitations (i.e., are there limitations or caveats in interpreting data?), and 4) Responsiveness (i.e., is the indicator responsive to human intervention?). Given the complexity of reef ecosystems and that objectives of conservation and management may vary by location and program, several indicators could be used in tandem to determine not only the status or trends in reef health, but also how effective management interventions are at preserving ecological health over time (De Leo and Levin 1997).

	Table. 1 Suggested Top Ten Ecological Indicators
1	**Benthic community composition (% cover)**
2	**Fish Size (Density/mean length)**
3	**Coral recruitment**
4	**Herbivore abundance (*Diadema*, herbivorous fish)**
5	**Coral and herbivore diversity (H', E)**
6	**Pollutant accumulation (sediments & biota)**
7	**Focal species abundance**
8	**Coastal habitat extent (satellite cover/patterns)**
9	**Water Quality (Temp./Water Clarity/Salinity)**
10	**Diagnostic Tools / Biomarkers**

Setting the Standards: Baselines, Benchmarks and Target Values

Understanding current and historic baselines is essential to understanding reef health and is a precursor to establishing baselines, benchmarks and targets. A baseline or standard reference condition is a characteristic that indicates the condition of an ecological system and acts as a reference point or norm to compare change over time. Ecosystem health can then be characterized by examining variances or deviations from these norms. In human medicine a person's health can be measured against normal values (norms) for widely used indicators like blood pressure and cholesterol. Yet many reef monitoring efforts continue to measure indicators for which there are no norms, benchmarks or targets to aid interpretation of the results.

When establishing ecological baselines or norms for coral reefs, we recognize that normal or even healthy reefs today may well be degraded with respect to an earlier baseline (Jackson 1997, 2001; Greenstein et al. 1998). Modern-day baselines in the MAR often have already been affected by earlier human behavior, which is more difficult to quantify. However it is important to try to determine the normal state of reef condition in the modern Mesoamerican Reef as it will provide a valuable yardstick to evaluate future reef condition. Benchmarks and targets can be quite valuable and informative particularly if they are clearly defined, measurable, scientifically sound, have ecological and management relevance, are adaptable from the site to regional scale, practical and straightforward. They provide useful tools that help practitioners decide when to take action because ecological conditions have fallen below an unacceptable level, as well as indicate when management or conservation objectives are being fully achieved (Jameson 2001). The benchmark and target values in this study were derived from a combination of historical data, reference conditions, and consensus judgment of international and regional experts. We acknowledge that our baseline has already been affected by human behavior/activities, but also believe it is reasonable to set intermediate targets with a 25-50 year time horizon that are practical for management and evaluation. These benchmarks and targets are necessary to provide quantifiable standards in which to gauge the extent of damage or recovery on a reef. Finally, we also recognize that the values established are representative of our current knowledge and given the complexity of reef ecosystems, we anticipate further revisions.

Consolidating and Communicating our Results

The Healthy Mesoamerican Reef Framework is being detailed in a guidebook (under preparation) for practitioners, which includes the standards for benchmarks and targets of each indicator. The guidebook is intended to help practitioners understand why a particular measurement is being collected, how the measurement contributes to understanding reef health, how to interpret and understand data collected in relation to local and regional data ranges, and most importantly,

how to recognize when data is signaling a disturbance and/or recovery.

We are also currently investigating the potential of integrating this information into a meaningful index of reef health, similar to the Index of Biotic Integrity (IBI) approach of combining multiple metrics or indicators into a single index. These IBIs are widely and successfully used in streams, rivers, and estuarine systems (e.g., Kerans and Karr 1994; Van Dolah et al. 1999; Llanso et al. 2003) and have proven to be very effective management tools (Kerans and Karr 1994) particularly since they can be expressed as a single numerical value grounded in scientific data. Single number results can foster greater public understanding and political support, especially when accompanied by a qualitative score (e.g., a ranking from 5 = excellent health to 1 = poor health). Such rankings are also useful to resource managers, effectively galvanizing their support base for conservation activities. The IBI approach has not yet been adopted for coral reefs (although suggested – see Jameson 2001) and we hope through further investigation and testing of our potential indicators, we will be able to develop an effective Index of reef health for the MAR.

To increase public understanding on the health of the MAR reef system, we are creating an environmental scorecard or report card, which presents and aggregates key indicators of reef health in a simple and understandable fashion (USEPA 1995; The Bay Institute 2003). For the HMRE scorecard, these will include the key structural and functional attributes, stressors and social issues. The scores will be applied at the site, national, sub-ecoregional and ecoregional levels. The HMRE will use the benchmarks/targets to enhance ongoing collaborative regional conservation planning efforts and assist with the interpretation of monitoring data and evaluation of conservation efforts. The addition of a common currency for these measures of success will help to address regional conservation needs in order to increase our collective conservation impact.

Finally, the HMRE also envisions convening a biennial regional scientific symposia accompanied by State of the Reef reports (e.g., The Heinz Center 2002) that will provide both a scientific foundation and public platform needed to raise awareness and engage stakeholders in sound decision-making.

Conclusion

In order to conserve reef health in the MAR, we need first to have common language and practical tools to track and measure reef health over wide spatial scales. We then must communicate this information to key decision makers and stakeholders, in a way that is both clear and inspiring. As scientists, we often spend disproportionate effort chronicling the details of ecosystem demise instead of creating a powerful, optimistic vision and a roadmap to achieve our conservation aspirations. The HMRE aims to promote a consensus-based vision of our ideal healthy Mesoamerican Reef. Only by knowing exactly where we want to go will we be in a position to evaluate our path and make the needed adjustments. There are many recipes for how to kill a reef that are currently in use throughout the world's coral reefs. What is more challenging and can no longer be postponed is the need to create new recipes for how to maintain healthy reefs for healthy people. We believe the HMRE Initiative offers this opportunity and we extend an open invitation to all those concerned with the future of this magnificent ecoregion to join forces with us to make a difference through informed decision making and a better understanding of what it will take to keep our Mesoamerican Reef healthy and thriving.

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Fig. 1. Key reef attributes/issues and their indicators.

STRUCTURAL ATTRIBUTES

	Biodiversity	Community Structure	Abiotic Factors	Habitat Extent
Indicators of Key Attributes	• Coral diversity-H • Fish diversity-H • Focal species abundance	• Benthic community (percent cover) • Rugosity	• Temperature • Salinity • Water clarity • Ocean Color • Sedimentation rates	• Aerial extent of mangrove • Aerial extent of seagrass (Various density classes)

FUNCTIONAL ATTRIBUTES

	Reproduction & Recruitment	Coral Mortality	Coral Condition	Herbivory
Indicators of Key Attributes	• Coral recruitment • Coral size frequency • Fish recruitment • Fish size frequency	• Recent partial mortality • Old partial mortality • Standing dead coral	• Disease incidence • Bleaching incidence • Predation	• Fish bite rates • Herbivorous fish abundance • Diadema abundance • Green turtle abundance

Key Attributes

MESOAMERICAN REEF

THREAT ISSUES

	Tourism/Coastal Development	Agricultural & Inland Runoff	Overfishing	Climate Change
Human Stressors	• Biomarkers • Coral damage index • Tourism index • Reproductive deformities • Pollution in sediments	• Coastal devel. index • Sedimentation rates • Bioaccumulation of pollutants • Molecular Biomarker • FORAM index	• Density/size fish • Spawning aggregation • Conch/lobster abundance	• NOAA temp hotspots • Extent bleaching & mortality • FORAM photo stress index • Biomarkers • Population movement

Indicators of Human Stressors

SOCIAL ISSUES

	Health	Economic	Cultural	Policy/Law
	• To be determined.	• To be determined.	• To be determined.	• To be determined.

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