Healthy Reefs for Healthy People

A Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region

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Healthy Reefs
For Healthy People

The *Healthy Reefs for Healthy People* Initiative (formally known as the Healthy Mesoamerican Reef Ecosystem Initiative) was launched in 2003 on the premise that healthy reefs are essential to sustaining healthy people. In turn, only when local people are healthy and thriving can they be expected to protect the reefs and other natural resources upon which their livelihoods and quality of life depend.

The main goals of the *Healthy Reefs* Initiative are to:

1. Promote the adoption and application of Healthy Reefs indicators by managers, policy makers and other leaders concerned with the integrity of the Mesoamerican Reef Ecosystem;

2. Standardize the analysis and interpretation of reliable scientific data to improve reef ecosystem management; and

3. Serve as an open forum for information sharing and networking among science and conservation partners.

The Healthy Reefs for Healthy People Initiative encourages dialogue and collaboration to strengthen efforts to protect the Mesoamerican Reef.

The Initiative's founding partners are the World Wildlife Fund, Perigee Environmental, The Summit Foundation, the World Bank, and the Mesoamerican Barrier Reef System (MBRS) Project of the Central American Commission for Environment and Development (CCAD) with support from the Global Environment Facility / World Bank.

Additional partners include The Nature Conservancy, Environmental Defense, the Smithsonian Institution, Atlantic and Gulf Rapid Reef Assessment Program, Conservation International, The Coral Reef Alliance, International Coral Reef Action Network, Wildlife Conservation Society, World Resources Institute, and numerous local partners and scientists.

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† Highest priority indicators

Preface

The people who care for and depend on the Mesoamerican Reef (MAR) have seen many changes in the past decades. Some of our most spectacular coral reefs have crumbled in the wake of coral bleaching, hurricanes, and disease. Large fishes, sea turtles and manatees have declined, and sea urchins have nearly disappeared.

Yet, we have surprisingly few data to document these dramatic declines or to measure the state of recovery (if this is, indeed, occurring) and few large-scale evaluation tools to monitor the effectiveness of our conservation efforts to promote the health of the reef ecosystem, including the human dimension.

Now, the Healthy Reefs for Healthy People Initiative is garnering an impressive network of partners to develop better ways to take the pulse of the reef and the people who live, work and play in its crystal waters.

Written for a non-specialist readership, this *Guide to Indicators of Reef Health and Social Well-being in the Mesoamerican Reef Region* provides the first version of an evolving toolkit for field scientists, managers and other stakeholders engaged in long-term study and conservation in the Mesoamerican Reef ecoregion.

Inside you will find:

- A menu of 58 carefully chosen indicators of environmental and social health tailored to the MAR;
- An overview of the current status of each indicator in the Mesoamerican Reef region;
- A discussion of available data, methods, feasibility and caveats;
- "Red flag" thresholds to help recognize when our indicators are signaling time-to-take-action conditions; and
- Short and long-term goals on the path to achieving lasting sustainability for the Mesoamerican Reef ecosystem and its people.

The guide also provides practical suggestions for how reef stewards can apply these indicators to real-life situations—building on the appropriate linkages among indicators. Ultimately, this guide is about turning indicators into action—to ensure the long-term ecological integrity and sustainability of our spectacular reefs.


Canon/Anthony B. Rath / WWF

Foreword

With the publication of the Millennium Ecosystem Assessment reports, the relationship between environmental health and human health has become increasingly clear. The urgent need to reinforce positive feedback loops, along with the consequences of ecosystem decline for the planet as a whole, has come into sharper focus. Coral reefs serve as eloquent metaphors of this relationship. As icons of biodiversity and productivity – healthy reefs represent nature at is finest, beautiful to look at while at the same time providing mankind with essential goods and services. But when under stress, as they are throughout much of their range, coral reefs serve to warn us that fundamental changes are taking place in the relationship between human populations and their environment. The signs are reversing and synergies are collapsing. Reading the signs right can help us preserve the former and prevent a steady decline beyond the point of recovery (no return).

The *Guide to Indicators of Reef Health and Social Well-being for the Mesoamerican Reef Region* is thus a timely and important tool in helping us to assess the nature of the coral reef-human ecosystem dynamic in one of the major coral reef hot spots of the world. The MAR is a jewel in the Caribbean—it is colorful, multi-faceted, vibrant yet fragile. We know from archaeological records that the livelihoods and well-being of indigenous groups, such as the Maya, were intricately linked to the natural bounty of this system of coral reefs, lagoons, seagrass beds and mangroves. Since pre-Colombian times, the economies of the region and its population have grown exponentially, putting increasing pressure on the MAR. Maintaining the ecological integrity of the MAR and the flow of benefits to the 1.5 million people who depend on it will require a new awareness of what was apparent to the ancient inhabitants of the region—that humans are part of a larger living system, that to defile it is to put one's own survival at risk.

With the *Guide*, we now have a set of indicators to measure and communicate more effectively to stakeholders the overall state of health of the Mesoamerican Reef ecosystem, how coral reef health is affected by human activities, the implications of declines in reef health for the health and well-being of surrounding communities and the wider region, and management actions needed to maintain or restore key aspects of ecosystem health to levels consistent with sustainability of the MAR.

A major asset of this guide is the selection of indicators that are both technically relevant and also resonate with those most affected by, as well as those who most influence, the state of MAR ecosystem health. Moving beyond the conventional metrics of biological and ecological health to include drivers of change, social and economic status, human health and governance, this manual helps us make connections between ecosystem processes and human actions which can be monitored, reported on and ultimately galvanize change. Understanding these links is essential to reducing poverty and catalyzing the positive synergies between environmental health and human welfare that are pre-conditions for sustainability.

Healthy Reefs for Healthy People is more than just a catchphrase. It is a principle that we must all embrace if we are to succeed in safeguarding the MAR for present and future generations.

Marea E. Hatziolos

Marea Hatziolos
The World Bank

Acknowledgements

We are grateful to all of the numerous individuals and institutions that contributed to making this guide possible. Our founding colleagues in the Healthy Reefs for Healthy People Initiative, Marea Hatziolos (the World Bank), Carlos Saavedra (The Summit Foundation), and Noel Jacobs (MBRS Project of the CCAD), have been instrumental in supporting and critically reviewing the work since the project's inception.

We are indebted to the experts who participated in the first consultative workshop held in Miami in June 2004. They helped solidify the original interpretive framework used in this guide, particularly the ecological indicators. This workshop was the beginning of a two-year process of research, regional and international interviews and consultations, and additional workshops and meetings. We list all of these contributors below in alphabetical order.

We wish to recognize the important contribution of the World Bank's work led by Marea Hatziolos to help identify and develop key socio-economic, health and governance indicators. Expert contributors to the World Bank's work *Measuring Coral Reef Ecosystem Health: Integrating Societal Dimensions* (2006) included: John Dixon, David Rapport, Luisa Maffi, John Howard, Ola Ullsten and Stefano Belfiore.

Maya Gorrez and Matthew McPherson were instrumental in shaping many of the drivers of change and social indicators presented in this guide. We are especially thankful to Carlos Saavedra for his insightful, creative, and consistent guidance throughout all phases of this project. Tonya Clayton's keen eye for detail and experienced editorial guidance greatly improved the quality of this product. We are grateful to Shalini Cawich, Emil Cherrington, Lauretta Burke, Marydelene Vasquez, and John Maidens for assistance with GIS and remote sensing products. Tonya Clayton, Valerie Paul, Judy Lang, Nadia Bood, and Maria Jose Gonzalez are acknowledged for proofreading various drafts of the guide. We appreciate the helpful contributions and suggestions by Judy Lang, Bob Steneck, Michelle Gilbert, Ann Lees, Beth Fisher and Ileana Solares. We also thank Lisa Carnes and Nadia Bood for their assistance with the Glossary and Figure 8.a.

We are also grateful to the Atlantic and Gulf Rapid Reef Assessment (AGRRA) project. Without the AGRRA Caribbean-wide database, our assessments of current status and formulation of reference values for several of these indicators would not be possible.

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Many other individuals have provided data, ideas and constructive insight that helped further develop materials included in this guide and that contributed to the overall Healthy Reefs for Healthy People Initiative. We are grateful to all. We sincerely apologize if we have inadvertently omitted any names.

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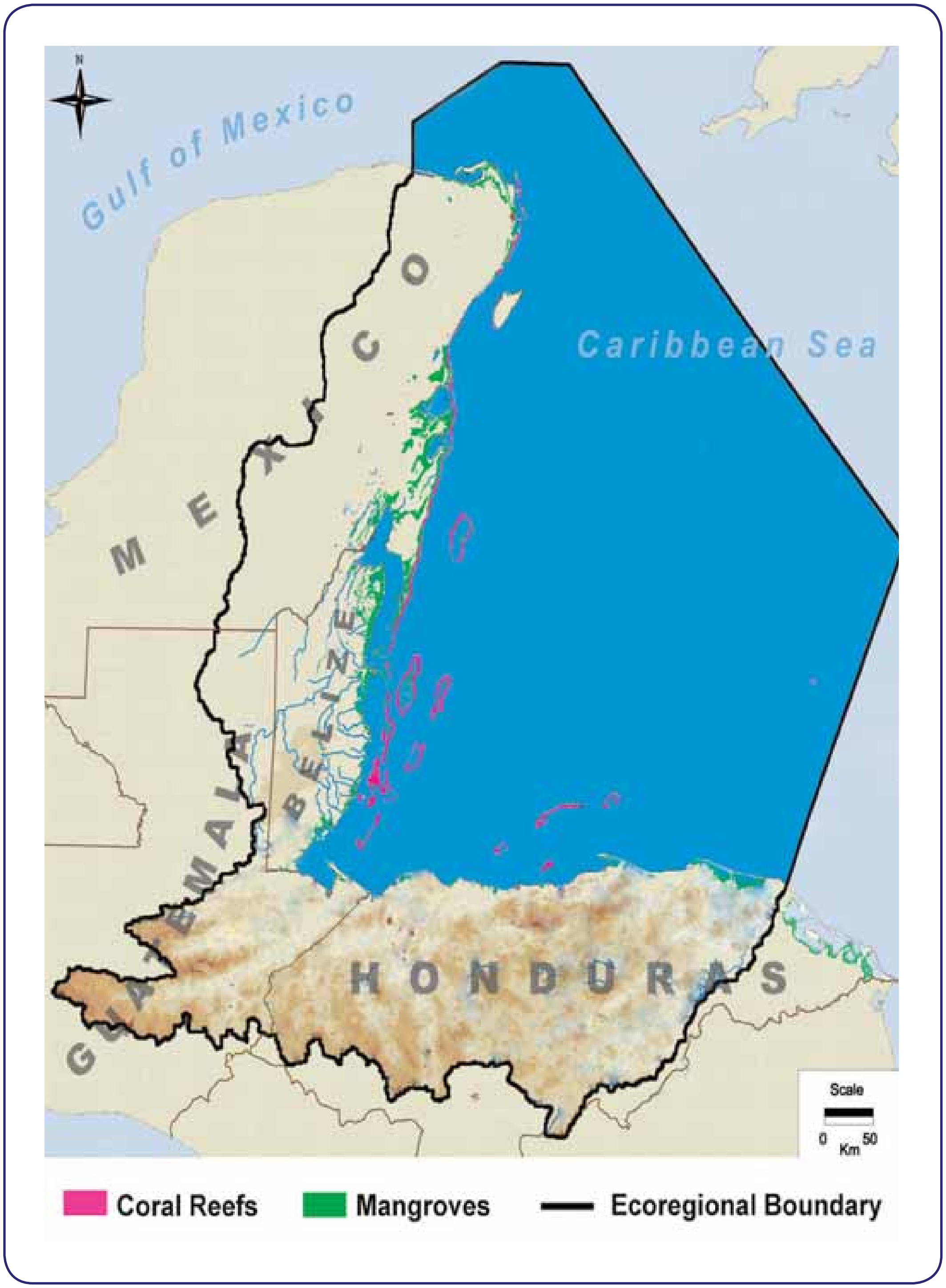
Figure 1.a. Map of Mesoamerican Reef Region



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1 The Mesoamerican Reef and its People

The spectacular Mesoamerican Reef (MAR) extends more than 1,000 km from the northern tip of Mexico's Yucatan Peninsula southward through the clear waters of Belize, Guatemala and northern Honduras (Figure 1). The reef ecoregion reaches inland to include the Caribbean watersheds of those four countries, and it stretches 1,000 km offshore to depths of over 5,000 m[1,2].

This reef system, which includes the Western Hemisphere's longest barrier reef, is one of the world's biodiversity hotspots[3]. The people of the region are also rich in ethnic and cultural diversity, with many traditional cultures still closely tied to marine and coastal resources. Here, more than most places, the health of the human population, our communities and our economies, depend largely on our ability to maintain healthy reefs.

Biologically rich and threatened, the Mesoamerican Reef encompasses a wide array of coral reefs: long barrier reefs, nearshore fringing reefs, offshore atolls, and patch reefs by the hundreds. Associated shallow and deep lagoons, mangrove forests and seagrass beds provide homes and foraging and nursery grounds for a great variety of marine life — including six endangered and five critically endangered marine species[4].

This culturally and ethnically diverse region is also home to many cultural groups, including Miskito, Pesche, Garifuna, Caribbean Creole, Mestizos, and K'ekchi, Mopan, and Yucatec Maya. Like the reef itself, coastal traditional societies are experiencing rapid change. Mass tourism, commercial fishing, and exposure to foreign cultures and the global market economy all encourage a more detached, globalized culture, especially among younger generations. Traditional cultural identity and ecological values and knowledge are being lost at an alarming rate.

Nevertheless, many coastal communities have managed to maintain a strong local identity and are working to preserve traditional languages and practices. The people have deep roots in the land and at sea, and their lifestyles and livelihood reflect the influences of geography and environment.

In all, more than one million people directly depend on the integrity and health of the Mesoamerican Reef (MAR) for their livelihood[5]. The reef and its associated habitats support commercial, recreational and subsistence fishing. The massive reef structure provides gentle passage and anchorage for boats, as well as storm and erosion protection for coastal environments and communities. And the national economies of Mexico, Belize and Honduras substantially benefit from the reef's appeal as an international tourist destination.

Still, little is known about the linkages between the well-being of the local people and the health of the Mesoamerican Reef system. For many centuries, the reef has provided sustainable livelihoods for coastal residents. Overfishing is considered by many scientists to be the most persistent and extensive threat on the Mesoamerican Reef. However, the recent escalation of coastal and tourist populations, along with the associated destruction of natural coastal habitats, including mangrove forests, is considered the most significant current threat by many of the region's stakeholders[6,7]. In addition, deforestation in the watersheds and expanding agrobusiness are also considered major threats to the reef, particularly in the southern half of the ecoregion[6,7]. Finally, the all-encompassing threats associated with global climate change (such as ocean warming, stronger hurricanes, and ocean acidification) are adding to the cumulative stress on the region's ecosystems[8,9].

Melanie McField/WWF

2 Historical Context

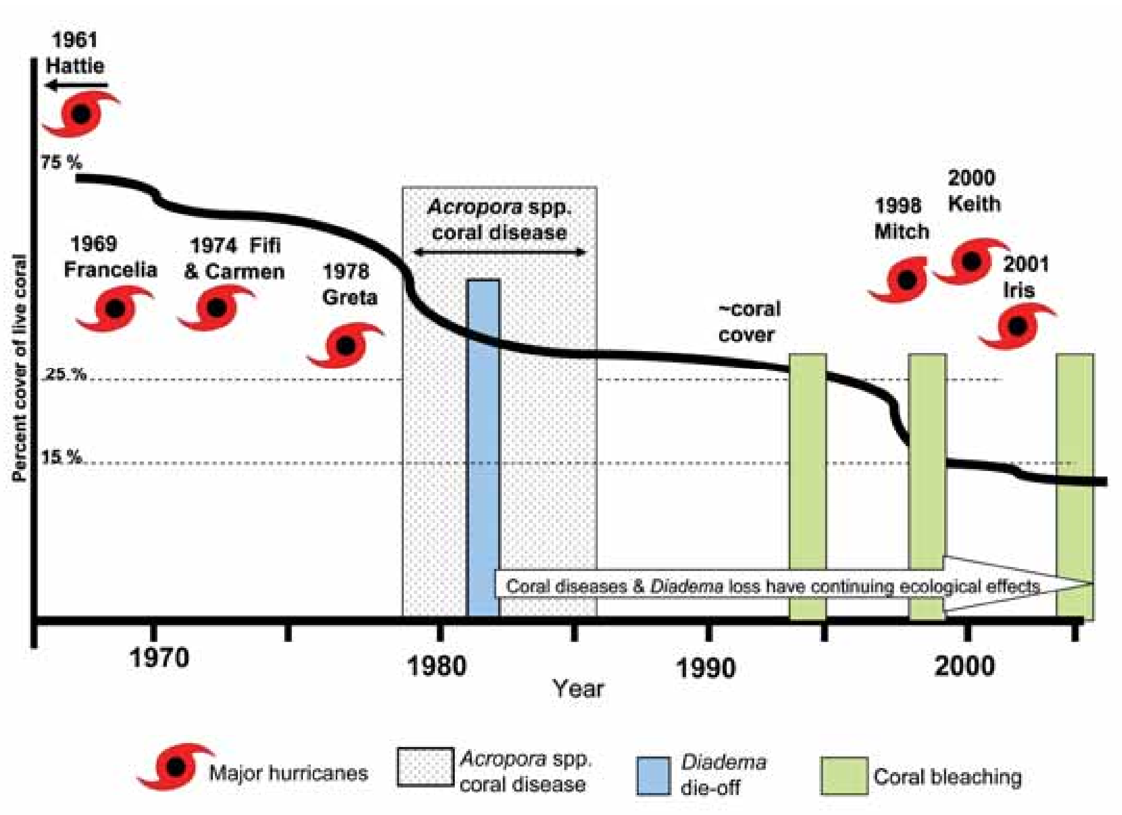
Formal marine conservation efforts began in the region about thirty years ago, with an emphasis on birds and coastal protection. Early protected areas included Belize's Half Moon Caye, nesting place of the famous red-footed boobies (1928 — declaration of part of the caye as a Crown reserve, 1982 — designation of the entire caye as a natural monument); Honduras's remote Rio Platano (1982); Sian Ka'an, now the largest protected area in the Mexican Caribbean (1986); and Guatemala's Biotopo Chocón-Machacas (1989).

Nearly coincident with the establishment of these early preserves, the Caribbean experienced a basin-wide catastrophe (Figure 2): the unprecedented die-off of one of its most ecologically important reef residents, the long-spined sea urchin (*Diadema antillarum*). A devastating 1983 disease outbreak wiped out 95% of these algae-eating echinoderms[10]. Algal growth probably accelerated immediately in many areas, although there was little quantitative reef monitoring at that time in the MAR region to record these changes, and abundant herbivorous fish populations may have prevented algal overgrowth in some areas. Coral disease also hit hard in the 1980s, and many elkhorn and staghorn corals, among the region's fastest-growing coral species, were lost[11].

The International Year of the Reef (1997) marked a turning point for marine conservation along the Mesoamerican Reef. Ten years after the establishment of the region's first marine reserve (Belize's Hol Chan in 1987), Belize celebrated the declaration of the Belize Barrier Reef World Heritage Site, and several international non-governmental organizations (NGOs) began setting up regionally focused conservation programs. On June 5, 1997, the presidents of Mexico, Guatemala and Honduras and the prime minister of Belize signed the Tulum Declaration, formally acknowledging the exceptional global value of the reef (considered to be relatively "pristine" among Caribbean reefs) and pledging to protect it for future generations[12].

One year later the region experienced concurrent natural disasters. By September 1998, reef waters had warmed to unusually high temperatures and the most severe coral bleaching event in recorded history was underway[13]. In late October, Hurricane Mitch hit,

Figure 2.a. Generalized History of Major Reef Disturbances in Belize



bringing torrential rains that produced catastrophic flooding and landslides. The result was tragic — more than nine thousand lives lost[14]. On the reef, the combination of coral bleaching and Hurricane Mitch impacts plus chronic "background" stresses led to dramatic reductions in live coral cover (loss of 50% live coral cover and greater in some places)[15,16]. Of course, the reef has been subjected to various disturbances over the years, but the last decade has been particularly damaging.

Over the past decade, the number and extent of marine conservation and monitoring programs in the region have grown rapidly. In fewer than 30 years, the number of marine and coastal protected areas has increased from a handful of coastal areas to more than 60 marine and coastal protected areas, safeguarding over 2.8 million hectares of land and sea[17]. At the same time, our marine resources have faced growing global, regional and localized threats. Recovery from coral disease and bleaching events has been slow, at best. The overall result is ongoing degradation, despite stepped-up conservation efforts[18,19].

We have come to realize that we need to advance our understanding of the real drivers of ecosystem health in the MAR, and to improve the way in which we track and evaluate our ecosystems, our society, and our own efforts in conservation.

Other similar efforts are underway in a number of places around the world (e.g., Chesapeake Bay, USA, and Moreton Bay, Australia) and globally. The Millennium Ecosystem Assessment was a multiscale assessment of the consequences of ecosystem change for human well-being and the analysis of policy or management actions to enhance well-being and ecosystem conservation. It involved over 1,300 experts from 95 countries as collaborators on a series of reports and had a four-year core budget of US$17 million. Despite these resources, the reports often lacked sufficient data, particularly those that could capture the important linkages between ecosystems and social well-being.

The Healthy Reefs for Healthy People Initiative is working towards similar objectives on a much smaller scale and with a particular focus on the region's coral reefs and associated marine ecosystems. Our efforts will help to ensure the long-term health and sustainability of this extraordinary ecosystem complex for generations to come. This guidebook — a compilation of standardized, science-based tools ("indicators") for assessing and interpreting the signs of reef health and associated social well-being — represents a major step in that direction.

"Gift to the Earth Celebration - March 2000" in Tulum Mexico. Celebrating the governments of Mexico, Belize, Guatemala and Honduras for their commitment towards conservation of the Mesoamerican Reef Ecoregion. In the photo Julia Carabias, former Minister of the Environment, Mexico; Kathryn Fuller former President and CEO, WWF-US; and Roger Sant, former President of the Board, WWF-US.

3 What is a Healthy Reef?

The Healthy Reefs for Healthy People Initiative uses the term "health" as an easily understood bridging concept that connects natural systems and humans[20]. But just what is a healthy reef? How can we, as managers, divers, researchers, fishers and other reef stewards, recognize a healthy reef?

Over the past year we posed that question to various audiences. People told us that signs of a healthy reef would be: "the presence of indicator species," "maintaining key processes like herbivory," "having higher fishing catches/landings," or even "just looking like it did in years past."

Clearly, there is no simple definition of reef health. Still, most people, from scientists to stakeholders, agree that Mesoamerican Reef conditions have deteriorated over the past 25 years. Corals — the structural engineers of a healthy reef — have dramatically declined, food webs and key natural processes have been disrupted, and populations of many important commercial species and focal species have been decimated. These signs are obvious ones of poor reef health.

Many reefs give us mixed signals. Some reefs, for example, have a relatively high abundance of predatory fish (indicating good health) but a low density of coral recruits or coral cover (indicating poor health). Nevertheless, the overall trend worldwide and on our own Mesoamerican Reef is one of continuing general decline. It is generally easier to recognize an unhealthy reef than to define what constitutes a healthy one.

It is important to remember that a reef is always part of a larger ecosystem—a dynamic community of people, plants, animals and microorganisms, all interacting with each other and with the environment in which they live. Any definition of reef health must therefore be aligned with the comprehensive principles of ecosystem health, recognizing that people are an integral part of the system too[21,22,23].

One of the most important aims of the Healthy Reefs for Healthy People Initiative is to compile a suite of practical, quantitative measures of reef health that can help transform a general definition into something more tangible, more amenable to measurement, and better equipped to offer answers to our fundamental question of "How can we efficiently track the health of our vast ecosystem — as well as our rapidly changing human communities?"

Healthy Reefs for Healthy People is a collaborative international initiative that generates user-friendly tools to measure the health of the Mesoamerican Reef Ecosystem, and delivers scientifically credible reports to improve ecosystem management and sustain social well-being.

Our working definition of reef health is based on a consideration of both ecological and social well-being:

A reef is healthy if it maintains its structure and function and allows for the fulfillment of reasonable human needs.

(- adapted from N.O. Nielsen, University of Guelph)

We need standardized techniques to assess and describe the physical structure of the reef itself, as well as the ecological structure of reef inhabitants. We need practical methods to monitor reef function through time—including the weeks, months and years following disruptive events (e.g., hurricanes or bleaching episodes). We also need measures of well-being among the human communities that rely on the reef for their food and livelihoods.

This guide therefore profiles, one-by-one, a comprehensive collection of 58 such indicators to assess the ever-evolving state of affairs on the reef in terms of ecosystem structure and function, the driving forces effecting change on the reef, and societal well-being and governance.

The indicators themselves are merely the fundamental ingredients for building our new measurable definition of reef ecosystem health. The variety of possible combinations of indicators and indices is limited only by our own creativity and understanding. The art of this science will be in the development of reliable indices and models drawing from a set of key indicators and a broad collaboration of the minds.

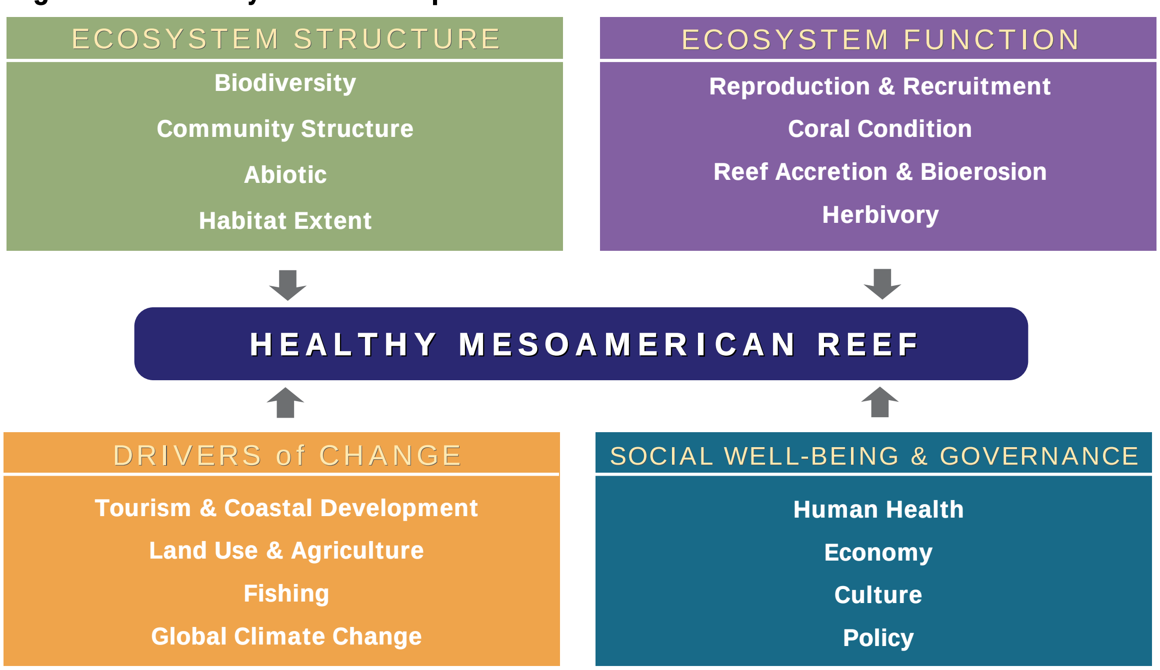
4 The Healthy Reefs Framework

The Healthy Reefs conceptual framework is grounded in the fundamental elements of ecosystem structure and function, while integrating human stressors and social issues (Figure 4.a). The framework links multiple indicators to improve our understanding of how humans impact reef ecosystems and, conversely, how the condition of reef ecosystems may be influencing local people and their livelihoods[24]. Such an integrated conceptual framework is necessary to provide interpretive tools for practitioners and decision-makers trying to evaluate the impact of their conservation efforts on the ecosystem.

The framework consists of four main components: Ecosystem Structure, Ecosystem Function, Drivers of Change, and Social Well-being and Governance. Each component is defined as a condition or state that affects reef health and integrity and can be directly or indirectly measured by specific indicators:

- Ecosystem Structure refers to the organisms present (e.g., diversity, abundance) and the physical conditions of the ecosystem (e.g., salinity, temperature). Reef structure plays an important role in determining the way a reef ecosystem functions. There are four main attributes of this component: Biodiversity, Community Structure, Abiotic, and Habitat Extent.
- Ecosystem Function includes key ecological processes (e.g., mortality, recruitment, herbivory). Functional attributes are the processes required to sustain biodiversity, and they influence how structural components interact. There are four main attributes of this component: Reproduction and Recruitment, Coral Condition, Reef Accretion and Bioerosion, and Herbivory.
- Drivers of Change include both anthropogenic and natural stressors 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. There are four main attributes of this component: Tourism and Coastal Development, Land Use and Agriculture, Fishing, and Global Climate Change.
- Social Well-being and Governance attributes recognize the role that the environment plays in sustaining people's livelihoods, health and culture, as well as the potential positive and negative effects of human activity on the ecosystem. Human values and stewardship will play a dominant role in the sustainable management of these ecosystems. There are four main attributes of this component: Human Health, Economy, Culture, and Policy.

Figure 4.a. Healthy Reefs Conceptual Framework



5 Selecting Indicators

Tracking changes in the Mesoamerican Reef ecosystem over time requires a set of key indicators that can be reliably measured and compared. Indicators are the “meter sticks” of the Healthy Reefs conceptual framework. They serve as signals to assess status and trends in ecosystem health and management effectiveness[25,26,27]. The aim of this guide is to provide a set of indicators to help field researchers (in biology, social sciences, economics, etc.) and managers interpret monitoring data and answer specific management questions, particularly those that aim for the big picture of eco-health on the ecoregional scale.

Most indicators of coral reef health currently used in the Mesoamerican Reef region are measurements of either biological structure (e.g., coral cover, species diversity, fish abundance) or environmental conditions (e.g., temperature, nutrients). There are fewer studies available that focus on ecological processes (e.g., recruitment, herbivory); diagnosing specific causal linkages (e.g., biomarkers of specific stressors); or linking to ecosystem services and human well-being.


Wolcott Henry

WHAT CAN INDICATORS DO?

- Describe changes in reef integrity or availability of ecosystem services.
- Differentiate, when possible, natural variation or disturbance from human impacts.
- Act as early warning signals and diagnostic tools.
- Help managers evaluate the effectiveness of management actions.
- Help develop and set priorities for monitoring and research.
- Help raise public awareness and engage communities in decision-making.

WHAT WILL INDICATORS NOT DO

- Due to the confounding effects of multiple causes, even the most reliable indicators can not always tell us why certain health attributes and indicators are declining. Nature remains full of surprises.
- Our understanding of the forces controlling reef dynamics is incomplete. These forces naturally vary in time and space. The ‘reference values’ presented here are a first iteration based on region-wide averages and will need to be refined as our knowledge and data increase.

The 58 key indicators presented (Figure 5.a) were evaluated based on several criteria and input from the following sources:

- A comprehensive review of relevant scientific and gray literature from local, regional, and global publications.
- Recommendations by international ecological experts at the Healthy Reefs Consultation Workshop held in June 2004 in Miami, Florida (see Acknowledgements).
- Consultancies led and funded by the World Bank (Dr. Marea Hatziolos) for the identification and development of key social indicators. Expert contributors in these consultancies include: John Dixon, Stefano Belfiore, David Rapport, Luisa Maffi, John Howard, and Ola Ullsten. The resulting report[28], *Measuring Coral Reef Ecosystem Health: Integrating Societal Dimensions*, constitutes an important contribution to this guide.
- Recommendations by regional and local ecological and social experts at the Tulum +8 Meeting held in September 2005 in Cancun, Mexico. See www.healthyreefs.org for more information.
- Discussions with many colleagues in local and international agencies (see Acknowledgements).

No single indicator can capture the complexity of ecosystem and social well-being, yet a long list of independent indicators not integrated at some level will be of little use to decision-makers. The approach we took was to assemble an integrated menu of indicators that are interconnected, in order to illuminate an understanding of the whole system, yet provide some flexibility in terms of which indicators are selected.

The indicators were evaluated based on the following criteria:

Ecological relevance: Do the data provide a true indication of reef health, given their utility as a proxy for the main attribute/stressor?

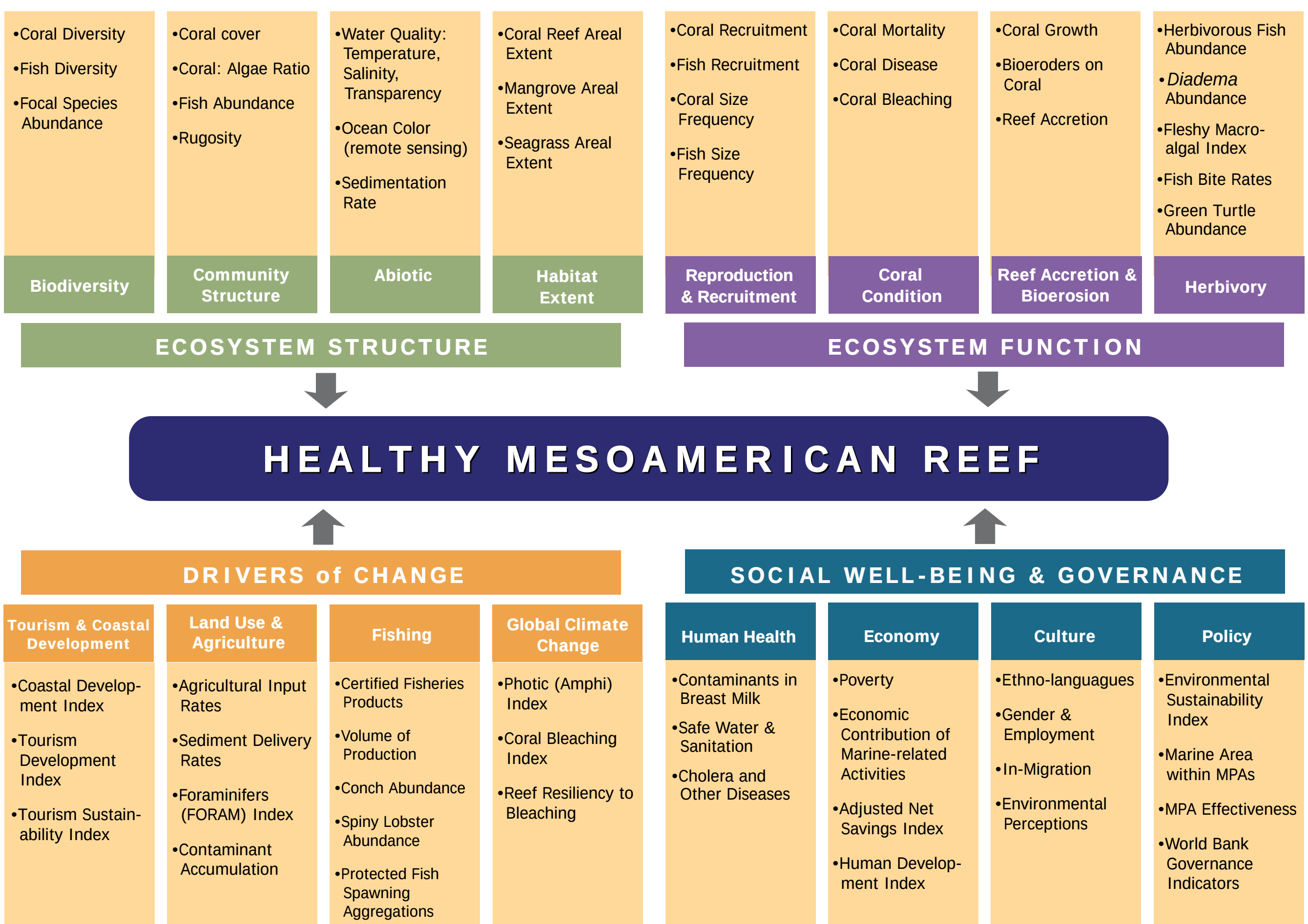
Feasibility: Are data collection methods realistic for the Mesoamerican Reef, given spatial scope and monitoring constraints?

Limitations: Are there limitations in collecting and interpreting the data?

Responsiveness: Is the indicator "sensitive" to human stress or human intervention?

For many of the indicators proposed here, standard units of measurement are not yet available and require further data to be developed.

Figure 5.a. Healthy Reefs Indicators



Healthy Reefs for Healthy People Initiative, November 2006

6 Baselines & Reference Values

Understanding Baselines

Baseline data describe reference conditions of an ecological system and act as a reference point or standard to compare change over time. Baseline data are often used to describe conditions existing before some event (such as Hurricane Mitch) or management action (such as the prohibition of fishing in a new marine reserve). Modern-day baselines often have already been affected by earlier (e.g., pre-modern) changes, which are more difficult to quantify[29,30].

For each of the 58 indicators, we have identified existing data sets where available. Unfortunately, baseline data are either lacking for most indicators or were collected at different times or with different methods. For practical purposes in this guide, we generally consider baseline data to be those that precede the 1998 disturbance events. We acknowledge that this time-frame reflects a “shifted baseline” which is likely quite different from earlier “pristine” conditions.

Nevertheless, it is important to determine current reef ecosystem conditions, as today’s measurements provide a valuable marker for assessing future changes. Reef managers need to know the normal ranges of the various indicators in order to determine how healthy (or not) a reef may be. For managers in the MAR this may entail comparisons of the data ranges at their site as compared to the MAR, the MAR compared to the wider Caribbean, or the MAR compared at the global scale (for some indicators).

Understanding the normal ranges of indicators involves consideration of many factors, such as:

- Are historical data available to determine baseline values for each indicator? If not, are there any potential sources (published and unpublished) to fill data gaps?
- To what temporal scale does the baseline correspond (e.g., historical or current conditions, 10 or 100 years ago)?
- On what spatial scales are the data representative [e.g., site-specific (1-10 km) or regional (>100 km) levels]?
- How does the indicator vary with different environmental and stressor conditions (e.g., depth, reef type, disturbance history)?
- How do linkages between reef ecosystem health and social well-being indicators affect the reference values?
- How can we use this information and the available data to set benchmarks, targets, and red flag values for each indicator (see below)?

Because few historical data are available for most indicators, we often could not summarize baseline data. Instead, we have characterized the current status of each indicator (when possible), covering approximately the last 5 to 6 years. These combined data were then used to develop preliminary reference values for most of the indicators.

Reference Values

To interpret our data and apply them wisely, we need context for our measured values. Reference values help provide that context. They are thresholds or conditions that have been determined (at least provisionally) to be meaningful indicator “meter sticks.” These meter sticks or reference values can greatly enhance the effectiveness of monitoring programs and increase our understanding of how reef health affects people and their livelihoods. They can help guide data interpretation and can be applied to making informed decisions. They serve as practical tools to help reef stewards decide when to take action[31]. To better use reference values, we developed three categories: benchmarks, targets, and red flags (defined in inset).

Reference values have been (or will be) established for each indicator based on historical data, current conditions around the Caribbean and the consensus

Benchmark

A benchmark is the minimally acceptable limit for the next five years.

Target

A target is the optimally feasible condition or goal to aim for in the next 15 to 20 years in order to achieve long-term ecological integrity.

Red Flag

A red flag is a value that provides a warning signal indicates a level of concern.

judgment of regional experts. For some indicators, we had sufficient data to develop target, benchmark, and red flag values. Others merely have placeholders of ‘to be developed’ until more information is available. In all cases, the reference values will need to be reviewed, tested and adjusted as more data become available. We adopted several approaches to setting reference values, depending upon specific management goals and objectives and the types of indicators used to track these goals.

Benchmarks And Targets

Benchmarks are the minimally acceptable level for an indicator over the next five years. Benchmark reference values help us mark progress along the way to our longer-term targets, or give minimally acceptable limits. Targets are the optimal goal to aim for in the next 15-20 years. For example, benchmark and target values for focal species will specify the number of populations of a particular size, the demographic variables (e.g., reproductive rates and mortality rates), and/or habitat-based variables (e.g., reserve size and habitat condition) necessary to ensure long-term persistence. Benchmark and targets for coral reef, mangrove and seagrass habitats, on the other hand, will include the amount of habitat to be protected, as well as key structural and functional attributes necessary to promote long-term integrity.

Some indicators have benchmark and target values based on a “limits of acceptable change” approach that allows managers to manage for desired ecological outcomes while still accommodating social and political issues by evaluating how much change is acceptable in an area[32]. Some indicators, particularly in the Social Well-being and Governance section, are inherently difficult to quantify, even in relative terms. What level of in-migration of outsiders into a small coastal community is desirable or acceptable? In these instances we have tried to define some trends that are generally desirable, but suggest different communities will need to establish their own specific targets for some of these indicators.

Red Flags

Red flags are warning signals that an indicator has reached a level of concern. Some indicators are inherently more conducive to red-flag determination than others, but we have attempted to incorporate these important warning signals as often as possible. For example, red flag values for ecological indicators, such as coral bleaching, disease prevalence and partial coral mortality, were developed by comparing data collected during major disturbance events with data from normal, non-disturbance time frames. It is more difficult to define a red flag value for many social indicators such as gender and employment. We have offered some suggestions that serve to begin what we hope will be an engaged discussion of these reference values on our website: www.healthyreefs.org.

Using Reference Values To Guide Interpretation: A Coral Mortality Example

In 1999 (about 8 months after the coral bleaching event and Hurricane Mitch) partial coral mortality was measured at a range of sites off the Yucatan peninsula with an average of over 12%. Clearly this value is a red flag – indicative of the serious effects of the 1998 disturbances.

By 2001, a MAR-wide survey of 35 sites ranging from Cozumel, Mexico, down to the Bay Islands, Honduras, measured an average recent coral mortality of 1.6% – meeting our established benchmark value. However, it did not meet our optimal target value – maintaining recent coral mortality rates below 1.5% for at least five consecutive years. Obviously, meeting the target will require more years free of any major causes of mortality.

While the reference value is designed to be used on data averaged from a number of sites, some indicators, such as recent coral mortality, can provide meaningful comparisons to reference values even for an individual site. For example, in 2001 Palancar Reef, Cozumel, had 3.2% recent mortality. Managers could ask, “What does that value mean? Is it indicative of a robust, resilient reef? Or, a reef that is dangerously ill?” Based on the reference standards presented in this guide, we find that a recent coral mortality value of over 3% is higher than our target value – but not as high as the red flag nor a cause for great concern. It should encourage additional monitoring to quickly detect any increase that might elevate the level to an alarm status.

Not all indicators have reference values that are as easily measured as coral mortality. Some indicators require a more descriptive framework of reference conditions.

Reference Values – Recent Coral Mortality

Benchmark: < 2% MAR-wide averages

Target: < 2% sustained for at least 5 years

Red Flag: > 5%

Database

As an end product, we are developing a searchable database of the Healthy Reefs indicators, including their target, benchmarks and red flag values for the MAR. These benchmark and targets can be incorporated into the monitoring and evaluation efforts of the different organizations working in the region, thus enhancing ongoing joint conservation planning and cooperation on the ground. Having a “common currency” for evaluating our progress will help increase our collective conservation impact and reduce duplication or gaps in effort. The challenge is developing practical yet encouraging targets that provide measures of success towards achieving the ultimate goal of long-term ecological integrity and sustainable use.

7 INDICATOR PROFILES

This section includes information on the four main attributes (Structure, Function, Drivers of Change, and Social well-being/Governance) and their corresponding indicators. For each attribute we present a Conservation Objective, list the main Threats to the attribute, and list Management Actions that are currently being used or are proposed to minimize threats.

The main focus of this section is to present the individual indicator profiles for each of the 58 indicators. The purpose of the indicator profiles is to briefly summarize the data on each indicator as an easy-to-use reference. These profiles should be viewed as living documents that will continually be reviewed and updated through the Healthy Reefs website (www.healthyreefs.org).

Each indicator has a "Profile" identified by an alphanumeric code as follows:

S = **Ecosystem Structure indicators**
F = **Ecosystem Function indicators**
D = **Drivers of Change indicators**
SW = **Social Well-being indicators.**

PROFILE CONTENTS

What Is It?
Defines and describes the indicator.

Why Do We Measure It?
Describes why conserving this indicator is important to reef integrity.

How Do We Measure It?
Describes methods used or monitoring programs.

Usefulness
Discusses the relevance, feasibility, and limitations of collecting data for this indicator.

Status
Describes the current status or condition of the indicator, when information is available.

Data Needs
Describes what additional data and information are needed.

Highest Priority Indicators

Given the complexity of reef ecosystems and the variety of management objectives throughout the region, this guide emphasizes the need to evaluate multiple indicators in tandem. However, we also recognize that most NGOs or monitoring agencies will not evaluate all of these indicators. Thus we have provided a short list of 10 Ecological and 10 Drivers and Social indicators. These indicators are denoted with the "Priority" seal (see inset) in the indicator profiles that follow. We believe these indicators represent a solid recommendation for covering the basic components of reef ecosystem health. However, we also recognize that, in addition to the basic ecological status or trends of reef health, managers are also concerned with evaluating the effects of their targeted management interventions. These issues are more fully discussed in Section 9 – From Indicators to Action.

HIGHEST PRIORITY INDICATORS	
Ecosystem Structure	**Drivers of Change**
S3 Focal Species Abundance	D1 Coastal Development Index
S4 Coral Cover	D2 Tourism Development Index
S6 Fish Abundance	D7 Contaminant Accumulation
S8 Water Quality	D10 Conch Abundance
S12 Mangrove Extent	D14 Coral Bleaching Index
Ecosystem Function	**Social Well-being**
F1 Coral Recruitment	SW2 Safe Water and Sanitation
F5 Coral Mortality	SW4 Poverty
F11 Herbivorous Fish	SW5 Economic Contribution of Marine...
F12 *Diadema* Abundance	SW11 Environmental Perceptions
F13 Fleshy Macroalgal Index	SW14 MPA Effectiveness

It is important to note that implementation of either the AGRRA or MBRS standard monitoring protocols will provide data for most of these priority ecological indicators. Additional data collection would be needed to measure focal species abundance, mangrove extent, and water quality (although some water quality data collection is included in the MBRS Synoptic Monitoring Program). Most of the Drivers and Social indicators are being collected, although not always on a regional scale with comparable methodologies. Thus there is a need for standardization in the reporting of these indicators.

Ecosystem Structure Indicators

The term *ecosystem structure* generally refers to a set of attributes (living and non-living) related to the instantaneous physical state of the ecosystem. For example, a characterization of coral reef ecosystem structure might include questions like these:

- How many different corals live on the reef, and in what numbers?
- How much of the reef surface is covered by macroalgae?
- What's the water temperature on the reef?
- How much mangrove forest fringes our coastline?

The Healthy Reefs Ecosystem Structure indicators (S) — thirteen in all — look to these sorts of questions to help keep an eye on how our reefs are doing and how they are changing (Table 7.a).

Harley Moody

Table 7.a. Ecosystem Structure Indicators.

Attribute	Indicator #	Indicator
Biodiversity	S1	Coral Diversity
	S2	Fish Diversity
	S3	Focal Species Abundance
Community Structure	S4	Coral Cover
	S5	Coral:Algae Ratio
	S6	Fish Abundance
	S7	Rugosity
Abiotic	S8	Water Quality: Temperature, Salinity, Transparency
	S9	Ocean Color (remote sensing)
	S10	Sedimentation Rate
Habitat Extent	S11	Coral Reef Areal Extent
	S12	Mangrove Areal Extent
	S13	Seagrass Areal Extent

Biodiversity

Conservation Objective

Promote reef ecosystem health in the wake of natural and anthropogenic disturbances by maintaining and increasing current levels of biodiversity, particularly within key functional guilds and threatened focal species.

Threats

Main threats include destruction of habitat and nursery areas; illegal or destructive fishing practices and overfishing (of groupers and sharks, for example); poaching (sea turtles and their eggs), overharvesting or accidental killing of threatened species (such as boats hitting manatees); pollution (including sedimentation and nutrification); coral bleaching and disease; competition/predation; hurricanes; and global climate change.

Management Actions

- Establish improved monitoring programs to determine the current status and critical habitats of key focal species.
- Develop management or recovery plans for currently unmanaged species (e.g., goliath grouper, whale shark, sawfish) and routinely update management or recovery plans for managed species (e.g., hawksbill turtle, manatee).
- Protect migration and larval corridors, and reduce destruction of mangrove, seagrass and coral nursery areas.
- Reduce illegal fishing and other destructive practices like marine dredging operations.
- Reduce or eliminate the direct take of World Conservation Union (IUCN) threatened species (Appendix 3).

Coral reefs are among the most biologically diverse ecosystems in the world. (In other words, they host a great variety of life.) These spectacular living formations account for one-third of all marine fish species.

It's important to monitor *biodiversity*, as changes in the great richness of reef life can help us spot important changes in ecosystem health. Within any given ecosystem, higher biological diversity is generally considered to be healthier than lower biodiversity, and extensive biodiversity loss can be used as a proxy for ecosystem degradation. Changes in the abundance of rare species or range-restricted species can also be important indicators of overall ecosystem disturbance.

Rachel T. Graham

Reefs with relatively high biodiversity, such as those in the Indo-Pacific, have generally shown greater resilience to disturbances than have reefs with fewer species, such as those in the Caribbean[1]. A similar pattern has been observed recently on the Mesoamerican Reef, where preliminary 2006 survey results indicate a greater resistance to climate change and bleaching among the more diverse inshore reefs. Other factors — ones unrelated to biodiversity — may also contribute to differences in resilience.

When planning to protect biodiversity, it is important to remember that marine ecosystems are inherently different from their terrestrial counterparts. Conservation lessons learned on land cannot be simply transferred to marine areas.

Marine ecosystems are generally open systems, with larvae, juveniles and adults often moving from one habitat to another at different life stages. Dispersal of many free-floating marine larvae occurs over very large areas, and marine larval distributions may demonstrate greater variability than would be typical for terrestrial species. For example, preliminary models of connectivity between fish spawning sites and predicted settlement reefs showed reefs in Mexico and Northern Belize receiving larvae from Cuba in some years, but not in others, due to the high variability of weather and oceanographic patterns, including eddy formation and duration[1.b.]. Activities that act as barriers (e.g., habitat fragmentation or disruption of larval flow) can reduce genetic diversity and overall ecosystem function. In the MAR ecoregion, the destruction of mangrove nursery areas is a particular concern.

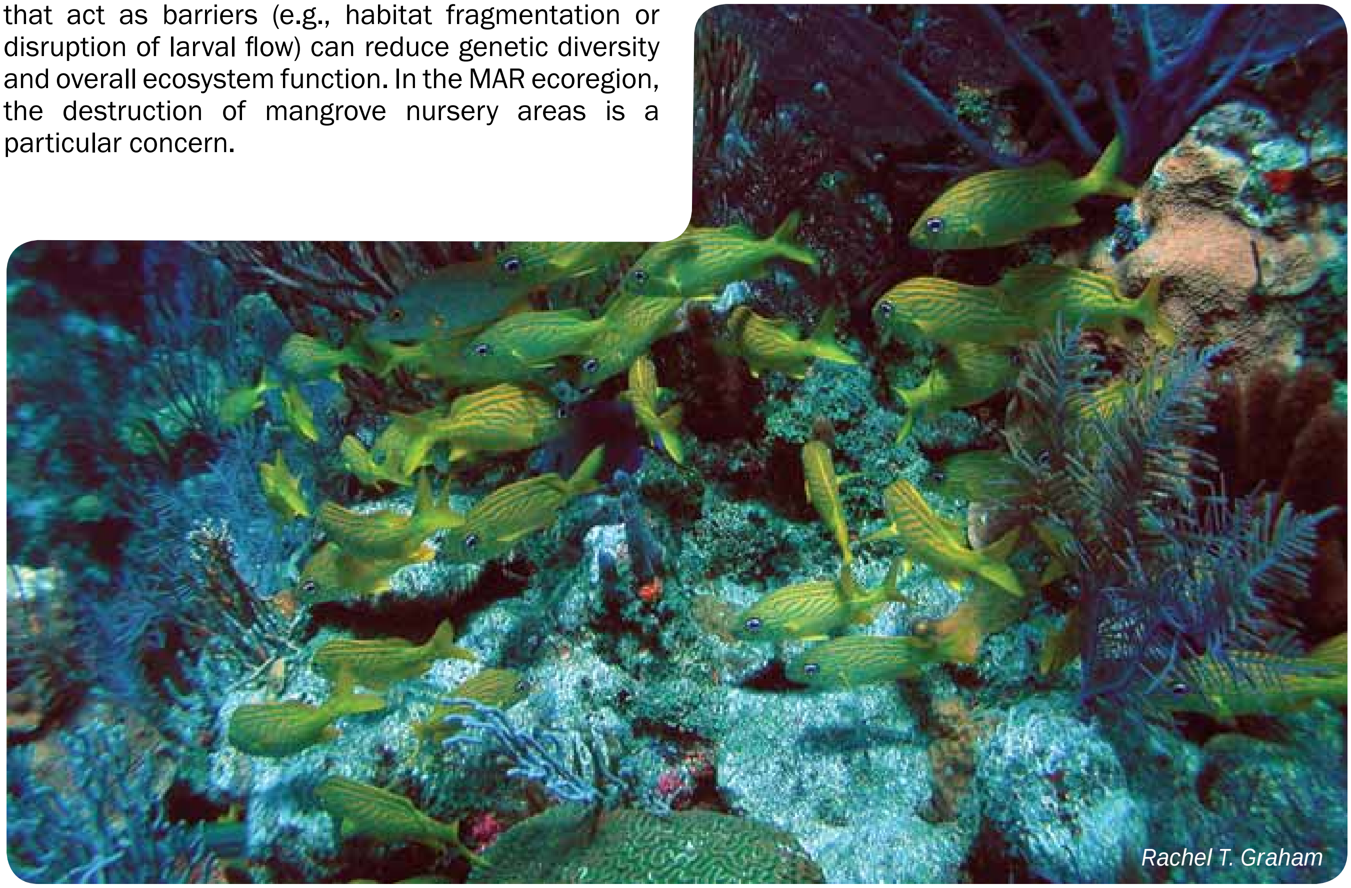
Another important consideration is the relatively narrow area to which some marine species, particularly reef organisms, are restricted. Corals, for example, have quite specific light and temperature requirements. Range-restricted organisms are more vulnerable to perturbations and extinction than are more wide-ranging organisms.

Today, loss of marine biological diversity is occurring at an alarming rate. Despite the ecological and economic significance of many species, marine biodiversity is significantly threatened by overexploitation, pollution, habitat alteration and global climate change. Scientists have documented at least one recent MAR marine extinction. The Caribbean monk seal, once vigorously hunted for its blubber, has not been officially sighted since 1952[2].

Maintaining high species diversity within key functional groups (such as coral and fishes) and preventing further extinctions are important elements of preserving reef ecosystem health[3].

Indicators selected to track biodiversity are:

- S1 Coral Diversity
- S2 Fish Diversity
- S3 Focal Species Abundance



Rachel T. Graham

S1 Coral Diversity

What Is It?

Coral diversity is a measure of the variety of corals living in a given area.

Diversity can be assessed in many ways. *Species richness* is the number of species present. *Evenness* is a measure of how equal in number the different coral species are. Here, we consider coral diversity in terms of both species richness and evenness. (Formulas are given in Appendix 3: Technical Notes.)

Benchmark

Maintain species richness and diversity at current levels.

Target

Diversity indices equal to or greater than 1997 levels of ~1.7 (Shannon-Wiener) on fore reefs and > 30 species per 225 m^2 area.

Red Flag

Any reduction in species richness.

Melanie McField / WWF

Why Do We Measure It?

Higher biodiversity is generally taken as a sign of better ecosystem health (within a specific habitat). We are especially interested in hard corals, as they are the 'structural engineers' of the reef. A decline in coral species richness or diversity indicates a decline in ecosystem health.

Reduced coral species richness or diversity makes reefs more susceptible to natural and anthropogenic disturbances, especially disease outbreak. Loss of biodiversity can thus reduce the reef's overall resilience to such disturbances.

Species diversity within key guilds or functional groups (e.g., reef-building corals, herbivores) may be of paramount importance.

How Do We Measure It?

In general, divers mark off an area of reef, then count all species present. Species richness can be measured in belt transects (long rectangular plots)[4]. Diversity is then calculated from coral cover (indicator S4), often using one of two common diversity indices that incorporate species richness and evenness into a single measure – the Shannon Index. Technical notes and formulas are provided in Appendix 3.

Usefulness

Biodiversity can be a powerful indicator of reef health, but its application has some limitations. Diversity can be easily calculated from coral cover data, but a larger total sample area is generally needed to adequately represent species richness in an area (thus increasing field sampling effort, cost, etc.)[5].

The relationship between a given biodiversity index value and reef health is not a simple one. There is no simple relationship between the numbers of species found on a degraded site versus a healthy site. Richness or diversity values naturally vary depending upon reef type, past disturbance and survey method. Species evenness might not be sensitive to species replacement. (In other words, species replacement could be occurring on the reef, but an evenness measure alone may not pick up that change.)

Datasets will be difficult to compare if there are (1) differences in the taxonomic categories used in different studies (e.g., one study may classify according to genus, while another may classify according to species or even sub-species), and (2) great variation in total sampling effort (sample area / sample size).

Moderate training in species identification, taxonomic standardization and field sampling is required.

Status

There are at least 67 species of corals in the Mesoamerican Reef region.

Coral diversity at many MAR locations has declined over the past 20 years due to high coral mortality. In some cases, once-dominant reef-building corals have been replaced by other species, such as *Porites asteroides*, which do not contribute as much to reef construction, given their smaller size and morphology.

One representative study conducted in 1997 on 12 fore reef sites throughout Belize measured a Shannon-Wiener diversity index of 1.8; species richness averaged more than 30 species per site (for a 225 m^2 sample area). These data were collected after several major reef events (*Diadema* die-off, acroporids losses, 1995 bleaching), but before the devastating 1998 bleaching and Hurricane Mitch events. In 1999, these same 12 sites had a diversity index of 1.4[6].

Data Needs

Comparable datasets are available for a limited number of sites in the MAR region.

Additional large datasets suitable for direct comparison are needed from across the region at multiple reef-habitat types. More informed targets can then be established.

Melanie McField / WWF

S2

Fish Diversity

What Is It?

Fish diversity is a measure of the variety of fishes living in a given area.

Diversity can be assessed in many ways. Here, we express fish diversity as the product of species richness and evenness (where richness is equal to the number of species present, and evenness is a measure of how equal in number the different fish species are).

Key Mesoamerican fish "guilds" or functional groups are the herbivorous fishes (e.g., parrotfishes) and the commercially significant fishes (e.g., grouper, snapper). We can also measure diversity within these selected groups.

Why Do We Measure It?

High fish diversity is generally equated with better reef health. (But measures of fish abundance and size distribution must also be considered.)

A long history of fishing in the MAR has directly affected fish populations by eliminating individual organisms, reducing reproductive potential and larval recruitment, and disrupting trophic structure. Fish populations are characterized to help understand changes in community dynamics and identify human impacts such as overfishing or habitat destruction.

On reefs, there are generally a few "driving" species that play a critical role in reef processes or functions. Often, there may not be another species locally capable of playing that driving role. Many more "passenger" species also live on the reef. Their role is less critical, or there may be many "redundant species" that could fill that passenger role (a type of ecological redundancy).

Maintaining ample biodiversity within these key functional guilds (e.g., herbivores) is critical in ensuring that functionality can be maintained even if a key driving species declines (e.g., *Diadema* sea urchins).

How Do We Measure It?

Many different protocols are used to estimate fish species diversity, richness and relative abundance. One example is the roving diver method developed by the Reef Environmental Education Foundation (REEF): a diver makes a timed swim while recording fish observations[7]. (See Appendix 3 for details).

Benchmark

No loss of fish diversity (averaged for subregions of MAR, habitat type) from levels observed in 2006 MAR survey.

Target

To be developed once additional data and analyses are available.

Red Flag

Any loss of fish diversity (averaged for subregions of MAR, habitat type) from levels observed in 2006 MAR survey.

Usefulness

The scientific expertise needed to measure total fish diversity is beyond the technical capacity of most regional monitoring programs. Monitoring total fish diversity over large spatial scales would be extremely time-consuming and costly. However, measuring the Shannon-Wiener diversity index from a limited list of commonly identifiable species from various trophic levels or guilds is feasible, relatively easy to measure, and can serve as a proxy for overall fish biodiversity.

The REEF roving diver method provides a practical management tool, enabling many sites across large spatial scales to be assessed in a relatively uniform and easy manner. An added benefit of using the REEF method is that the data can be submitted to a large web-based database, and analyzed results are returned to the surveyor. Interpretation of REEF fish data has limitations, but the caveats are well-defined by REEF. (For example, more REEF surveys are available from popular dive locations, and many areas have not been surveyed yet.)

Measurements of total fish biodiversity are useful but require numerous experienced taxonomists and can be very costly.

Status

Diversity of reef fish in the MAR is similar to other reef areas in the Caribbean. The "condition" is considered fair to good based on the number of species, but not abundance. At least 245 species of marine reef fish are found along the Yucatan Peninsula, 317 in Belize, 218 in Guatemala, and 294 in Honduras. Important families include Scaridae (parrotfishes), Pomacentridae (damselfishes), Labridae (wrasses), Acanthuridae (surgeonfishes and tangs), Lutjanidae (sea perches and snappers), Haemulidae (grunts) and Serranidae (groupers and sea basses)[8].

The number of species (average of 197) and number of families (48-54 families) are rather similar throughout the MAR; however, density and sighting frequencies differ, depending on location. In the Caribbean, a total of 768 species has been reported, with Bonaire having the highest number of species (338). (These data may also reflect the fact that more surveys have been conducted in Bonaire than in other areas)[8].

Data Needs

Many different visual censuses have been used in the MAR, but few are directly comparable because of different methodologies. Analyzing the widely used Atlantic and Gulf Rapid Reef Assessment (AGRRA) database for "within-guild fish diversity" provides a feasible option.

REEF data on density and sighting frequency are available from 2,195 expert surveys in the MAR.

Baseline and follow-up data representative of all reef types are needed across the region. A region-wide fish survey was conducted in 2006 in the four MAR countries. Meta-analyses of older (> 15 years) publications and records are needed to establish long-term targets.

Wolcott Henry

S3 Focal Species Abundance

What Is It?

Focal species abundance refers to the abundance of key marine species of concern, including those on IUCN's Red List of Threatened Species. (See Appendix 3 for the list of threatened species found in the MAR).

Examples of Mesoamerican focal species include the critically endangered hawksbill and leatherback sea turtles, largetooth sawfish, goliath and Warsaw groupers, as well as the charismatic and threatened manatees and whale sharks.

Why Do We Measure It?

The status of focal or "flagship" species is often indicative of the condition of many other flora and fauna that rely on similar habitats. A decline in threatened species (e.g., whale sharks or manatees) signals a potentially significant reduction in overall biodiversity for the region. Such losses may result in direct economic losses as well, through accompanying decreases in tourism value.

At least one large marine vertebrate has become extinct in the last 50 years: the last Caribbean monk seal sighting was recorded in the 1950s in Seranilla Bank, between Honduras and Jamaica[2].

How Do We Measure It?

Manatee abundance is estimated by aerial surveys and direct observation.

Sea turtles are monitored by counting nest abundance on beaches.

Doug Perrine

Benchmark

No population decline from current levels. Assessments of sawfish and goliath grouper undertaken on a regional scale.

Target

Stabilize populations to a level warranting removal from the IUCN Red List. For managed species (e.g., manatee, hawksbill turtle), targets should meet stated management goals. For threatened species without management plans (e.g., whale shark, goliath grouper, sawfish), the target is to have the regional abundance of each species double over the next 20 years.

Red Flag

Any increase in manatee strandings.

More than 10% reduction in turtle nests in a single year or consistent decrease for 2-3 years.

Any consistent (2-3 year) decrease in whale shark abundance at aggregations.

Whale sharks are visually counted at aggregation sites in Belize and Mexico during aggregation periods. They can be tagged with visual, acoustic or satellite tags.

Goliath and Warsaw groupers and sawfish numbers are too low to sample with traditional means. These populations are monitored by surveys of fishermen's catches.

Usefulness

"Charismatic megafauna" is how conservationists often refer to the large, exciting animals, many of whom now waver on the verge of extinction, capturing the attention of the general public with their plight. The focal-species indicator is highly relevant to assessments of reef health, as the functional importance of biodiversity is well recognized and supported by the general public. The species discussed in this profile are not all-inclusive, as all of the red-listed species should be monitored and conserved.

Sensitive focal species that inhabit a variety of habitats can also help "monitor" these habitats remotely: if an important habitat is failing, then its focal-species populations will be ailing as well. Manatees, for example, use a variety of habitats (freshwater rivers and lakes, seagrasses, mangroves and coral reefs), so they are important indicators of habitat integrity. The endangered hawksbill also uses different reef habitats for different life stages. (For example, adults roam reefs, forage on sponges and nest on beaches, while juveniles roam the open waters of the pelagic zone.) Whale sharks display a strong fidelity to Belize's Gladden Spit spawning aggregation site, although they have been tracked throughout the entire region from Yucatan to Honduras.

The plight of high-level predators and iconic species (like goliath groupers and sawfish) can be valuable tools to inspire the public to engage in conservation efforts.

Some focal species are difficult or expensive to monitor. Aerial surveys, for example, are expensive, as are surveys in remote areas.

Status

At least 27 MAR marine species (not including birds) have earned a spot on the IUCN Red List: 15 species are listed as Vulnerable, six as Endangered, five as Critically Endangered, and one as Extinct (see Appendix 3).

Regional manatee abundance was estimated (1998) at approximately 1200 individuals, with 6-12 manatees along the Yucatan coast, 250 in Chetumal Bay at the Mexico–Belize border, 400-900 in Belize, 22-106 in Guatemala and 120-140 in Honduras[9].

The current, extreme vulnerability of Caribbean hawksbills is demonstrated by the recent, sharp decline in hawksbill nestings in the Yucatan Peninsula, Mexico[9]. This area had 6,400 nests in 1999 (representing 43% of all nests reported for the Wider Caribbean), but numbers plummeted to fewer than 2,400 by 2004. This drop represents a 63% decline in five years, in the largest population in the Atlantic basin and one of the four largest nesting beaches in the world[10]. The records of the nesting season of 2005 suggest that the decline may have stopped[11]. The fact that the cause of the decline remains unknown, despite great investments over 30 years in nest protection throughout the nesting range in the Yucatan, is alarming[11]. The most important nesting beaches in Guatemala (Punta de Manabique) and Belize (Manatee Bar) have also experienced declines. The manatee bar nesting beach had well over 100 nests in the mid-1990s but had only 65 in 2005[12].

The population of whale sharks at Gladden Spit is transient and composed primarily of juvenile males. The minimum viable population level for this species is not known. However, their life-history traits (late maturity, longevity, low birth rate) make them vulnerable to overexploitation. Whale sharks are not exploited within the MAR region, but the full range of the MAR population is not known and this population may suffer from fisheries exploitation in other regions[13].

Additional information is needed on goliath groupers and sawfish. A combination of fieldwork and more than 154 fisherman interviews in Belize suggest a dramatic decline in abundance. Due to lack of consistent sightings or captures throughout Belize in the past 15 years, both the largetooth and smalltooth sawfish species are considered ecologically extinct (that is, their numbers are so small that they no longer have a significant ecological effect). They are also likely locally extinct in some areas[14].

Data Needs

Data on some focal (threatened) species are available at the national level, although such data are not often published or readily available to the public.

Manatee monitoring programs and sea turtle nesting beach monitoring programs are established in most areas.

Extremely limited monitoring data are available for goliath groupers and sawfish, although some efforts are underway in southern Belize. No data are available on Warsaw grouper, other than anecdotal stories of some catches decades ago.

A routine, regionally consistent monitoring protocol and reporting mechanism need to be implemented for all of these focal species.

Community Structure

Conservation Objective

Restore benthic community composition such that the relative abundance of corals and other calcifying organisms are sufficient to maintain reef accretion; minimize human activities that encourage macroalgal overgrowth; and minimize human activities that diminish reef rugosity or fish abundance.

Threats

Main threats include loss of habitat and nursery areas, overfishing, marine and watershed pollution, coral disease and bleaching, direct human impacts such as boat groundings, hurricanes, and global climate change. Nutrient enrichment threatens to increase algal and sponge abundance at the expense of corals.

Management Actions

- Reduce coral mortality caused by human activities (e.g., discharge of untreated sewage).
- Increase protection for key herbivorous fishes.
- Reduce illegal fishing and overfishing of commercial species.
- Strictly limit and control other destructive practices (e.g., marine dredging).
- Investigate opportunities to restore or enhance reef structure (e.g., restore damaged reefs, re-introduce herbivores, enhance coral-recruitment habitat, restore water quality and larval corridors).

WWF-Canon/Anthony B. Rath

The term *community structure* refers to the organization of a biological community — in this case, a coral reef — in terms of what organisms live there and in what quantities or proportions. Many complex factors, physical and biological, control a reef's community composition.

Fierce competition for limited "prime real estate" — especially between macroalgae and corals — is one of the most important determinants of benthic (sea bottom) community structure on a reef. An established, dense cover of macroalgae, sponges or turf algal/sediment mats greatly reduces the availability of the clean, hard substrate needed for coral recruitment and recovery. This substrate (space) limitation can have lasting effects on community structure and function, and can even threaten the very existence of reef frameworks.

Several case studies have documented an overall shift from coral to algal domination on many Caribbean reefs in the last few decades, including some in the Mesoamerican region. The patch reefs of Glover's Reef Atoll (Belize), for example, had approximately 80% coral and 20% macroalgae in 1971 but had shifted to about 20% coral and 80% macroalgae by 1996, followed by further declines in coral (to 13%) and increases in macroalgae (to 57%) by 2000[15].

Herbivorous and carnivorous fishes are the other key players in influencing a reef's community structure. If herbivorous fishes crop down fleshy macroalgae, then coral larvae have a better chance of settling and surviving on the reef.

Rugosity — a measure of the physical complexity of the reef surface — is also important. The physical "roughness" of the reef strongly influences — and is influenced by — the reef's community composition. Reefs with higher topographic complexity, for example provide diverse habitat for fish and other reef biota, and they generally support communities of higher biodiversity.

Indicators selected to track community structure include:

- S4 Coral Cover
- S5 Coral:Algae Ratio
- S6 Fish Abundance
- S7 Rugosity

Coral Cover
Coral:Algae Ratio

What Is It?

The general term *benthic reef cover* refers to the living organisms covering the reef surface. Coral and macroalgae are key components of benthic cover.

Benthic cover is often expressed in terms of the amount of living coral cover relative to other functional groups such as algae, sponges, dead corals, and other sessile (attached) invertebrates. Two closely related indicators are important in describing benthic cover:

(1) Coral cover — the amount of live stony coral tissue, and

(2) Coral:algae ratio — the proportion of live coral cover to macroalgal cover.

Why Do We Measure It?

Reef-building corals are the main contributors to a reef's three-dimensional structure — the structure that provides critical habitat for many organisms. Coral cover is therefore a good indicator of general reef health.

The coral:macroalgae ratio provides a good indication of "Who's winning?" in the ongoing competition for space between corals and macroalgae — a primary concern when looking at overall reef health.

A "healthy reef" can be characterized as one with a relatively high cover of live corals (for the habitat type); moderate levels of crustose coralline, calcareous and short turf algae; and low cover of fleshy macroalgae. A sign of an "unhealthy reef" is benthic cover dominated by fleshy macroalgae instead of live coral.

A shift from coral-dominated reefs to reefs dominated by turf and fleshy algae can lead to eventual loss of reef framework. Changes in the abundance of fleshy macroalgae and live coral cover may be a sign of human stressors at work, although it is difficult to distinguish among the many potential influences, including natural variability.

We are concerned about benthic cover in the MAR because there has been a drastic reduction in live reef-building coral, presumably due to a combination of factors. Likely candidates include disease, bleaching, hurricanes, overfishing, nutrient enrichment and other forms of pollution stress. Extensive loss of corals has resulted in a shift from coral-dominated reefs to reefs dominated by turf and fleshy algae—which can lead to coral loss, decline in reef structure and function.

Benchmark

An increase in the regional average coral cover of at least 5% in the next 5 years, with a coral:macroalgae ratio no less than 1.

Target

A 25-30% increase (vs. ~2000 levels) in coral cover over the next 10 years.

A 30-40% increase (vs. ~2000 levels) in coral cover over the next 25 years.

A coral:macroalgae ratio no less than 2.

Red Flag

Any decrease in coral cover of 5% or more in one year.

A coral:macroalgae ratio of 0.5 or lower.

How Do We Measure It?

Usually, a diver or snorkeler swims along a pre-defined transect, identifying and measuring organisms under the line, at specific intervals along the line, or sometimes videotaping the transect for later analysis. Details of each of these options are provided in the AGRRA protocol[16], MBRS protocol[17], and other publications[4,18].

Alicia Medina / WWF

Coral and macroalgal cover are typically expressed in terms of their relative proportions (in relation to each other and other functional groups). Benthic cover can be analyzed in various ways — from a single coral cover measurement to multivariate analysis of multiple biotic classes[4].

Usefulness

Coral cover is one of the most commonly measured parameters in reef monitoring programs. It is used to assess the status of the reef-building corals and is the end result of all reef processes (e.g., competition, herbivory, mortality, reproduction).

The Mesoamerican Barrier Reef System (MBRS) Project's Synoptic Monitoring Program and the AGRRA program use an accepted line transect method to measure coral and macroalgal cover[16,17]. The transect method requires training in species identification but is cost-effective and relatively easy to use. Video-based monitoring offers the advantage of producing archive imagery and enabling more transects and data points to be collected in a single dive, but these benefits are offset by the cost of the video equipment (US$2500), possibility of equipment failure, decreased taxonomic resolution (especially of algae) and added time required for image analysis. Relatively large sample areas are usually required.

Including crustose coralline cover and other functional benthic components strengthens, but also complicates, the analysis. Full-community multivariate analysis is complex and moderately difficult to interpret — especially without comparable historical data — but has more power to distinguish among various influences than do single measures of coral cover.

Coral cover is naturally highly variable from reef to reef, due to factors such as latitudinal location, depth and wave energy. Thus, directly diagnosing the causes of coral cover decline is often difficult. Comparing across similar habitats is important in distinguishing natural from human stressors.

Although changes, particularly in macroalgal cover, can be rapid, coral cover is not an "early warning sign" of adverse changes in reef health, since the coral death has already occurred, often in a gradual, even insidious, manner.

Coral cover can be an effective management and communications tool as it is easy to understand. However, it is often difficult to see an immediate response in coral cover related to management actions because most Caribbean corals grow very slowly. Changes in coral and macroalgal cover are also influenced by numerous abiotic factors and processes not directly under the control of local managers.

Status

On a regional scale, AGRRA surveys (1999-2001) found an average of 14% live coral cover, with 15% cover on fore reefs and 11% on reef crests[19]. These values are consistent with other regional and large-scale (Belize) assessments, but are lower than the AGRRA Caribbean average (20% for all habitats, or 26% on forereefs)[6,19,20,21]. The average coral cover for MBRS synoptic monitoring sites (Belize and Mexico, all habitats, 2004/05) was 23%[21].

Significant loss of coral cover occurred after the decline of acroporids (staghorn and elkhorn corals) and the die-off of *Diadema* sea urchins in the 1980s[22]. Bleaching events in 1995 and 1998, along with several hurricanes (notably Hurricane Mitch in 1998), caused additional punctuated declines in coral cover[6].

Macroalgal abundance (from the same AGRRA dataset) in the MAR region averages 25%, with higher amounts on fore reefs (27%) than reef crests (19%)[16]. The MAR value is lower than the Caribbean value (34% for all habitats). However, the MBRS Synoptic Monitoring Program (SMP) found 35% macroalgal cover (Belize and Mexico, all habitats, for 2004/05)[17].

Data Needs

Several datasets are available from site-level surveys within the MAR, but are difficult to compare due to different methodologies, habitat types, and depths. Semi-historical baseline data are available (ca. 1980s) for the MAR and Caribbean.

A large-scale AGRRA survey was conducted across the MAR in summer 2006 and will complement other routine monitoring programs, most of which are focused on marine protected areas (MPAs).

We recommend that a concerted effort be made to synthesize existing and historical data, to reconstruct historical baselines and trends, particularly prior to 1960. Special effort should be devoted to tracking down hard-to-get data, such as that found in masters' theses, and to conducting a large-scale, historical meta-analysis.

Future revisions of this indicator profile may include crustose coralline algae coverage as a third parameter in the ratio, given the importance of this taxon as a facilitator of coral recruitment.

S6 PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

Fish Abundance

What Is It?

Fish abundance is a count of the number of fish in a given area. Fish abundance data can be presented in terms of total fish abundance or in terms of the abundance of key species or guilds. Size is an important ancillary measurement, as abundance and size together can be used to calculate fish biomass.

Two useful indicators for the MAR ecoregion are:

(1) Total fish biomass, and

(2) Commercially significant fish biomass.

For more information about parrotfish biomass, see indicator F11 – Herbivorous Fish Abundance.

Benchmark

No decrease from current MAR-wide averages for total fish biomass (~4600 g/100m^2) or commercial fish biomass (~1100 g/100m^2).

Target

At least a 20% increase in total fish biomass (to ~5520 g/100m^2 MAR-wide average) and commercial species biomass (to ~1300 g/100m^2). Consolidation of an ecologically representative, well-managed, regional MPA network.

Red Flag

MAR-wide fish biomass averages (for all habitats) that fall below ~ 4100 g/100m^2 total fish biomass or 1000 g/100m^2 for commercial species.

Why Do We Measure It?

Total fish biomass is indicative of trophic structure and overall reproductive output. Commercially significant fish biomass can be used as an indication of overall status of fish stocks, fishing pressure, habitat conditions and recruitment success.

Fish populations are characterized in order to understand changes in community dynamics and to help identify human impacts, such as overfishing and habitat destruction. Intense fishing directly affects fish populations by eliminating organisms (especially large-sized individuals), reducing spawning potential and decreasing larval recruitment.

"Healthy" reefs should have intact fish assemblages (no depleted functional groups), which are integral to the functioning of coral reefs.


Shalini Cawich / WWF

How Do We Measure It?

The AGRRA protocol (which is also used in the MBRS protocol) calls for a diver to swim along 10 belt transects (2 meters wide and 50 meters long) at each site, estimating the number and size ranges of certain fish species[16,17]. Surveys count key fish species that (a) play an important role in reef ecology (e.g., herbivore, carnivore), (b) are commercially important (e.g., all snappers and groupers), or (c) are likely to be affected by human impacts (e.g. commercial species, and those species that depend on mangroves, like the rainbow parrotfish). Fish size and density (number of fish per unit area) are measured for thirteen key families and species. (See Appendix 3 for a list of the thirteen key families and species.)

Usefulness

Tracking the abundance of fish assemblages on the reef is a core element of any monitoring program. Fish surveys must be carefully planned. Fish biomass can vary with habitat characteristics, depth, recruitment, and fishing pressure. Many commercial species have

Wolcott Henry

larger home ranges and move reef to reef. Therefore multiple, representative surveys are needed. Different survey methods may be needed for species with different behaviors and life histories (e.g., groupers, which tend to be more cryptic).

Fish surveying techniques are moderately cost-effective, requiring approximately the same amount of time to collect as benthic cover data. Surveyors need training in consistent fish identification and size estimation, with routine re-calibration and consistency training for the surveyors.

Rachael Graham

Status

AGRRA data indicate that total fish biomass in the MAR region averages 4618 g/100m^2, with an average of 4459 g/100m^2 on fore reefs and 5009 g/100m^2 on reef crests. The MAR average is lower than the Caribbean value of 6367 g/100m^2 [19].

Biomass of commercially significant fish in the MAR region averages 1083 g/100m^2, with 1175 g/100m^2 on fore reefs and 857 g/100m^2 on reef crests. The MAR average is lower than the Caribbean value of 1493 g/100m^2.

Data Needs

A region-wide AGRRA survey is currently underway (2006). The new data are for representative reef habitats and will complement data previously collected by other site-specific programs largely focused on MPAs (e.g., local monitoring programs and the MBRS Synoptic Monitoring Program).

A comprehensive database and meta-analysis are needed to synthesize existing information.

S7 Rugosity

What Is It?

Rugosity is a measure of the "ruggedness" or topographic complexity of the reef surface. One expression of rugosity (among many) is given by the maximum reef relief. In this book we use the terms "rugosity" and "maximum reef relief" interchangeably.

Reef relief is defined as the distance between the tallest coral or reef rock and the lowest point on the reef substratum[16]. Thus this is different than measuring the overall extent of the reef's structural development (e.g. a hard bottom versus high-relief spur and groove which would be measured down to the sand floor off of the reef substrate).

Why Do We Measure It?

A reef's structural complexity affects how the reef functions. Reefs provide shelter and microhabitats for many organisms. The spatial distribution of reef organisms is often closely related to a reef's rugosity. Branching corals and massive species (e.g., *Montastrea faveolata*), in particular, give a reef higher rugosity and complexity than most other, smaller corals.

Reefs that are more structurally complex provide a wider variety of habitat (although a higher rugosity may not equate directly to overall better health). Loss of habitat complexity has direct impacts on numerous plant and animal inhabitants and associated productivity.

How Do We Measure It?

We recommend using the AGRRA methodology, which entails a diver making five quick measurements along the same 10-m transect lines used for studies of benthic cover[16]. The diver measures the reef height – that is, the distance from reef top to reef bottom. (Reef bottom in this case refers to the base level at which corals grow. Measurements should not include the lower sand valleys in spur-and-groove systems). This metric of "maximum reef relief" is measured as the difference (in centimeters) between the highest and lowest points within a one-meter radius of established intervals along the benthic transect line, as in AGRRA.

Benchmark

No reduction in current MAR-wide average rugosity values by habitat.

Measurable increase in rugosity in shallow reefs impacted by recent hurricanes.

Target

To be developed after additional data are acquired.

Red Flag

To be developed after additional data are acquired.

Usefulness

Rugosity is a useful indicator of overall reef structure.

As an indicator of reef structure, rugosity is not an early warning signal. However it can provide a useful tool in assessing damage from human (e.g., boat groundings) or natural (e.g., hurricane) events. Rugosity varies naturally with reef type (i.e., some reefs have low complexity and are 'healthy'). Comparisons among different reefs should take into account different habitat types.

Reef relief (i.e., distance between highest and lowest point along a transect line) is quick and easy to measure and can be done over small and large spatial scales, although some resolution of microhabitat complexity may be lost.

Status

Overall, the status of MAR reef rugosity is considered fair because it is an "average" of the "poor" state of rugosity at shallow reefs (low rugosity due to widespread coral breakage during hurricanes), and the "good" state (high rugosity) at deep fore reefs[19].

For shallow reefs, the Caribbean average for rugosity (AGRRA maximum reef relief) is 72 cm. Reefs in Mexico (64 cm) and Belize (49 cm) are below the Caribbean norm[19]. Shallow reefs throughout the MAR region were affected by the 1998 bleaching event and catastrophic hurricane (Mitch) that killed, flattened and even removed many corals.

For deeper fore reefs, the Caribbean norm (66 cm) is less than the norm for Mexico (92 cm) and Belize (97 cm)[19].

Honduras reef crests and fore reefs show a similar pattern, with decreased rugosity on shallow reef crests and higher rugosity on fore reefs, although these reefs had some of the highest mortality after the 1998 events.

Data Needs

Ongoing AGRRA surveys and data from the MBRS SMP will provide additional rugosity data that are more representative of the entire region and across all reef habitat types.

Melanie McField / WWF

Abiotic

Conservation Objective

Maintain water quality conditions that support healthy, sustainable coral reefs, mangrove forests and seagrass meadows.

Threats

Main threats are primarily associated with coastal development (including direct impacts from sewage contamination and urban run-off and indirect impacts of vegetation clearing along the coast), deforestation, agriculture, aquaculture, mining and dredging. Some of these processes also mobilize contaminants. Rising sea surface temperatures and ocean acidification, attributable to increasing atmospheric CO_2, are of growing concern.

Management Actions

- Reduce sediment and contaminant runoff due to agricultural practices or coastal development.
- Prohibit clearcutting of mangrove forests.
- Monitor coastal development projects to ensure water quality standards are not violated.
- Improve the treatment and disposal of human sewage.
- Reduce marine pollution (e.g., from oil tankers, cruise ships).
- Reduce the use of toxic chemicals that can adversely affect coastal areas (e.g., pesticides).
- Investigate opportunities to restore or enhance water quality (e.g., restore natural drainage patterns or replant deforested areas).
- Reduce activities contributing to global climate change.
- Develop and implement methods to better track water quality in the region.

Abiotic (that is, non-living) factors strongly influence life on a coral reef. Reefs require highly specific environmental conditions, and corals, in particular, have adapted to relatively narrow ranges of light, temperature and substrate type. Reef development begins with settlement of reef-forming organisms on a pre-existing hard surface in shallow, warm, well-illuminated water.

Many abiotic factors are important in controlling modern reef distribution. Small-scale controls influence organisms at a reef-wide level (e.g., light). Intermediate-scale controls function within ocean basins and include physical oceanographic factors (e.g., current patterns). Large-scale controls act on a global scale and long time periods (e.g., sea level rise).

Some human activities can alter abiotic conditions in ways that stress reef biota. For example, dredging a shipping canal may "stir up" sediments that block light from reaching corals on the sea bottom. These sediments can also smother or abrade the corals and inhibit larval recruitment. Leaky septic tanks release nutrients that interfere with calcification, disrupt the coral-algal symbiosis and promote the growth of benthic algae at the expense of corals.

Indicators selected to track abiotic factors are:

S8	Water Quality: Temperature, Salinity, and Transparency
S9	Ocean Color (remote sensing)
S10	Sedimentation Rates

Sergio Hoare / WCS

Note on the absence of nutrient data in indicators of water quality:
We have not been able to locate any long-term (> 2 years) routine (weekly) monitoring data for nitrogen and phosphorous within the region. Quite possibly some exists but we have not been able to access it. Numerous one-time surveys have occurred, but without routine time series capturing the full range of seasonal and climatic variability these data do not give enough information to interpret the status of nutrients. Nutrient levels would need to be evaluated on a site-specific basis as deviations from norms (standard values for each parameter) over the full range of seasonal variation. Even if frequent, consistent data were to be collected, there are the additional problems associated with the sensitivity of the instruments needed to take accurate measurements in waters with relatively low nutrient concentrations (compared to other marine ecosystems) and with the rapid biological uptake of these nutrients into phytoplankton. Once the nutrients are taken up by phytoplankton, or even cycled into zooplankton, they are no longer in the dissolved inorganic form (and thus not measurable as such). However, there are important changes in trophic dynamics (favoring filter feeders like sponges versus autotrophic feeders like corals) that result from changes in plankton concentrations fueled by nutrient enrichment. Thus, it is the measurement of the associated decrease in water clarity or transparency (S8) and chlorophyll pigment within phytoplankton as seen from satellite remote sensing as "ocean color" (S9) that we suggest can be more feasibly and accurately measured over the long term on the scale of the MAR, and can serve, in some regard, as a proxy for nutrient concentrations.

S8

Water Quality:
Temperature, Salinity, Transparency

What Is It?

Water quality, as an indicator, refers to the physical, chemical and biological properties of the seawater bathing the reefs. Three key parameters important to reefs and associated ecosystems are: water temperature, salinity, and water clarity (or transparency).

Why Do We Measure It?

Reefs depend on highly specific environmental conditions, and corals and many of their inhabitants have adapted to tolerate relatively narrow ranges of these conditions. Water quality has declined in several areas in the MAR, affecting reef habitat, critical nearshore nursery habitats and feeding areas. Chronic (long-term) declining water quality can eventually exclude reef growth altogether.

Optimal coral growth occurs when water temperatures are 25-29 °C. Monthly averages that exceed 0.5 °C above the historical average for that month are likely to result in coral bleaching.

In some nearshore areas, salinity and water clarity can serve as indicators of fluvial (river) run off, which may also contain contaminants (nutrients, metals, chemicals) that are more difficult to measure. Inorganic nutrient inputs are rapidly taken up by phytoplankton, thus water clarity can serve as a proxy for nutrient concentration. Optimal coral growth generally occurs at salinities of 34-37, but more site-specific 'norms' could be developed for specific areas within the MAR, based on actual long-term data collection.

Measures of water transparency can be used to characterize light penetration through the water column. Light is essential for the symbiotic zooxanthellae that provide the corals with much of their food. The intensity of light reaching the sea bottom affects the coral's growth and nutrition, and ultimately the depth to which coral reefs can exist.

Benchmark

Temperatures between 25 and 29°C.

Salinity between 34 and 37.

Water clarity – norms to be developed for different classes of reefs.

Following a general guide: 35% of incident light reaches 5-m depth for inshore reefs, and 60% of incident light reaches 5-m depth at offshore reefs.

Target

Monthly average temperature values no greater than 0.5°C above historical monthly average for that month.

Salinity values not in excess of 34-37.

For water clarity: No net decrease in "baseline" water transparency (to be determined after more data are available).

Following a general guide: ~35% of incident light at 10 m depth for inshore reefs; 60% of incident light at 10 m depth for offshore reefs.

Red Flag

To be developed.

How Do We Measure It?

Temperature measurements are relatively easy and inexpensive to obtain with small recorders that can be deployed for months of automatic and frequent recording. Temperature data loggers are inexpensive (US$200) and can be used in most reef monitoring efforts. Remotely sensed (satellite) sea surface temperature data are freely available on the Internet.

Salinity measurements are usually made with a handheld refractometer (US$150) or a conductivity sensor.

Water clarity can be assessed using a Secchi disk (a circular black-and-white disk attached to a calibrated rope: (cost US$100) or a turbidity sensor and logger.

Usefulness

These basic water quality indicators are very important for inclusion in long-term monitoring programs at well-established monitoring sites, where routine measurements can be taken (or using automated stations).

Temperature can be a good early-warning indicator — useful for coral-bleaching rapid response actions. Temperature fundamentally influences most physiological processes.

Salinity, possibly in conjunction with water clarity, can be used as an easy-to-measure indicator of fluvial influence on some reef areas. In areas not subject to surface runoff, these parameters may be used as a proxy indicator for groundwater influence, with lower salinities (and possibly lower water clarity) indicating higher fluvial or groundwater influence.

Water clarity is a very simple, yet very telling indicator. The clarity of the water is the main factor determining the amount of light that reaches the seafloor, supporting all plant communities and autotrophic animals (e.g., corals). Water clarity is affected by the amount of plankton biomass (largely determined by nutrient concentrations), the amount of sediment suspended in the water (determined by run-off from land or resuspension from the seabed due to weather or human disturbances like dredging), and finally the amount of colored dissolved organic matter (largely determined by decaying organic matter from land or mangrove areas). Although it will be impossible to distinguish among these causes, it does clearly and simply indicate the summation of these factors that ultimately determine how much light reaches the corals at various depths.

The simpler methods for measuring water quality parameters are feasible and cost-effective. However, the frequency and consistency of measurements made by humans *in situ* is often inadequate to discern any meaningful patterns given the high variability (even on daily or weekly time frames). Automated stations with an array of instruments are more costly ($\geq$ US$25,000) and require maintenance, but provide much more consistent and frequently collected information.

Status

NOAA HotSpots maps, derived from remotely sensed (satellite) temperature data, indicate that the years 1995, 1998 and 2005 were particularly warm in the MAR[24]. These years also experienced the most extensive coral bleaching events.

Data collected from the automated station at the Smithsonian Institution research station on Carrie Bow Caye, Belize, include approximately 49,000 data points a year for each parameter measured (recording every 10 minutes)[24]. (See Appendix 3 for a sample product).

Data Needs

No regional water quality database is available for the Mesoamerican Reef. A variety of single-site datasets likely exist, but these data have not been compiled and most are not easily accessible for any regional synthesis.

Water quality data are collected at several sites in the MAR, including some MPAs and additional sites within the MBRS Project Synoptic Monitoring Program. An automated meteorological and oceanographic monitoring station at the Smithsonian Institution's lab on Carrie Bow Caye in Belize monitors these three parameters and several others, with the data fully available on the Internet (see Appendix 3 for details). Other data may be available (but need to be consolidated) from other research stations in the MAR (like in Puerto Morelos, Mexico; Glover's Reef, Belize; and Cayos Cochinos, Honduras). Some of these research stations collect water quality data as part of the Caribbean Coastal Marine Productivity (CARICOMP) network of sites[25]. More sites throughout the MAR need to be regularly monitored and data compiled into a database.

NOAA temperature data (maps) from satellite measurements are available, including a reference site near Glover's Reef, Belize. However, specialized data processing would be required to calculate meaningful averages by subregion in the MAR.

Salinity contour maps were produced for Belize in 1975, but have not been updated since[26].

Additional water quality monitoring efforts and a coordinated data sharing mechanism are needed throughout the MAR. Of particular interest would be data sufficient to discern long-term trends. In addition, water quality monitoring should be included with coastal development projects and watershed management projects.

Recent evidence suggests that the oceans are becoming more acidic (pH is going down) due to absorption of anthropogenic carbon dioxide (CO_2) from the atmosphere — a process that will make calcification by corals and other organisms more difficult[27]. A region-wide (or better yet, Caribbean-wide) specialized oceanographic survey of the chemical properties of the open ocean and reef-associated waters should be conducted to establish a baseline for monitoring the extent of any future changes. The equipment, precision, and expertise required, however, make these measurements more suitable for a single regional research cruise (possibly run every 5 to 10 years) versus an indicator to be collected by many different organizations on a more routine basis.

S9 Ocean Color (remote sensing)

Benchmark

No net increase in average ocean color (chlorophyll concentration) or the severity of seasonal peaks.

Target

To be developed.

Red Flag

To be developed.

What Is It?

Ocean color, in the context of this indicator, refers to a satellite-derived characterization of the color of ocean waters.

The ocean color seen by the human eye or by a satellite sensor is influenced by the concentration and composition of colored materials suspended near the ocean surface. Clean, open-ocean waters typically appear bluish, for example, while nearshore waters, rich in chlorophyll, often have a greener hue.

Satellite ocean color data are often given in terms of chlorophyll concentration.

Why Do We Measure It?

Ocean color measurements provide a way to study large-scale patterns in the distribution of chlorophyll and other pigments, ocean primary productivity and global biogeochemistry.

Ocean color can be used to track the movement and evolution of waters colored by chlorophyll (from phytoplankton), colored dissolved organic matter (CDOM) and suspended nearshore sediments. Ocean color data can also be used as a proxy for nutrients, which fuel the growth of phytoplankton and are associated with colored material (sediment, detritus) from fluvial sources.

Researchers are now working to develop methods for using ocean-color data not just in open-ocean waters, but in more challenging coastal areas as well. Nearshore applications include the monitoring of phytoplankton blooms, which can be associated with red tides and can be fueled by large-scale runoff of nutrients[28].

Because coral reefs normally thrive in shallow, clear waters, they present a special challenge and a special opportunity for using satellite-derived ocean-color measurements. Eventually, such measurements might be useful as one "red flag" indicator of water quality and even of potential red tides, which threaten some fisheries, marine mammals and human health. (See indicator SW3 – Cholera and Other Diseases).

How Do We Measure It?

Specially designed, satellite-mounted sensors are used to estimate remotely sensed ocean color. NASA's SeaWiFS and MODIS sensors provide quantitative data and maps on global ocean bio-optical properties[29,30]. Special data processing is sometimes required to use these data in nearshore environments. Several programs focusing on the coastal environment are underway, and real-time data are readily available on the Internet[31].

Usefulness

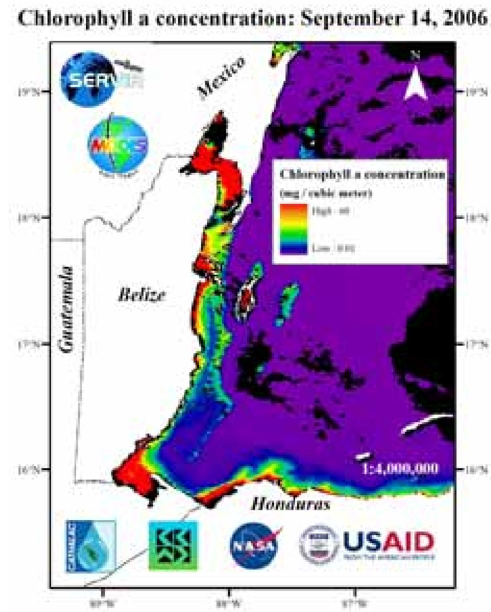
Ocean color data can contribute to our understanding of connectivity, sedimentation and nutrification of coastal areas. More information is needed to determine the feasibility of using this information at regional scales in nearshore environments. The MAR region has an exceptionally low percentage of usable satellite images, due to the frequent cloud cover and fires (smoke) that obscure a satellite's view of the ocean waters.

Status

SeaWiFS imagery showed that terrestrial runoff from flooding caused by Hurricane Mitch (1998) in Honduras reached offshore coral reefs at Glover's Reef in Belize[32].

Development of shallow-water algorithms (data-processing methods) is underway in several universities and in conjunction with the International Coral Reef Action Network (ICRAN) Mesoamerican Reef Alliance. Preliminary data from this project show a pronounced seasonal trend in ocean color, probably associated with rainfall and fluvial runoff. The Gulf of Honduras region peak values for colored dissolved matter are 2.2 times higher than average values for the rest of the year, and the northern coast of Honduras approximate peak values are 2.4 times higher than average[33].

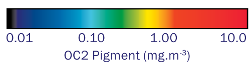
SERVIR (Mesoamerican Regional Visualization and Monitoring System) provides real-time data and video animations of ocean color (chlorophyll concentrations) based on MODIS/Aqua data[31].

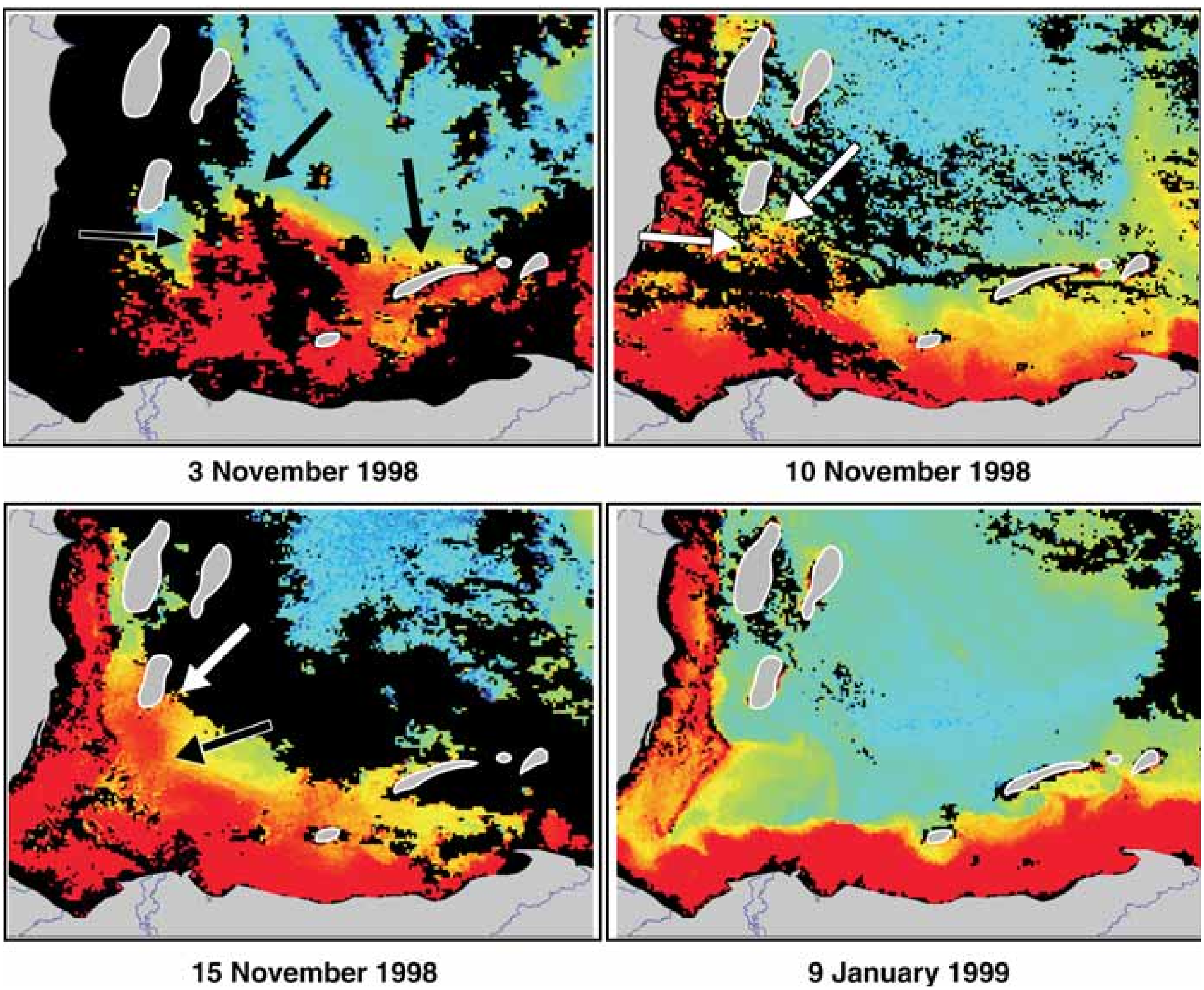


Source[31]

Data Needs

Methods for using ocean color data in coastal areas are in the developmental stage with established oceanographic researchers. Regional training in data collection, analysis, validation and output production should be offered to enable technicians in the region to use SeaWiFS and MODIS data for monitoring fluvial runoff and processes affecting ocean color. We need to raise public awareness of the existing capacity and products readily available on the SERVIR website[31].





Source[32]

ABIOTIC S9

S10 Sedimentation Rate

What Is It?

Sedimentation refers to the process of depositing sediments (solid fragments of inorganic or organic material, such as sand or mud) onto the seafloor.

This process is usually quantified in terms of the amount of sediment accumulated over some specified area during some specified period of time (for example, 5 mg of sediment per cm^2 per day).

A sedimentation rate of 10 mg/cm^2/d is often cited as a general rule-of-thumb threshold for deleterious effects on corals[34]. Sensitivity to sediment accumulation varies among coral species. Small-polyp species and corals with plate-like growth forms are often more susceptible to the lethal effects of high sedimentation.

Benchmark

Average sediment deposition rates less than 10 mg/cm^2/d.

Target

To be developed. At a minimum, should meet the benchmark values.

Red Flag

Average sedimentation rates above 10 mg/cm^2/d for more than two consecutive sampling intervals.

Why Do We Measure It?

As stationary, benthic (bottom-dwelling) animals, corals have a real problem when excessive sediments fall on their surface, interfering with phytosynthetic and active feeding activities. Most corals can produce mucus to trap and slough off sediments, but this has an energetic cost to the coral.

Sediment accumulation and resuspension are natural processes that can be affected by anthropogenic activities (e.g., dredging operations, coastal land clearing) and also by natural weather events (e.g., storms, cold fronts). High rates of sedimentation can reduce coral growth rates, species richness, and zonation patterns of corals and even seagrasses.

Some reefs (containing more sediment-tolerant species) do exist in areas of high sedimentation. An abrupt change in sedimentation rate, lasting for an extended period, is likely the most problematic to coral reefs or species not accustomed to higher rates of sedimentation.


Lisa Carnes

High sedimentation rates can be indicative of stressful conditions on the reef, potentially associated with changes in land use (e.g., deforestation, agriculture and aquaculture) or marine dredging operations. Many pollutants (pesticides, fertilizers, heavy metals) can be associated with these sediments, resulting in additional perturbation of the benthic marine life.

How Do We Measure It?

Researchers use sediment traps (often PVC tubes) to collect particles raining down through the water column onto the reef. The trapped particles are then dried and weighed. Sometimes the particles are separated into different particle types or size classes. By knowing how much time it took to collect a certain amount of sediment, analysts can calculate the rate at which particulates are accumulating on the reef.

The MBRS SMP details a methodology for monitoring sedimentation rates[17].

Usefulness

Sedimentation rate data are fairly easy and inexpensive to collect using basic lab equipment. Data collection and analysis require a moderate investment of time.

Sedimentation data can be especially useful when used to monitor for effects of a specific activity (e.g., dredging operation, shrimp trawling, high-volume snorkeling or diving activity). The sampling design should include both impact and control sites (unaffected but physically similar sites) and should be initiated before the activity begins and continue at least several months after the activity ends (for periodic events like dredging or pier construction).

Status

A variety of different monitoring sites are needed to provide representative data on sedimentation rates in the MAR. However, some insight into the variability of these data within one site (the Hol Chan Marine Reserve, in Belize) is illustrated by a small study (covering four 2-week intervals of measurement in 1992).

Ten sediment traps were deployed around the highly visited reef near the channel and in the adjacent back reef. Average sedimentation rates were approximately 4 - 11 mg/cm^2/day, although a maximum of 58 mg/cm^2/day was recorded in one sediment trap. High variability was also noted among the ten traps during each sample period, possibly related to their proximity to highly trafficked areas along the regular snorkeling routes[35].

Data Needs

No regional data are available at present. We recommend establishing a meta-database of all such data collected in the MAR, possibly through the MBRS Synoptic Monitoring website.

Some site-level data should be available, although there is little such information in readily accessible publications. Some sedimentation rate data have been collected through the MBRS SMP and several other groups. A regional synthesis and meta-analysis of these existing data would be useful. Additional study sites and a longer time-series of data are likely needed to establish regional reference values.

Data from sedimentation and resuspension studies should be analyzed in conjunction with complementary water transparency data.

Melanie McField / WWF

Melanie McField / WWF

Habitat Extent

Conservation Objective

Determine the extent and condition of coral reef, mangrove and seagrass habitat; develop methods for tracking change; develop a target for the limits of acceptable change; and minimize losses due to direct human actions.

Threats

The main threats to coral reef habitat are coral disease, coral bleaching, competition from macroalgae and sponges, hurricanes, effects of overfishing, pollution (including sedimentation and nutrification), direct removal or damage, and global climate change. The greatest threats to mangrove and seagrass habitat are direct losses associated with coastal development or other land alteration, plus freshwater flow alterations that adversely impact water quality.

Management Actions

- Develop a regional GIS database of habitat maps; develop refined remote-sensing techniques to monitor habitat extent regularly.
- Prohibit direct removal of coral reef, mangrove or seagrass habitat during coastal development projects.
- Reduce sediment and contaminant runoff associated with agricultural practices or coastal development.
- Investigate opportunities to restore or enhance habitat extent or quality (e.g., replanting mangroves or restoring linked habitats).
- Develop regional program to survey regulatory compliance of coastal development projects (i.e., aerial surveys).
- Investigate and map historical habitat distributions.

Habitat extent refers to how much area a given habitat, such as a mangrove forest, covers. If there is too little of a particular habitat (or if it is divided up into too-small pieces or is too far removed from other, functionally related habitats), the existence of some coastal organisms or even other habitats may be threatened.

Coral reefs, seagrass beds and mangrove forests form a complex and dynamic mosaic that provides critical foraging areas and nurseries, plus physical and chemical buffering. Proximity and connectivity among these environments facilitates energy and material flows, creates corridors for transient species and provides critical habitat for many reef species at a variety of developmental stages.

Coral reefs dissipate wave energy, thus providing environments suitable for seagrass and mangrove colonization. Seagrasses and mangroves stabilize sediments and take up nutrients, helping to sustain the clear, low-nutrient waters in which corals thrive.

Seagrass beds and mangrove forests also provide critical habitat for the juvenile life stages of many commercially important reef fish and invertebrates (e.g., lobsters). The rainbow parrotfish, a key reef herbivore, depends on nearby mangroves and seagrass meadows for nursery habitat, as do grunts, barracuda and several snapper species.

These critical linkages among habitats can be broken by direct habitat destruction or by more subtle coastal degradation, and the ecological consequences may not be immediately evident. It is important to monitor regularly the extent and connectivity of key coastal habitats.

Indicators selected to track habitat extent are:

S11 - Coral Reef Areal Extent

S12 - Mangrove Areal Extent

S13 - Seagrass Areal Extent


Melanie McField / WWF

S11 Coral Reef Areal Extent

What Is It?

Coral reef areal extent is a measure of the area (e.g., hectares or km^2) covered by coral reef habitat. (This measure is not the same as the measure of percent living coral cover on the reef.)

Sites of extensive reef development include the Belize Barrier Reef and atolls, Sian Ka'an and Banco Chinchorro Biosphere Reserves in Mexico, and the Bay Islands in Honduras.

Why Do We Measure It?

Measurements of the areal extent of coral reefs tell us, first and foremost, just how much sea bottom is covered by coral reef habitat. This measure is a key indicator of habitat extent and can provide an indication of how much habitat is still available versus how much has been lost (when historical data are available).

Large-scale disturbances, like hurricanes or massive coastal developments, can result in the loss of entire coral reefs.

There has been a significant loss of live, reef-building corals in the MAR. Dead reefs with intact structure still provide viable habitat, but without net reef accretion they will eventually erode or be washed away by storms.

Benchmark

No decrease in current coral reef extent.

Target

Any increase in coral reef extent.

Red Flag

Any decrease in current coral reef extent.

How Do We Measure It?

Remote sensing (by satellite or aircraft) can be used to estimate and track coral reef areal extent. Conversion of satellite images into habitat maps is a technically complex process often occurring in well-established university centers. In order for data to be fully comparable, the same processing methods and decision rules need to be applied over the entire region and during the full time series of the analysis. Data are normally entered into a GIS format where they are readily accessible for a variety of uses.

Usefulness

Satellite- or aircraft-derived reef habitat maps are very useful when selecting field monitoring and sampling sites, allowing representative sites within each habitat class to be chosen.

When data are collected at more than one point in time, these data can also be used to track changes in the areal extent of reefs, although large discrepancies can occur if standardized image processing and decision rules are not followed.

The Millennium Coral Reef Mapping Project is producing maps that are based on a standardized method of classifying and comparing reef types[36].

Satellite data are not, however, able to differentiate live versus dead coral, or coral versus algae. As a result, a totally dead reef might still be mapped as reef habitat. The maps will need to be ground-truthed and, as needed, corrected.


WWF-Canon/Anthony B. Rath

Status

The areal extent of coral reef habitat has not been fully estimated in the MAR region (with a consistent methodology and ground-truthing of data) although some regional datasets have been created from various national and local mapping projects[37]. This database cataloged 96 km^2 of emergent reef crest within the MAR, but did not attempt to classify all reef areas.

The Reefs at Risk Caribbean assessment was derived by WRI from a variety of sources including 30 m Landsat data classified and converted to shapefiles, and digitized maps and charts converted to a raster format (500 m resolution). This dataset found 2,315 km^2 of coral reefs in the MAR. The breakdown by country includes 511 km^2 in Mexico (22%), 1,422 km^2 in Belize (61%) and 383 km^2 in Honduras (17%)[38].

The Millennium Coral Reef Mapping Project has produced a preliminary global map of coral reefs, based on geomorphology. Their assessment currently includes unverified reef classes (including sparse coral communities and some areas that should not be classified as coral reefs).

Data Needs

Detailed habitat maps are available for Belize and some of the Bay Islands of Honduras and many areas in Mexico. However, these maps are not directly comparable due to differences in the classification schemes.

A current analysis is ongoing to standardize reef classification for the region and to estimate coral reef areal extent based on the Millennium Coral Reef Maps. The Millennium maps are now being ground-truthed and analyzed in more detail through the 2006 AGRRA assessment (organized by The Nature Conservancy, World Wildlife Fund and the Healthy Reefs Initiative).

We recommend that a regional protocol for mapping reefs be established. Once a regional estimate of coral reef extent is available, subsequent estimates can be made for comparison every five years or after severe disturbance events (e.g., hurricanes).

S12 MANGROVE AREAL EXTENT

PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

What Is It?

Mangrove areal extent is a measure of the area (e.g., in hectares or km^2) covered by mangrove vegetation. Key species include *Conocarpus* sp. (buttonwood mangrove), *Laguncularia* sp. (white mangrove), *Rhizophora* sp. (red mangrove) and *Avicennia* sp. (black mangrove).

Expansive mangrove habitats can be found along much of the MAR's mainland coastline as well as in many of the coastal lagoons, watersheds, and offshore cayes (islands).

Why Do We Measure It?

Mangroves have a significant ecological role as physical habitat and nursery grounds. Mangrove ecosystems are a mosaic of different types of forest, with each providing different physical habitat, niches, microclimates and food for a diverse assemblage of animals.

Mangrove forests are undergoing dramatic changes in the Mesoamerican Reef region. Some forests are being cleared for commercial development and residential land uses. Others have been extensively damaged by hurricanes.

Mangrove habitat extent is a key indicator, tracking how much of this critical habitat is still available versus how much has been lost (when historical data are available).

Cinthya Flores / WWF

BENCHMARK

No net decrease in current mangrove habitat. Any losses should be offset by natural growth or restoration projects.

Priority conservation areas need to be identified and formally protected.

TARGET

Restore mangrove cover to 1990 levels.

RED FLAG

Any decrease in current mangrove area.

How Do We Measure It?

Remote sensing (by satellites or aircraft) is used to estimate the areal extent of mangrove forests.

Usefulness

Remote sensing provides an up-to-date, efficient way to track the change of mangrove forests over time. Keeping track of these changes is essential for sustainable coastal forest management, ensuring the many ecological benefits of mangroves are maintained.

Landsat satellite images provide relatively inexpensive and consistent coverage of the entire MAR for annual monitoring programs, although data processing time must also be considered. There are a number of regional programs (e.g., CATHLAC) already working with these data. Aircraft-based sensors have greater spatial resolution for detailed needs, ground-truthing, or monitoring of areas of high development pressure, major construction projects, etc., but the cost is generally higher.

Status

There are approximately 3,500 to 3,650 km^2 of mangrove forest within the MAR ecoregion[37]. This estimate is based on a compilation of various national habitat maps rather than a regionally consistent protocol. The compilation relies on Landsat satellite imagery from different years, different processing protocols, and some data from digitized maps where processed satellite data were not available.

Based on World Wildlife Fund's (WWF) ecoregional assessment (primarily based on Landsat images from the late 1990s) the breakdown of mangrove cover by country within the MAR ecoregional boundary is as follows[37]:

- Mexico: 2,247 km^2 (64%)
- Belize: 812 km^2 (23%)
- Honduras: 405 km^2 (12%)
- Guatemala: 39 km^2 (1%).

Data Needs

Regionally consistent data, including historical baseline data from approximately 1990, need to be analyzed and made available.

We recommend: 1) regularly tracking mangrove forest extent, using a regionally standardized assessment protocol, 2) sharing information in a readily assessible database, and 3) basic monitoring by remote sensing coupled with field-based ground-truthing.

Canon/Anthony B. Rath / WWF

S13 SEAGRASS AREAL EXTENT

What Is It?

Seagrass areal extent is a measure of the area (e.g., hectares or km^2) covered by seagrasses. Extensive seagrass beds are found throughout the MAR on most shallow platforms (approximately < 15 m).

Why Do We Measure It?

Seagrasses are highly productive, faunally rich and ecologically important ecosystems that often act as a transitional zone between mangrove and coral reef communities. Seagrasses provide critical nursery and breeding habitat for commercial fish and invertebrates, help stabilize sediments, reduce beach erosion and promote water clarity. Productivity is the main process of concern. Overall extent, density and diversity (including the epiphytic community) are the primary structural components of health.

Measuring the areal extent of seagrass beds indicates how much of this critical habitat is available. When measurements are available for more than one point in time, we can track how much valuable seagrass habitat has been lost or gained.

Seagrasses in the MAR region have been damaged by dredging operations, prop scars and poor water quality.

BENCHMARK

No net decrease in the extent of seagrass from current levels.

TARGET

No decrease in extent, or restoration to 1990 levels.

RED FLAG

More than a 5% reduction in area in any subregion's annual or biennial assessment, compared to that subregion's previous survey.

How Do We Measure It?

Remote sensing (by satellite or aircraft) can be used to estimate the areal extent of seagrasses, in a process similar to the one used for coral reefs and mangroves.

Melanie McField / WWF

Usefulness

Remote sensing provides an up-to-date and efficient way to track the change of seagrasses over time. The same Landsat or other satellite images that are used to measure the extent of coral reefs and mangroves can be used to map seagrasses. A region-wide analysis protocol is needed to accurately compare the extent within subregions (or countries). The same image-processing standards and decision rules need to be followed in subsequent analyses to allow accurate temporal comparisons.

Status

Maps and areal estimates are available for some locations, including all of Belize. The Belize Coastal Zone Management Institute data (based on Landsat images from the early 1990s) indicate that approximately 48% of the shelf area (continental shelf plus atolls) is covered by seagrass, an extent of approximately 4957 km^2 [39].

No regional estimate of total areal extent of seagrasses is currently available.

Data Needs

Regionally consistent seagrass maps are not yet available, but The Nature Conservancy (TNC) has recently completed a regional analysis that is scheduled to be released soon.

The regional extent of seagrass habitat needs to be determined and tracked on a regular basis for the entire MAR.

Melanie McField / WWF

WWF-Canon/Anthony B. Rath

Ecosystem Function Indicators

The term *ecosystem function* generally refers to the many critical processes that control interactions among ecosystem components — especially the flows of things like energy (food) and genes.

A consideration of coral reef ecosystem function might include questions like these:

- How many baby corals took up residence on the reef recently?
- How severe is coral bleaching on the reef (or, how many corals have kicked out the partner algae that feed them)?
- How many bioeroding worms and sponges are living on and in the reef, munching it to bits like termites?
- How many urchins live on the reef, cropping down the macroalgae that compete with corals?

Many human activities can inadvertently disrupt "flow" processes such as these, but the effects on function may not be readily visible. Sometimes the first noticeable signs of disruption are cascading effects on structural components.

For example, it may not be so easy to see the disruptive process of overfishing the plant-eating parrotfishes. But divers can see visible changes in reef community structure when corals can no longer compete successfully against the macroalgae that the fished-out parrotfish would have been eating: a rugged, rainbow mosaic of coral transforms to a monotonous carpet of greenish-brown fuzz.

The fifteen *Healthy Reefs for Healthy People* Ecosystem Function indicators (F) focus on four key areas to help monitor reef processes: reproduction and recruitment, coral condition, reef bioerosion and accretion, and herbivory (Table 7.b).

Table 7.b. Functional Indicators.

Attribute	Indicator #	Indicator
Reproduction & Recruitment	F1	Coral Recruitment
	F2	Fish Recruitment
	F3	Coral Size Frequency
	F4	Fish Size Frequency
Coral Condition	F5	Coral Mortality
	F6	Coral Disease
	F7	Coral Bleaching
Reef Accretion & Bioerosion	F8	Coral Growth
	F9	Bioeroders on Coral
	F10	Reef Accretion
Herbivory	F11	Herbivorous Fish Abundance
	F12	*Diadema* Abundance
	F13	Fleshy Macroalgal Index
	F14	Fish Bite Rates
	F15	Green Turtle Abundance

Reproduction and Recruitment

Conservation Objective

Maintain or restore conditions optimal for coral and fish reproduction and recruitment; preserve pathways of larval connectivity and minimize actions that disrupt them.

Threats

Main threats are diseases, coral bleaching, algal overgrowth, competition and predation, overfishing and unregulated fishing, hurricanes, pollution (including sedimentation and nutrification), direct removal or damage, and global climate change.

Management Actions

- Reduce sediment and pollution runoff associated with agricultural practices and coastal development.
- Fully protect all spawning aggregation sites.
- Severely restrict marine dredging operations.
- Reduce production of (and clean up existing) marine pollution.
- Reduce destruction of mangrove, seagrass and coral nursery areas, protecting migration and larval corridors.
- Reduce illegal fishing and destructive fishing practices.
- Improve management of existing marine protected areas.
- Reduce activities contributing to global climate change.

Reproduction and recruitment are among the most critical processes governing reef communities. *Reproduction* refers to the process by which organisms produce new offspring. *Recruitment* refers to the successful addition of individuals to some defined group (e.g., a specific population of parrotfish).

For many corals and fishes, the ability to replenish their populations depends on linkages between their larval source and nursery areas. Some reef species rely on local currents to help retain or return locally produced recruits. Other species rely on upstream and sometimes distant areas as sources for larvae. These linkages are not well defined, and they may vary from year to year.

Coral reef, mangrove and seagrass areas serve as necessary habitat for many reef species at various developmental stages. These habitats also serve as corridors for transient species.

For many larger, commercially important reef fishes such as groupers and snappers, spawning aggregations (that is, temporary gatherings of fishes that have migrated specifically to reproduce) are critical. Fishing of these vulnerable aggregations reduces the overall reproductive success of these species. In the Caribbean Sea, the Nassau grouper has been especially hard-hit.

An additional challenge to reproduction and recruitment of reef corals and fishes is terrestrial runoff. Runoff from land can decrease water quality and introduce chemicals that may negatively impact reef organisms (e.g., chlorpyrifos reduces coral settlement)[1].

Loss of key environments may be reducing the overall recruitment success of some fish and invertebrate species in the MAR. Protection of spawning sites, restoration of nursery habitats and reduction of pollution can all help ensure reproductive success on the Mesoamerican Reef[2].

Indicators selected to track reproduction and recruitment are:

F1	Coral Recruitment
F2	Fish Recruitment
F3	Coral Size Frequency
F4	Fish Size Frequency

F1

Coral Recruitment

Benchmark

(Very Preliminary) No decline from 2000 values: Regional average of 3 recruits per m² (for recruit size < 2 cm)

More data are needed on settlement rates (i.e., plate data).

Target

(Very Preliminary) On par with ~2000 Caribbean average: At least 4.5 recruits per m² (for recruit size < 2 cm).

More data are needed on settlement rates (i.e., plate data).

Red Flag

(Very Preliminary) A regional average of less than 3 recruits per m² (for recruit size < 2 cm).

What Is It?

Recruitment is the process by which planulae (tiny, swimming "baby corals") establish themselves as members of the reef community. Coral recruits are typically quantified in terms of the number of small stony corals per unit area. ("Small" in this case is defined as up to 2 cm, although some studies have used up to 10 cm maximum diameter, depending on objectives.)

Coral planulae require specific conditions in order to settle and survive (i.e., recruit into the population). Areas with high recruitment potential tend to have abundant crustose coralline algae and little fleshy macroalgae.

Recruitment rates ("success" rates) depend upon the number and species distribution of reproducing adult corals; their fecundity (ability to produce offspring); survival of the larvae (planulae) during their open-ocean swimming phase; linkages between larval sources and settlement sites, which depend in part on poorly understood, small-scale current patterns; and larval survival after settlement, which depends in part on habitat conditions.

Corals under stress may have lower reproductive output and/or lower recruitment rates. Examples of potentially stressful conditions might include high partial coral mortality, disease, coral bleaching, contaminants (e.g., heavy metals, agrochemicals or sewage) or physical abrasions from storms and hurricanes.

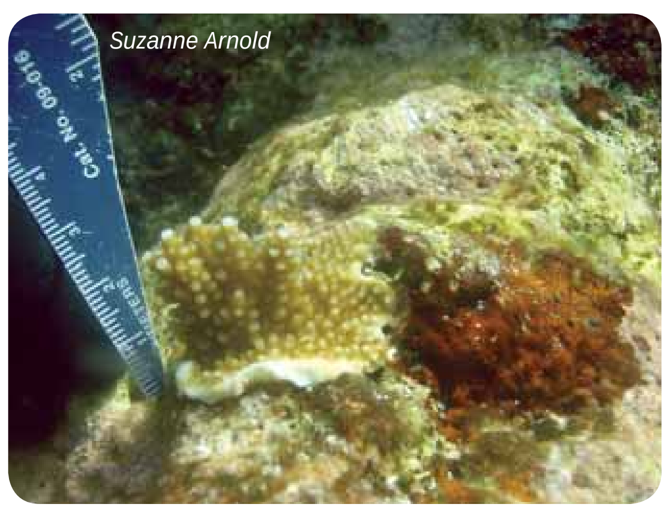
Why Do We Measure It?

Recruitment is one of the most critical processes governing reef communities. The abundance of recruits is an important indication of a reef's potential for growth and recovery after major disturbances. Recruitment also includes particularly sensitive life phases (i.e., macroalgae and contaminants interfere in settlement). Healthy reef ecosystems depend on replenishment of populations and connectivity among reefs.

How Do We Measure It?

Most recruitment data for the MAR region are based on the AGRRA method[3]. To quantify coral recruits, a diver counts the number of stony coral recruits (up to 2 cm maximum diameter) within a 25 cm x 25 cm quadrat placed every 2 meters along a 10-meter transect line. This method generally covers approximately 3 m² per site. Other studies have used larger (50 cm x 50 cm) and more numerous quadrats or belt transects to attain the minimum recommended sample area per site[4,5,6].

Some researchers in the region (e.g., the Global Environment Facility (GEF) / World Bank Targeted Research & Capacity Building Program) are using settlement plates (square tiles that offer larvae a well-defined place to "land") to study recruitment rates[7].



The MBRS protocol, in which clay tiles are attached to a PVC array, includes a detailed method for monitoring with settlement plates[8].

Usefulness

Coral recruitment is a critical component of ecosystem health, particularly during times of reef recovery from major disturbances (as we are now experiencing in the MAR). Recruitment studies allow us to look to the future.

The monitoring methods require a moderate to high level of expertise to correctly identify the small recruits. Some training has been offered by the Global Environment Facility (GEF) / World Bank Targeted Research & Capacity Building Program to expand their data collection effort.

Suzanne Arnold

Settlement plates provide more information on initial settlement patterns (especially smaller class sizes) than do studies of recruitment onto natural reef substrate. However, plate studies often require a greater commitment of time, expertise, and money. Under the MBRS protocol, recruitment is a Level II (more difficult) indicator, and few MPAs have found time to include it.

Measuring recruitment on the natural reef substrate provides a more realistic picture of recruitment success than do plate-based studies. Studies on natural substrate include the effects of natural mortality levels, which are influenced by the site's benthic community structure (particularly the amount of macroalgae and crustose coralline algae).

Status

The average number of small ($\leq$ 2 cm maximum diameter) recruits in the MAR averaged 3 recruits per m^2, with the highest value of 14 recruits per m^2 observed at Long Caye, Lightouse Reef, Belize. The MAR average is slightly lower than the Caribbean average (4.5 recruits per m^2)[9].

MAR fore reefs had slightly more average recruits (3 recruits per m^2) than did reef crests (2 recruits per m^2). Most coral recruits were brooding species, such as agaricids. (Brooders produce planulae that settle relatively close to their "mother colonies.") Recruits of major reef-building corals were rare or absent[9].

Melanie McField / WWF

One study on a Glover's Reef Atoll patch reef reported a 53% decline in coral recruits and a corresponding 48% decline in coral cover between 1998 and 1999, following the 1998 coral bleaching event[10]. The low recruitment density in 1999 was attributed to a loss of corals (existing recruits in 1998 and larger mother colonies), potentially reduced fecundity resulting from bleaching and scouring stress from Hurricane Mitch, and increased macroalgae.

The 2006 regional AGRRA assessment greatly adds to the regional pool of data available on recruitment.

Data Needs

No recruitment data are yet available from the MBRS Synoptic Monitoring Program. Additional financial and personnel support are needed to assist MBRS sites in monitoring this Level II component. Settlement-plate data from the GEF Targeted Research program should soon become available. These data will greatly enrich the overall understanding of settlement and recruitment in the MAR.

Additional analysis is needed to understand patterns of minimally viable recruitment levels, connectivity patterns, and processes controlling recruitment success in the MAR. Habitat-specific reference values need to be developed, possibly for each subregion of the MAR, based on an increased number of sampling sites and regional meta-analysis.

Virtually no data are available from settlement plate studies in the MAR.

F2

Fish Recruitment

What Is It?

Fish recruitment can be defined in two ways:

- One definition refers to the number of young-of-year fish entering a population in a given year.
- The second definition refers to the size at which a fish can be legally caught, or the size at which a fish becomes susceptible to a particular fishing gear.

Why Do We Measure It?

Fish recruitment can indicate the status of a fish population, especially for important commercial species like snappers and groupers. It can also be an indicator of overfishing (when the average size declines and/or all of the larger fish are missing).

Fish populations are influenced by the source of larvae and can be larvae-limited, particularly if adult fish populations have declined, if connectivity between populations has been disrupted, or if nursery areas have been degraded or lost.

In other words, recruitment data will reflect the influence of many different processes.

How Do We Measure It?

Fish recruitment can be monitored by setting special traps, such as fish larvae light traps.

Recruitment can also be expressed in terms of juvenile abundances, from counts taken along one-meter-wide belt transects. These transects can be the same ones used for adult fish, as detailed in the MBRS Synoptic Monitoring protocol[8]. Taxonomic distinctions in juvenile fish are difficult. Thus, a small subset of species is counted in the MBRS protocol, with variable maximum sizes for each species recruits (2 - 5 cm)[8].

Usefulness

To be determined. A high degree of training and technical expertise are required to identify fish recruits accurately.

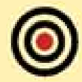
Status

Baseline data for fish recruitment were collected under the MBRS Project´s Synoptic Monitoring Program at 43 monitoring sites throughout the MBRS region. These data are available on the Project website. Few other data are available although a large research effort is underway (details under Data Needs).

Benchmark

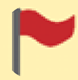
To be developed.

Target



To be developed.

Red Flag



To be developed.

Data Needs

Several research programs are currently underway that will help to fill the gaps in our understanding of the status of fish recruitment in the region and will help further develop this indicator. Notably, the GEF Coral Reef Targeted Research and Capacity Building (CRTR) Program has a component on Large-Scale Ecological Processes, Recruitment and Connectivity, chaired by Peter Sale, University of Windsor, Canada, which is conducting research on fish recruitment within the region[11,12].

Melanie McField / WWF

F3 Coral Size Frequency

What Is It?

Coral size refers to the overall size of an individual coral head — a measurement that is not entirely straightforward, given the variety of shapes and irregularity of many coral species. Size can be characterized in terms of colony maximum diameter, perpendicular width, and height (*x*, *y*, and *z* dimensions).

Three useful metrics can be calculated from these measurements:

(1) average coral size (average maximum diameter) — used in AGRRA until 2005, but now being replaced by the more accurate:

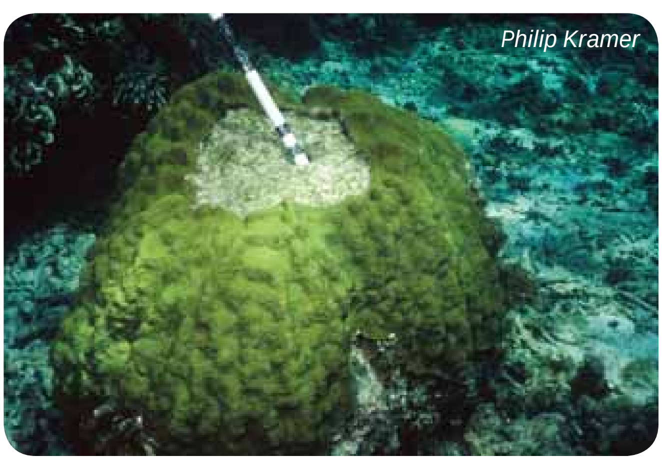
(2) average coral volume (including maximum diameter, perpendicular width and height), and

(3) coral size frequency distributions (i.e., numbers of coral heads in different size classes according to either maximum diameter or volume measurements).

Why Do We Measure It?

Coral size is used as a proxy for colony age, helping us to track general coral population dynamics. Scientists often use colony size rather than age for population-level studies of colonial organisms like corals, as size tends to correlate more closely with probabilities of mortality and natality (birth rate) than does age in these populations.

Size frequency distributions, based on coral size estimates and abundance, can be used to infer characteristics of mortality, regeneration and survivorship. Coral size can often be measured even after a colony dies, thus providing the ability to hindcast previous populations' size structures (e.g., acroporids).



Benchmark

No decrease in average coral size (maximum diameter) from ~2000 values of 55 cm on fore reefs and 98 cm on reef crests.

Target

To be developed — including size frequency distribution targets by species.

Red Flag

(Preliminary) Average coral size of < 45 cm (maximum diameter) on fore reefs, < 80 cm on reef crests.

High densities of large colonies ("old growth" stands) suggest low disturbance or favorable growing conditions.

How Do We Measure It?

A variety of methods can be used to measure coral size. Most data from the MAR region (AGRRA, MBRS) rely on a diver to measure head size by using a 1-meter PVC bar marked off at 10-cm intervals. Each coral head encountered along a 10-m transect is characterized in terms of its maximum diameter (*x*), width (*y*) and height (*z*)[3,8].

The most basic and commonly used metric of average coral size is the maximum diameter (*x*). This parameter is measured directly, and is simply averaged by each species or for the general coral population at a site by pooling all species from that site.

The somewhat more accurate coral volume measurement of size is currently being developed, but will entail incorporation of the three-dimensional measurements into a volumetric equation that may differ for different growth forms (e.g., plate, head, branching).

Size frequency distributions can also be constructed for each species by summing the number of corals within each size class (with size classes being binned at 10- to 20-cm intervals for maximum diameter measurements). Size frequency data from two or more sites may be combined in order to attain an adequate sample size for each species (minimum of 50 coral heads per species).

Usefulness

Coral size is easy and inexpensive to measure, but consistency training is required for data collectors.

First, it is important to define and distinguish an individual colony. Here, a colony is defined as any free-standing coral skeleton that is identifiable to genus level (preferably to species level) based on the presence of living tissue or identifiable corallites.

Coral size varies naturally by coral species, reef type, depth and disturbance history. Coral colonies are susceptible to partial mortality and bioerosion, which may affect size estimates. Some species are able to retain their size "signature" longer than other species (e.g., species with dense skeletons). Average coral size is not an early warning signal and may not change immediately after a disturbance.

As corals grow larger, they may be exposed to disturbances that result in partial mortality (that is, in tissue loss that exposes coral skeleton). Partial coral mortality can result in isolated tissues reducing the apparent original size of a colony. (For more information, see indicator F5 - Coral Mortality). Alternately, fusion of separate colonies of the same species can result in an apparently larger coral size.

Shalini Cawich / WWF

Details for dealing with these issues are provided in the AGRRA methodology and in training sessions that all data collectors should attend.

The single "average size" parameter provides an adequate proxy for the coral's age, provided one accounts for variations in growth in different species. A more comprehensive equation for average size estimates is currently being developed by the AGRRA partnership.

Size frequency data provide a population charcterization that integrates over a relatively long time frame. On a typical reef, these data will include measurements of corals that are less than a year old and corals that are more than 100 years old.

Status

The average coral size (maximum diameter) in the MAR is 60 cm[9]. The MAR average is similar to the average Caribbean value (61 cm – maximum diameter). MAR reef crests tend to host corals of larger average size (98 cm). Average size on fore reefs is considerably smaller (55 cm)[9].

Recent disturbances (1998 disease and bleaching) resulted in the loss of many large corals (e.g., *Montastraea* spp.). Recovery of these corals has not been observed, nor has replacement by other corals.

Fewer large corals are present on reef crests now versus several decades ago, due to the loss of large elkhorn corals in the 1980s, recent bleaching events (e.g., 1995, 1998) and hurricanes (e.g., Mitch in 1998)[9,13].

Data Needs

The 2006 regional AGRRA survey included three-dimensional data (*x*, *y*, and *z* planar measurements), which are being analyzed to develop appropriate calculations for volume measurements. This undertaking will greatly improve the quality of the data available on coral sizes, by adding the new volumetric measures.

Population models and size frequency distributions have not been developed for most coral species, thus making it difficult to develop projections of minimum viable population sizes.

More information on how pesticides and other potential contaminants affect growth, mortality and reproduction is needed.

F4 Fish Size Frequency

What Is It?

Fish size refers to the estimated length of a fish. Fishes are often grouped by size into the following size categories: : 0-5 cm, 6-10 cm, 11-20 cm, 21-30 cm, 31-40 cm and > 40 cm). Fish lengths can also be converted to biomass by using available conversion factors[14].

Why Do We Measure It?

Characterizing fish populations in terms of size can help us to understand changes in fish population dynamics and to identify human-induced influences such as overfishing and habitat destruction.

The abundance of large herbivores such as parrotfishes and surgeonfishes is a good indicator of potential herbivory. (Herbivory serves to reduce algal overgrowth and is discussed in more detail under F11 - Herbivorous Fish Abundance.)

Large groupers and snappers are used as indicators of the status of important commercial species and the effectiveness of fishing regulations. They are often the first species to show decreases in average size as fishing pressures increase.

Overfishing has resulted in a reduction of fish sizes, especially for species targeted during spawning aggregation events (e.g., Nassau and black groupers, mutton and cubera snappers). Removing large-sized individuals decreases spawning potential exponentially and has the indirect effect of reducing larval recruitment.

The exponential increase in fish egg production associated with increasing size is a well-established biological association that also applies to most invertebrates (e.g., lobster and conch)[15]. For example, a 40 cm grouper produces about one million eggs but a 100 cm grouper produces about 15 million eggs[16]. Thus, size does matter — bigger fish produce more eggs, and more eggs produce more fish. This is one of the primary benefits of fully protected marine reserves, the last refuges for most "Big Mamma" fish that are commercially exploited.

How Do We Measure It?

Divers count and measure key species encountered along ten transects (2 m wide by 30 m long) at each site. The fish are typically classified according to these (AGRRA) size categories: 0-5 cm, 6-10 cm, 11-20 cm, 21-30 cm, 31-40 cm, and > 40 cm)[3]. The method of data collection is the same as for Fish Diversity (S2), but with a focus on fish length or biomass rather than diversity of species. Key fish families and species in the western Atlantic are listed in Appendix 3, under Indicator S2.

Fish density (individuals per unit area) can be calculated from the count data. Density and size are in turn used to calculate biomass.

Benchmark

No decrease of average fish size.

Target

To be developed.

Red Flag

To be developed.

Usefulness

Measuring fish size is easy, rapid and inexpensive. Methods have been carefully standardized to ensure high data quality and to minimize artifacts associated with methodology.

Separating out carnivore density (using length classes or converting to biomass estimates) is considered to be a more sensitive indicator of the type of fishing pressure than is a measure of total fish size or biomass. Measures of total fish density (and biomass) tend to be more effective than looking only at carnivores in areas with very intensive overfishing.

Status

According to the AGRRA database, the size of most groupers in Belize and Mexico were in the 11-20 cm size class. No groupers larger than 30 cm were observed in the surveys[9].

Most parrotfish surveyed were also in the 11-20 cm size class, with none greater than 40 cm, indicating relatively high fishing pressure for these traditionally non-targeted species[9].

Data Needs

The MBRS Synoptic Monitoring Program has recently made data available online, including fish size data[17].

Data from a large-scale regional AGRRA assessment in 2006 should be accessible by summer 2007.

Fish size data representative of all reef types are needed across the region to establish a baseline from which to track change. The summer 2006 AGRRA region-wide survey complements local and MBRS SMP data.

Coral Condition

Conservation Objective

Maintain (or create) the environmental conditions (including fish populations, water quality characteristics, etc.) needed to support healthy corals, identify areas of high and low coral resilience. Develop strategies to minimize human impacts, particularly during times of disturbance (e.g. bleaching events or hurricanes). Longer-term goal: maintain or restore coral abundance to levels sufficient to maintain net reef accretion.

Threats

The main threats to corals are disease, bleaching, competition and predation, hurricanes, effects of overfishing of herbivores, pollution (including sedimentation, nutrification and contaminants), direct removal or damage, and global climate change.

Management Actions

- Develop an early-warning network for coral bleaching events in the MAR, plus a regional rapid response monitoring program.
- Severely restrict human activities that negatively impact coral condition (e.g., dredging, coastal construction near reef areas) during times of thermal stress in the late summer months and particularly during coral bleaching events.
- Re-evaluate MPA design and incorporate considerations of resiliency into planning.
- Reduce sediment and pollution runoff associated with agricultural practices, coastal development, and marine pollution — through the development and implementation of better management practices.
- Increase conservation practices, education, and environmental property management by implementing codes of conduct for marine recreation providers, hotels and cruise lines.
- Reduce human activities contributing to global climate change. For example, switch to 4-stroke outboard engines and invest in wind and solar power instead of generators.

Coral condition takes into consideration coral mortality (partial or complete), disease and bleaching. These conditions are affected by natural and human factors, and it is often difficult to tease out the effects of the various agents of change.

Corals can experience complete or partial mortality. As a result, their population dynamics are complex and not fully understood. The appearance of dead corals, both recent and old dead, offers the potential to hindcast when the corals died. Patterns of partial mortality are related to coral size, colony morphology, and the distribution and intensity of disturbances. Increased coral mortality has had obvious negative consequences for many important ecological processes in the MAR region within the last several decades.

Coral diseases seem to have been on the rise over the past ten years, and Caribbean reefs have been significantly impacted[18]. These diseases, which result in varying amounts of mortality, generally indicate a reduction in coral vitality, which is directly related to overall reef health.

Coral bleaching occurs when stressed corals eject the symbiotic, pigmented algae that normally live within the coral's tissues. Natural or background bleaching is often temporary, with corals regaining their algal partners — and therefore their pigmentation — after several weeks or a few months.

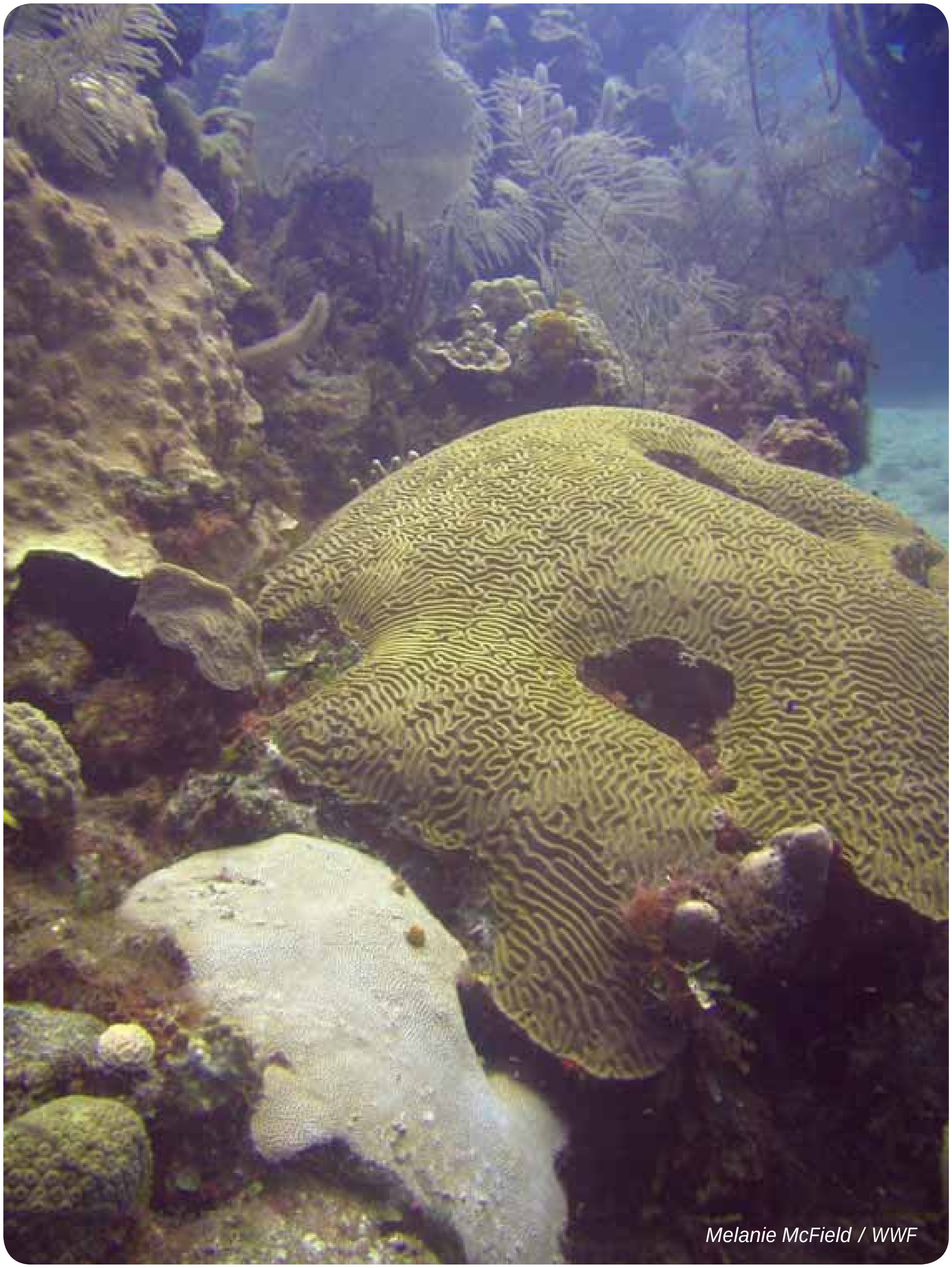
However, mass bleaching seems to have increased in frequency and severity recently and is of great concern. Severe prolonged or mass bleaching may result in partial or total mortality of a coral, reduced coral skeletal growth, a decline in reproductive output, and an inability to resist disease or compete successfully with algae or other invertebrates.

Following the 1998 bleaching event and damage from Hurricane Mitch, a strong linkage was observed between coral reefs that experienced severe bleaching and those that subsequently experienced disease outbreaks (approximately eight months later), with extensive coral mortality.

Over time, severe bleaching and disease can lead to a reduction in species diversity, coral cover and, eventually, loss of reef framework. Reef-building communities can eventually be transformed to alternate, non-reef-building states.

Indicators selected to track coral condition are:

F5	Coral Mortality
F6	Coral Disease
F7	Coral Bleaching


Melanie McField / WWF

F5

Coral Mortality

What Is It?

Coral mortality is the estimated percentage of a coral colony that is dead.

Corals are colonial animals that are unique in that they can experience partial tissue death and still remain alive. As corals grow, they are exposed to continual disturbances that may result in mortality of part of their colony (i.e., tissue loss exposing coral skeleton).

Partial mortality is separated into three categories:

• *Recently dead* refers to any non-living parts of the coral in which the corallite structures are either white and still intact, or slightly eroded but identifiable to species. Recently dead skeletons may be covered by sediment or a thin layer of turf algae.

• *Old dead* refers to any non-living parts of the coral in which the corallite structures are either gone or are covered over by organisms that are not easily removed (certain algae and invertebrates).

• *Standing dead* refers to colonies that are 100% dead, and identifiable to generic level based on colony morphology (e.g., *Acropora palmata*) or corallite character (e.g., *Diploria* spp., *Montastraea cavernosa*).

Small corals tend to have no or very low partial mortality, while larger colonies often have greater partial mortality. It is fairly common for corals to regenerate partial dead areas if the lesions are small enough (< 1 cm) relative to their remaining live tissues. However, corals may not regenerate new tissue if lesions are too large or too many. Certain kinds of injury may also preclude regeneration. Dead skeletal areas quickly become overgrown or eroded by algae or other bioeroding organisms.

Benchmark

MAR-wide averages of recent mortality <2% of a colony, old mortality <24% and standing dead <7%.

Target

Maintain MAR-wide averages of recent mortality below 2%, old mortality below 20% and standing dead below 5%.

Red Flag

Recent mortality above 5% exceeds the norm and is a signal of a recent disturbance.

Why Do We Measure It?

Corals die from both natural and human causes, and it is often difficult to discern between the two. It is very difficult to determine what levels of mortality are abnormal. However, establishing a baseline of partial mortality can assist in making this distinction.

High chronic or acute disturbance resulting in dead coral tissue may, depending on the extent of disturbance or tissue loss, prevent regrowth of new coral tissue or may invite invasion by other species (e.g., algae). Examples of chronic disturbance include competition and predation. Examples of acute disturbance include storms and bleaching events. Chronic high levels of mortality can potentially lead to reduced colony size, reproduction and fitness, plus increased susceptibility to other disturbances like disease. Total tissue loss can lead to population reductions and, in extreme cases, phase shifts in community structure or loss of habitat structure and function.

Being able to identify "hotspots" of recent mortality can allow managers to initiate proactive management responses. Recent mortality is a good indicator for distinguishing transient versus lethal effects resulting from significant recent disturbances like bleaching and disease events. Old mortality represents more of an integration of disturbance over time (including both chronic and acute). It is often difficult to distinguish causes of old mortality. Standing dead (100% old, standing dead colonies) is an important indicator of historical abundance and distribution.

In general, we expect a "healthy" reef will show little evidence of recent coral death (e.g., average < 3% of colony is recently dead). Reefs with high levels of recent mortality (e.g., > 5%) would indicate a major, recent (months to years) or current disturbance event. Reefs with many standing dead coral colonies, or those that have high old mortality (e.g., average > 30% of the colony is old dead), would indicate significant past disturbance events.

How Do We Measure It?

The most common way to estimate partial mortality of a colony surface is through visual observations from a planar view perpendicular to the axis of growth. Mortality for each colony is distinguished as "recent," "old," or "100% dead" and presented as a percentage. Details are given in the AGRRA and MBRS methodologies[3,8].

WWF-Canon/Anthony B. Rath

Usefulness

The use of partial coral mortality as an indicator of reef condition is well established.

Data on recent mortality are particularly useful in the first several months after major disturbances such as hurricanes or bleaching events. Such data help researchers gauge the ecological significance of these events.

The mortality signal can be lost or obscured due to such factors as bioerosion, hurricanes, algal overgrowth, predation and time elapsed since death.

A complicating factor is the variability in mortality signature among different species. For example, *Acropora palmata* (elkhorn coral) skeletons retain their colony structure long after death (up to 15-20 years), while other, less robust skeletons do not. As a result of this variability, mortality data may include an artifactual bias towards those species that retain their mortality signature.

Measures of partial mortality are relatively easy, inexpensive and quick to obtain. Training is required for data collectors, to ensure consistency and accuracy.

Status

The average recent mortality (1998-2001 AGRRA) in the MAR region averaged 2% (average percent of colony with recently dead tissue), which was similar to normal background levels reported for the Caribbean[9]. In a 2001 WWF survey, recent mortality averaged 1.7%, and ranged from a low of 0.2% (Coordillara, Sian Ka'an) to a high of 4.4% (Pelican Cay, Belize Barrier)[4].

Old dead in the MAR (1998-2001 AGRRA) averaged 24% and was higher on reef crests (32%) than on fore reefs (21%)[9].

The proportion of standing dead colonies in the MAR averaged 7%. Standing dead corals were more common on shallow reefs (24%) than on deep reefs (3%), due to high numbers of dead *Acropora palmata* in the shallow areas[9].

Data Needs

Additional regional AGRRA data are currently (2006) being collected across the MAR and will complement existing MBRS SMP data.

These data should be used to examine the ability of reefs to absorb disturbances, resist phase shifts and recover from disturbances. Causes of mortality need further examination—particularly the roles of contaminants, human-induced nutrients and the impacts of degradation or conversion of adjacent coastal and watershed habitats.

F6 Coral Disease

What Is It?

Coral disease refers to a negative deviation from a coral's normal state or condition. This deviation can include functional or structural impairment. Coral diseases are often characterized in terms of their identity (e.g., black band disease) and their prevalence (the percentage of total colonies affected).

Coral diseases can kill coral tissue quickly (up to 2 cm/day), which is much faster than average coral growth rates (~2 cm/year).

Why Do We Measure It?

Disease is a signal of coral stress and is a potential cause of mortality. This indicator is central to the concept of reef health, as health can be considered, in part, as the absence of disease.

Disease is an effective indicator of condition, particularly when combined with estimates of partial mortality and other measures of coral condition (e.g., remnant bleaching, predation, physical damage). Diseases have played a significant role in the widespread mortality of important reef-building species in the MAR over the last couple of decades.

The main concern is that coral diseases are infecting a greater number of coral species, increasing in frequency and distribution, and are spreading to new areas faster than previously observed. Increases in coral disease have been associated with increased sea surface temperatures and bleaching. It is still unclear whether bleaching causes corals to be more susceptible to opportunistic pathogens, or if pathogens normally present exacerbate levels of bleaching and bleaching-related mortality. Some coral diseases may be linked to human sewage and other contaminants, as well as increasing temperatures[30].

Ken Marks

Benchmark

(Preliminary) Yearly reports of disease incidence less than 3 to 4%.

Target

(Preliminary) Yearly reports of disease incidence of approximately 1% (or less).

Red Flag

Coral disease prevalence > 5% is of concern and should be monitored to track potential effects.

How Do We Measure It?

Disease prevalence is expressed in terms of the percentage of total colonies affected[3,8]. Since it is difficult to identify a specific disease, diseases are distinguished using color categories[21,22]:

- BB = Black band. Concentric/linear band, maroon to black, 1-30 mm wide.
- WB = White band (*Acropora* only). Exposes skeleton in a band advancing from the base toward the branch tips.
- WS = White pox (or spot), patchy necrosis (*Acropora* only). Irregular lesions on the top sides of branches, 5-10 cm diameter. Re-infection results in a mosaic of recently exposed and older, algae-covered lesions.
- WP = White plague. Denuded skeleton is intact. The disease front is a sharp line; no microbial community is visible.
- RB = Red band. Dense band, maroon to red, 1-25 mm wide. Less common than black band disease.
- YB = Yellow band, yellow blotch. Concentric pale yellow band, living tissue. Small spot in the center is recently killed and becomes large as the disease expands outwards.
- DS = Dark spot. Irregular dark patches of tissue. Surface is often slightly depressed.
- UK = Unknown.

Usefulness

Coral disease is an important signal of coral condition, often associated with visible tissue mortality. Susceptibility to specific diseases varies among coral species and with depth. Causes for most coral diseases have not been identified.

Coral disease is not an early warning signal, but disease occurrence can be extremely useful in enhancing our understanding of the relative causes of reduced coral cover.

Tissue mortality areas must be examined closely, as diseases can resemble other sources of mortality, particularly predation by snails and fish. Identifying a disease requires expertise, and field guides have been developed in an effort to clarify and standardize disease names[21,22].

Status

Coral disease prevalence varies year to year. In 2001, coral disease prevalence averaged 3% in the MAR (i.e., of the total colonies surveyed, approximately 3% were affected to some extent by disease). In 2000, it averaged 8%, with 9% prevalence on fore reefs and 4% on reef crests.

Following the 1998 MAR bleaching event, unprecedented levels of diseases and associated mortality were observed on *Montastraea annularis*, affecting 10-22% of colonies in many reefs[13]. White plague on fore reefs was especially notable and devastating. Disease prevalence varied by depth and latitude (which corresponds to the latitudinal gradient of excessive temperature and hurricane waves, both higher in the southern half of the ecoregion).

Disease prevalence in summer 1999 (percent of colonies affected) was:

Fore reefs: Honduras (10%), Belize (5%) and Mexico (3%);

Shallow reefs: Belize (6%), Mexico (3%) and Honduras (2%)[13].

Some localized reefs had very high disease incidence, reaching from 10 to 50% of corals infected (e.g., Bacalar Chico, Cay Caulker and South Water Caye, Belize; Utila and West End, Roatan, Honduras)[13].

The MBRS Synoptic Monitoring Program (Mexico and Belize, all habitats, 2004/05) had an average disease prevalence of 0.37% of colonies affected.

Data Needs

Additional information is needed on the causes of diseases and the long-term effects of disease on coral survivorship.

Little information is available to guide potential intervention during disease outbreaks. Additional strategies need to be developed to help minimize human impacts and proactively reach disease benchmarks and targets.

Melanie McField / WWF

Coral Bleaching

What Is It?

Coral bleaching occurs when the coral's symbiotic zooxanthellae (single-celled algae) are released from the original host coral due to stress (e.g., unusually high or low water temperatures, high or low salinities, or excessive sedimentation). The coral loses its pigment (color) when the pigment-rich zooxanthellae are expelled. Coral bleaching can be characterized in terms of bleaching intensity (e.g., pale to fully bleached) and extent.

Bleached tissue may appear white (translucent) or pale, but live polyp tissue can still be seen above the skeleton. Bleaching is not always uniform; it may result in a mottled appearance.

Corals are highly sensitive to changes in water temperature, with increases of only 1 to 2°C having potentially lethal effects. Temporary bleaching does not always kill coral polyps; they often regain their pigmentation after several weeks or a few months. However, polyps will die if the stress lasts for an extended period of time or is very severe.

Mass bleaching events — which are almost always associated with elevated sea surface temperatures (SST), sometimes in combination with elevated light levels (due to calm seas) — were unknown before 1979[23]. Human-induced global warming is believed to be responsible for recent increases in sea surface temperature, with prediction models for the next 100 years suggesting that the warming trend will continue and that bleaching events will become more frequent and more extreme[24].

Melanie McField / WWF

Benchmark

No mass mortality of corals (including disease outbreaks over six months after the event).

Target

No increase in the frequency of occurrence of large bleaching events (last decade had three events in 10 years in the MAR). This requires some acclimatization or adaptation of corals (or reef systems) to increasing temperatures.

Red Flag

Coral bleaching prevalence >10% (average % of corals exhibiting bleaching). Corals should be monitored for about a year after bleaching to track subsequent effects on mortality, coral cover, etc.

Why Do We Measure It?

Bleaching is an important signal of coral condition. We are most concerned with mass coral bleaching events related to elevated SST, especially because the intensity and frequency of such events have increased over the last decades and will likely continue to pose a threat.

Bleaching does not necessarily result in coral mortality. Corals can recover, depending on the severity of the bleaching. Bleaching can have the following non-lethal deleterious impacts: inhibition of the coral's ability to recover from small-scale tissue damage, increase in partial or total mortality, reduced reproductive success, and increased susceptibility to disease and other stresses.

Severe or prolonged bleaching may result in diminished reef growth and the transformation of reef-building communities to alternate, non-reef-building states.

How Do We Measure It?

Coral bleaching can be assessed in terms of degree of bleaching (percent of bleached tissue within each colony) and prevalence of bleaching (the percent of colonies affected by bleaching in a given area). These parameters can be calculated at the site or regional level (including all coral species in one reef-wide average) or calculated by species, at a variety of scales.

The degree of bleaching can be categorized by severity (e.g., AGRRA)[3,8]:

0 = No bleaching,

1 = Pale (discoloration of coral tissue),

2 = Partly Bleached (patches of fully bleached or white tissue), and

3 = Bleached (tissue is totally white, no zooxanthellae visible).

Bleached corals can be monitored for subsequent mortality or disease.

Usefulness

The coral bleaching signal depends on when observations are made (i.e., during or after an event). If a bleaching event is not monitored over time, it may be difficult to determine the extent of resulting tissue mortality. Coral bleaching varies depending upon coral species (e.g., some species bleach earlier, and some tend to stay bleached longer), water depth, reef type, physical environment (e.g., water clarity, proximity to a channel) and disturbance history.

Coral bleaching is not an early warning signal. However, NOAA HotSpot maps do provide a good alert to water-temperature conditions that may cause bleaching. (See Indicator D14 - Coral Bleaching Index). Coral bleaching may be a good indicator of climatic changes.

Status

The prevalence of coral bleaching will vary naturally year to year. In summer 2000, which was not a mass bleaching year, the average prevalence of bleaching in the MAR was 9%, with 11% bleached on the fore reef and 7% on the reef crest[9]. This level is approximately the amount expected for a non-bleaching-event year and may be related to a variety of smaller-scale stressors. However, the MBRS Synoptic Monitoring Program (Mexico and Belize 2004/05, all habitats) found only 2.5% colonies bleached.

The most significant mass bleaching events in the MAR occurred in 1995 and in 1998 with ~50% to 90% of corals bleaching in some areas[25,26]. Moderate bleaching (~30% to 40% of corals bleaching) occurred in some areas of the MAR in 2005[27].

Melanie McField / WWF

Data Needs

Coral bleaching data are available from the MBRS and AGRRA websites, along with various monitoring program reports and research publications, some of which may not be readily accessible in the region.

Although several monitoring programs assess coral bleaching in the MAR, we recommend developing a BleachWatch program, modeled on the existing programs in the Great Barrier Reef and Florida Keys[28,29]. These programs provide training, planning, and rapid response monitoring teams to track the progression of coral bleaching events (including any delayed mortality associated with coral disease outbreaks). This approach would provide regionally consistent data and a better indication of the impacts following a bleaching event. Collaboration and training could involve marine tour guides and divemasters, who can act as “first responders” to alert managers and scientists of signs of a bleaching event.

More research is needed on the response and adaptability of corals and their algal symbionts, bleaching effects on reproductive fitness and strategies of corals, and effects on calcification. Additional research is needed on the resilience of reef areas to coral bleaching, and these findings need to be incorporated into MPA design and management.

In order to develop better benchmarks and targets that encompass the ecological outcomes of bleaching, the resiliency and potential susceptibility of various areas need to be evaluated, and an index similar to the “LD50” index of toxicology studies needs to be developed for different levels of coral bleaching. Such an index would encompass the severity (degree of bleaching in each colony) and the prevalence of bleaching (percent of corals affected in an given area).

Reef Accretion & Bioerosion

Conservation Objective

To promote the environmental and ecological conditions that sustain reef accretion and the maintenance of reef frameworks for long-term viability. Identify areas and causes of high bioerosion (e.g., areas of nutrient enrichment) and implement mitigative measures.

Threats

Coral growth can be reduced by disease, bleaching, competition/predation, hurricanes, pollution (including sedimentation and nutrification), direct removal or damage, and global climate change. Nutrient enrichment from sewage and continental runoff (due, for example, to coastal development or agriculture) can increase bioeroders. Increased atmospheric carbon dioxide concentrations could lead to reduced coral calcification, which would further reduce reef accretion.

Management Actions

- Improve our understanding of bioerosion and reef accretion in the MAR.
- Eliminate sources of direct human impact, especially dredging and boat groundings.
- Restore coral abundance to levels sufficient to maintain net reef accretion.
- Re-evaluate MPA design to ensure reef accretion is incorporated into planning.
- Reduce runoff, especially nutrients associated with agricultural practices and coastal development (through better farm management and sewage treatment).
- Reduce human activities contributing to global climate change.

Reef accretion (that is, reef build-up or reef growth) occurs when reef framework (which is composed mostly of calcium carbonate) accumulates faster than it is eroded.

Processes contributing to reef accumulation include calcium carbonate deposition by reef organisms (e.g., corals), as well as lithification or submarine cementation (e.g., by coralline and calcareous algae). Processes contributing to reef erosion can be physical or biological. *Bioerosion* is the erosion of rock and skeletons by boring algae, sponges and other species that consume calcified materials.

Community composition is an important determinant of reef accretion — or non-accretion. If the community is dominated by non-calcifying organisms, such as fleshy macroalgae, reef accumulation may not be able to "keep up" with erosion. If a reef experiences a die-off of corals, coralline and calcareous algae, it may actually shift from a state of net framework construction to a state of net erosion.

Reefs in most areas must also grow fast enough, over the long term, to outpace not just erosion but also rising sea level. It is unclear whether projected rates of future sea level rise may outpace some slow-growing reefs.

If calcification rates decrease for some reason — for example, due to a detrimental change in water quality — a reef's ability to keep up with rising sea level may decrease; its susceptibility to bioerosion and physical damage may increase; and its community structure may change from calcifying to non-calcifying. Ultimately, there may be a loss of the reef structure itself.

Reef accretion, which receives little to no attention in most monitoring programs, is really the "bottom line" of the reef's ecological balance sheet.

Indicators selected to track reef accretion and bioerosion are:

F8 Coral Growth

F9 Bioeroders on Coral

F10 Reef Accretion


Wolcott Henry

F8 Coral Growth

Benchmark

To be developed.

Target

To be developed.

Red Flag

To be developed.

What Is It?

Corals are the structural building blocks of reefs, and calcification (deposition of calcium carbonate) Is the fundamental process supporting coral growth. *Coral growth* is a combination of two processes: (1) development of new polyps, and (2) accumulation of skeletal mass. Growth rates are typically characterized in terms of the extent of carbonate accumulation (in cm) per year.

Corals generally grow very slowly, at rates as low as 0.5 cm/yr though sometimes as high as 10 cm/yr. Branching, shallow-water corals (acroporids) often have the highest growth rates, followed by finger corals (e.g., *Porites porites*), mound or head corals (e.g., *Montastraea, Diploria*) and then platy corals (e.g., agaricids). *Acropora palmata* grows ~10 cm/yr, *Montastraea annularis* grows ~1 cm/yr, and *Diploria labyrinthiformis* grows only ~0.5 cm/yr[30].

Coral growth rates are influenced by light availability, nutrient concentrations, sedimentation and disturbances (e.g., chemicals). Generally, growth rates decrease with increasing water depth (i.e., decreasing light levels).

Why Do We Measure It?

Coral growth rate can be an indicator of reef condition and the processes of accretion and bioerosion. (Coral growth rate should not be confused with measures of coral size. As an indicator, coral size is more applicable to studies of community dynamics or the status of a coral population). Growth rates have important repercussions for overall reef accretion.

Coral growth rates, combined with skeletal density measurements, yield calcification rates. This information, together with the amount of burrowing seen in coral cores, can be used to infer bioerosion rates.

Sclerochronology is the analysis of growth patterns (somewhat akin to tree rings) in animal "hard parts," such as coral skeletons or gastropod shells. Such studies — for which corals are especially useful — have yielded much information about historical environmental conditions on reefs.

Coral growth rates can be reduced by disease, bleaching, competition/predation effects, hurricanes, excessive nutrients and sediments, direct removal or damage by humans, and global environmental change. Increasing atmospheric CO_2 is changing ocean chemistry in ways expected to make calcification more difficult for corals. By 2100, ocean acidification could cause a reduction in calcification of 17-35% compared to pre-industrial levels, and could result in weaker coral skeletons, growth rate reductions, increased susceptibility to erosion, and reduced ability to maintain reef growth[31].

How Do We Measure It?

Various methods are available for assessing coral growth. To study growth bands, scientists use an underwater drill to take a coral core. The cores are then taken to a laboratory where an electric saw cuts the coral parallel to the maximum growth axis. On x-ray images of the slab, scientists then mark the annual density bands (i.e., yearly growth rings). From the distances between dated bands, annual linear extension rates can be estimated.

Growth rates can also be measured by staining with alizarin red dye, direct visual measurement by tracking pins placed in the coral for reference, weighing or volumetric determination.

To calculate average annual calcification rates, the annual extension rate is multiplied by the average annual skeletal density.

Geochemical studies of stable isotopes and trace elements in seasonal and annual bands can also be used to determine calcification profiles. This approach provides an independent chronology to complement visual studies of annual banding.

Usefulness

Examination of coral colony growth provides insight into the life history dynamics of individual species. The skeletons of long-lived, massive corals are useful natural archives of past climatic and environmental conditions.

Some studies have shown that coral tissue growth is more sensitive than is skeletal growth to changes in environmental conditions. Thus, the use of coral tissue properties may be better than skeletal growth alone as an indicator of coral reef condition.

Coral growth rates have important repercussions for overall reef accretion. An important control of coral calcification (growth) is the seawater calcium carbonate saturation state. Global environmental change (specifically increasing atmospheric CO_2) will increase the accumulation of CO_2 in surface waters, acting to lower the seawater pH (i.e., increase its acidity). Thus, coral growth rates may be the best indicator of the effects (if any) of this acidification on coral health.

The research equipment needed for growth rate analysis is beyond the capacity of monitoring programs in the Mesoamerican region. Partnerships, such as that established between the Healthy Reefs Initiative and Woods Hole Oceanographic Institution and Scripps Institution of Oceanography, can facilitate the collection of such data. Growth rate measurements need not be repeated on a frequent basis (possibly every decade).

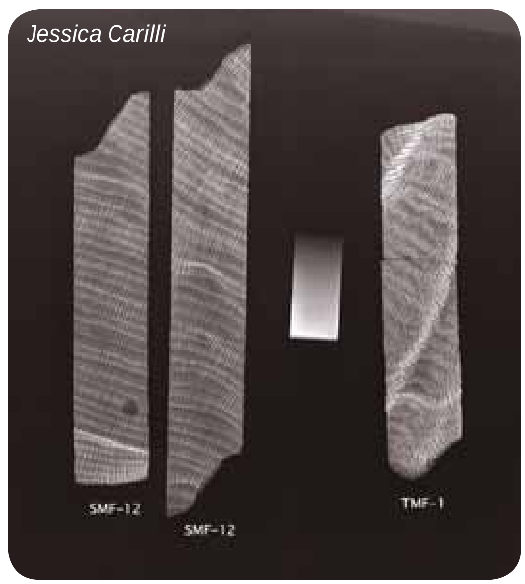
Status

A study of annual growth bands from Belize corals showed intense stress banding and a corresponding significant decrease in growth rate correlating with the extreme 1998 bleaching event[32]. Geochemical data from the coral cores are being analyzed and are expected to indicate an increase in storm-related terrestrial input coinciding with Hurricane Mitch in 1998.

Preliminary results from these studies of long-term trends indicate that coral growth rates may be decreasing in the Sapodilla Cayes, while remaining stable at Turneffe Atoll[32].

Data Needs

Additional data are needed to adequately assess coral growth rates on a regional scale.



F9 Bioeroders on Corals

What Is It?

Bioeroders are organisms that weaken or erode the calcareous skeletons of reef-building corals. Their presence on the reef is typically quantified in terms of their visible numbers (per unit area) on live coral or coral rubble.

This group includes a diverse variety of boring algae, sponges, worms and other species. These small "termites of the reef" are found everywhere — on top of the reef, within crevices and inside coral skeletons. The biomass of bioeroders inside the reef is even greater than on the reef surface. The immense diversity of bioeroding species has not yet been examined fully.

Why Do We Measure It?

Bioeroders play a critical role in the competing processes of reef growth versus erosion. The net result of this competition is reef accretion if growth outpaces erosion, or loss if erosion rates are greater than growth rates. These "termites of the reef" convert skeletal calcium carbonate to loose sediment, thereby weakening the overall reef structure.

Bioerosion intensity can be higher on nearshore reefs than offshore reefs, especially in nearshore, nutrient-rich environments.

For reef framework to grow, reef accretion rates must exceed erosion rates. Bioeroders therefore play a key role in whether a reef can sustain itself over the long term.

How Do We Measure It?

Bioeroders can be measured in two ways: the density of bioeroders on coral rubble, or visible bioeroder density on live coral. The "rubble method" and the "live coral method" are described in more detail on the Healthy Reefs website (www.healthyreefs.org).

Some earlier work documenting a relationship between bioerosion and high nutrient concentrations relied on methods destructive to corals: slabs were cut from live corals for x-rays of internal eroders.

This indicator has not yet been incorporated into most standard monitoring programs. A standardized method for application in the MAR needs to be developed.

Benchmark

To be developed.

Target

To be developed.

Red Flag

To be developed.

Usefulness

High densities of bioeroders can be a proxy indicator of high nutrient concentrations and can indicate a reef in trouble. If coral growth and reef-wide calcification are not outpacing biological and physical erosion, then there will be no reef accretion and likely no persistence of the reef in the long term (with global sea levels rising).

Bioerosion levels are expected to vary with the nutrient content of the water, with higher-nutrient waters generally supporting a higher density of bioeroders. These variations in nutrient concentrations can be natural or anthropogenic in origin. Bioeroder density can also vary naturally depending on such factors as reef type and types of bioeroders present.

A high density of bioeroders greatly reduces a reef's ability to withstand the forceful waves generated by storms and hurricanes. This effect will become increasingly important given the projections for stronger hurricanes associated with anticipated global warming.

An optimal, "healthy reef" community of bioeroders would allow for a positive balance between the rates of coral and algal calcification (growth) and biological and physical erosion. However, no absolute numbers can yet be established for "optimal," given the lack of relevant data.

Both procedures for characterizing bioeroders require some technical experience to identify bioeroding species (e.g., clionid sponges) accurately.

This indicator needs to be further developed.

Status

Comparisons of bioerosion at healthy and degraded sites in the MAR have not been conducted. However, it is hypothesized that bioerosion will be higher at reefs exposed to higher nutrient levels.

In Barbados, a "polluted reef" had approximately 41% of the *Porites* rubble pieces invaded by clionid sponges, whereas a comparable unpolluted reef had 24% invaded[33]. Results from a Cayman reef showed sewage-impacted reefs can have five times more bioerosion than comparable non-impacted reefs[34]. In the Australian Great Barrier Reef, offshore reefs tend to have less bioerosion than do the inshore reefs, which are closer to continental runoff[35].

Data Needs

We recommend examining the frequency of bioeroding organisms in coral rubble along well-known nutrient gradients and at some of the AGRAA 2006 sampling locations. This non-destructive and relatively simple method has been field tested in Barbados and should be replicated in the MAR. The abundance of visible bioeroders on live coral could be assessed at the same study sites to compare the results of the two methods and help determine which method may be preferable. These data would help establish reference values for a bioeroders indicator.

If *Diadema* urchins ever return to former densities of ~10 urchins/m^2, they too should be considered as one of the primary bioeroders on reefs.

Eric Mielbrecht

F10 Reef Accretion

What Is It?

Reef accretion or long-term reef "net growth" represents the continual battle between constructive and destructive processes on the reef. The reef framework is created through the construction processes of biological accretion by corals and calcareous algae and by sediment accumulation, but is counteracted by destructive processes such as bioerosion and net sediment export.

Reef accretion should not be confused with the growth of individual reef organisms. Coral growth and calcification occur at the organismal level, while reef accretion and bioerosion occur at the ecosystem level.

Why Do We Measure It?

This indicator helps with assessments of a reef's ability to maintain itself. Long-term reef sustainability could be threatened by a shift in the balance between accretion and erosion or by a shift in the balance between calcifying organisms (e.g., corals) and non-calcifying organisms (e.g., fleshy macroalgae).

Reef accretion is the "bottom line" of the reef's ecological balance sheet — although it receives little to no attention in most monitoring programs.

For a coral reef to persist, its rate of accretion must equal or exceed deconstruction losses due to biological and physical erosion and transport of sediment away from reef framework. A reduction of the populations of corals and coralline/calcareous algae may result in a reef becoming dominated by non-calcifying organisms (macroalgae, some sponges), thus shifting the carbonate budget from one of net construction to one of net erosion. A decline in the population of calcifiers and/or an increase in the population of bioeroders can result in a shift to a state of no net accumulation of reef framework. In the long term, the reef framework itself may potentially be lost.

In addition, if accretion rates decrease (due, for example, to higher nutrient concentrations or lower pH), a reef's ability to keep up with sea level rise may decrease, and its susceptibility to bioerosion and physical damage may increase.

Benchmark

To be developed.

Target

To be developed.

Red Flag

To be developed.

How Do We Measure It?

This indicator is under development.

Reef accretion can be directly measured from dated core samples taken through the reef substrate[36].

Potential accretion rates can also be estimated in terms of gross production (that is, the total amount of carbonate produced on a reef during a specified period of time). Productivity and calcification profiles can be developed from measurements of seawater pH and oxygen concentration[37].

Usefulness

Techniques are available to estimate accretion by measuring primary productivity and calcification by corals plus respiration of the reef community. However, these methods require equipment and expertise not widely available in the region.

Cores of individual corals provide useful data for studying one coral colony's growth (see Indicator F8 – Coral Growth), but more information is needed on the correlation (if any) of core data to the reef community level and studies of reef accretion.

Status

One of the highest Caribbean reef accretion rates was reported at Alacran Reef in Mexico (about 12m/1000 years)[38]. In general, coral reefs “grow” approximately 2 m to 10 m every thousand years, with that rate being influenced in part by the different growth rates of different coral species. Disturbances, particularly hurricanes, can remove carbonate material and confound the analysis of the cores[39].

Gross production rates generally range between 0.8 and 1.4 $kg/m^2/yr$ for whole reefs, and between 2.1 to 8.9 $kg/m^2/yr$ for specific reef zones. An average coral reef can accrete roughly 4 kg/m^2 of limestone per year[37].

Data Needs

This indicator needs to be further developed.

Existing reef accretion rate data need to be synthesized for the region and compared with recent ecological data.

Methods for evaluating gross production, calcification, respiration and net production need to be evaluated in terms of their potential use for or adaptation to monitoring studies.

Richard B. Aronson

HERBIVORY

Conservation Objective

Maintain or restore herbivory levels in the MAR to rates high enough to prevent algal overgrowth. The overall aim is to have higher populations of herbivores.

Threats

Although most fishing effort generally targets carnivorous fishes, herbivorous fishes are also taken on an opportunistic basis and can account for a large percentage of the total catch. Any decrease in their abundance can have significant effects on reef condition. Human activities that degrade water quality and increase nutrification can create environments more favorable for algae than corals, thus requiring even more herbivores to control algal populations. Green turtles in the MAR are at risk due to long-term harvesting of eggs and adults, plus habitat degradation and loss.

Management Actions

- Reduce fishing of herbivores, especially large-bodied parrotfishes, through species protection or gear restrictions.
- Determine the feasibility and effectiveness of restoring *Diadema* populations at high-priority sites.
- Assess the effectiveness of marine reserves and herbivore restoration programs in increasing herbivorous fish and *Diadema* populations.
- Reduce activities that introduce nutrients into the marine environment.
- Promote regional monitoring of sea turtles, and promote coordinated management strategies to reduce human impacts on turtles. Such strategies would include reduction of destructive development practices on nesting beaches, elimination of illegal take and trade, increased enforcement of existing regulations, and restoration of nesting and foraging habitats.

Herbivory (the consumption of plant material) is probably the single most important factor influencing interspecific interactions on Caribbean reefs. Corals and fleshy macroalgae are locked in a fierce competition for precious reef space, and the presence or absence of herbivores to eat the macroalgae can tip the scales one way or the other. Reduced herbivory rates can rapidly result in a significant shift from a (calcifying) coral-dominated community to a (non-calcifying) macroalgae-dominated community.

Sea urchins and fishes are the two most important groups of reef herbivores. They control the abundance and species composition of both corals and algae — particularly the larger macroalgae that are in direct competition for space with corals. Thus, a decline in sea urchins or herbivorous fishes can result in a rapid increase in macroalgae.

The long-spined sea urchin (*Diadema* spp.) is perhaps the most significant herbivore on Caribbean reefs, in terms of influence on coral reef structure and composition. Their presence in moderate abundances tends to be associated with low levels of large algae, relatively sparse algal turfs and high levels of coralline algae — conditions that foster coral recruitment and higher live coral cover. A 1983 die-off of long-spined sea urchins throughout the Caribbean coincided with a dramatic and rapid increase in macroalgal cover on many reefs.

Grazers like parrotfishes and surgeonfishes are especially effective herbivores because they occur in large numbers. However, their feeding can also result in incidental coral loss, as they scrape and chew at the reef surface.

Other key species include megaherbivores, such as green sea turtles and manatees, which were once responsible for significant grazing on seagrass beds. Now, however, their numbers are low, and their herbivorous influence has dramatically declined, leaving many seagrass meadows looking like overgrown fields.

Indicators selected to track MAR herbivory are:

F11	Herbivorous Fish Abundance
F12	*Diadema* Abundance
F13	Fleshy Macroalgal Index
F14	Fish Bite Rates
F15	Green Turtle Abundance

Melanie McField / WWF

F11 PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

Herbivorous Fish Abundance

What Is It?

Herbivorous fish are fish that eat plant material. Their key functional role on reefs, through their grazing activity, is to keep non-encrusting algae in check so the algae do not outcompete corals for space. Relatively high levels of grazing are necessary for corals to retain a competitive advantage.

This indicator measures the abundance of herbivorous fishes and focuses on two key families: surgeonfish (Acanthuridae) and parrotfish (Scaridae).

Benchmark

Maintain current levels of herbivorous fish abundance (regional average of 3 to 6 large parrotfish/m^2).

Target

To be developed.

Red Flag

To be developed.

Why Do We Measure It?

Herbivory is probably the single most important factor influencing interspecific interactions on Caribbean reefs. Changes in herbivory rates can produce significant, rapid changes in reef community structure. However, directly measuring herbivory rates is difficult, so we often use herbivorous fish abundance as a proxy indicator instead.

Herbivorous fishes, through their grazing and scraping activities, help constrain the growth of non-encrusting algae and affect algal distribution, abundance and species richness. Their ability to keep algae cropped provides corals better habitat to recruit and grow.

In the wake of the 1980s regional die-off of the herbivorous long-spined urchin (*Diadema*), herbivorous fishes play an even more important role in grazing macroalgae and reducing overgrowth on coral reefs. In particular, parrotfishes have become critically important herbivores, although they may not be able to fully "replace" the functional role of the long-spined urchin *Diadema*. Reefs where both herbivorous fish and *Diadema* are prevalent tend to have much lower macroalgal overgrowth and provide a more conducive habitat for coral growth.

Herbivorous fishes may be able to keep macroalgae in check on reefs dominated by hard corals (> 40% coverage) and other sessile organisms. But on the low-coral-cover reefs that are common today (< 20% coral cover), the overwhelming abundance of macroalgae exceeds the ability of herbivorous fishes alone to graze down the algae. Thus many MAR reefs today are dominated by macroalgae.

Grazers like parrotfishes and surgeonfishes are especially effective herbivores because they occur in large numbers. (At the same time, their feeding can also result in incidental coral loss, as they scrape and chew at the reef surface.) Large-bodied parrotfish are very effective in cropping algae. Reducing or even eliminating fishing of parrotfish and surgeonfish, in order to sustain high abundances, is essential for sustaining reef function and ecosystem integrity.

Production of algal biomass is estimated to be about 8 g (wet weight) per m^2 per day on shallow patch reefs[40]. If herbivores eat 10 to 20% of their body weight per day in algae, then an herbivore biomass of 40 to 80 g/m^2 would be needed to maintain the algal biomass at equilibrium. This would be equivalent to three to six moderately large (500-1000 g) parrotfish every square meter (if they were the only herbivores).

How Do We Measure It?

Divers measure fish density and size along belt transects. For example, the AGRRA and MBRS methodologies recommend ten replicate transects, 2 m wide by 50 m long[3,8].

A stationary visual census technique, where fish are counted for a specified time within a visual cylinder, has also been used in the region, though not as commonly[41].

Density (fish per unit area) and size together are used to estimate biomass.

Herbivorous fish guilds are categorized according to how they graze. Scaridae (parrotfish) are scrapers, Acanthuridae (surgeonfish) and *Microspathodon chrysurus* (yellowtail damselfish) are browsers, and other Pomacentridae (damselfish) are denuders.

Usefulness

A strength of this indicator is that it can respond to management actions (i.e., if fishing pressure changes, changes will be observed in fish abundance).

Parrotfish tend to have relatively small home ranges. Therefore their abundances tend to be fairly consistent under constant conditions and are reflective of conditions in the immediate reef area.

Herbivore biomass can vary naturally with depth and habitat type, and is also affected by abundance of predators.

For some species, like the largest parrotfish (rainbow parrotfish), their abundance also depends on the availability of mangroves for critical (obligatory) nursery habitat.

Herbivorous fish abundance is easy and inexpensive to monitor.

Status

Herbivorous parrotfish biomass in the MAR averages 1302 g/100m^2, with greater biomass on reef crests (1390 g/100m^2) than on fore reefs (1267 g/100m^2). The MAR average is lower than the Caribbean average value (2074 g/100m^2)[9].

At many reefs, few herbivorous fishes greater than 20 cm in length are found[9].

Data Needs

Data from the ongoing regional AGRRA survey will enhance our understanding of the natural distributions of herbivorous fish and biomass in relation to reef location, reef type and condition, and predator abundance.

A comparison of the herbivorous fish biomass within and outside MPAs in the MAR is needed. Such an analysis could help focus management efforts on highest priority areas.

If increased protective measures are implemented, the effectiveness of these measures needs to be tracked.

Bob Steneck

F12 Diadema Abundance

What Is It?

Diadema antillarum, known as the long-spined or black sea urchin, is easily recognized by its long, needle-like spines, which radiate up to 30 cm from a relatively small (7.5 cm) test. The spines are coated with a mild toxin.

Diadema urchins are found throughout the Caribbean, as well as in tropical waters of the eastern and western Atlantic Ocean. They live in a wide variety of habitats, but usually inhabit shallow coral reef and seagrass areas. During the day, these urchins tend to hide in crevices in the reef or aggregate in groups. At night, they are more active on the reef and nearby seagrasses.

Black sea urchins are very important herbivores on the reef, as they help to maintain the balance between coral and algal growth. Algal turfs and macroalgae are their preferred foods, but the urchins can also eat other materials, including live coral. *Diadema antillarum* was once the most abundant and important herbivore on Caribbean reefs[42].

In 1983, a lethal disease outbreak rapidly killed almost 98% of *Diadema* urchins throughout the Caribbean, in what is considered to be the most severe and significant mass mortality for a marine organism in modern times[43]. This significant loss of *Diadema* has contributed to a shift in many coral reef communities from coral dominance to macroalgal dominance. This shift was even more severe in areas where overfishing had also reduced the numbers and sizes of herbivorous fishes.

Very little recovery on the regional scale has been observed, although some sites now host abundant *Diadema* populations, and anecdotal information indicates some recovery may be underway. Several factors may be contributing to the lack of large-scale recovery. Despite their protective spines, *Diadema* are a common food for numerous reef consumers (e.g., queen triggerfish and other fin fish, lobster, fighting conch). Larval supply may be limited by the very low densities of reproducing adults. Recruitment may also be limited by inadequate substrate, predation pressures, contaminants (e.g., metals) or poor water quality.

Why Do We Measure It?

Diadema urchins play several important roles on reefs. They are key grazers and bioeroders, and their long spines provide shelter and protection for small fish and invertebrates (e.g., crabs, fishes).

Diadema abundance is an indicator of their level of herbivory. *Diadema* reduce macroalgae and increase open settlement space for coral recruits. Reefs with more *Diadema* tend to have less macroalgae and often are healthier (or have the potential to be).

Healthy reefs should have a *D. antillarum* density that can provide a balance between survival of coral recruits, algal coverage, and sustainable bioerosion rates. An average-sized *Diadema* urchin weighs about 100 g and eats approximately 1-2% of its body weight in algae per day. To keep algae cropped on a typical shallow patch reef, then, 400 to 800 g/m^2 of urchins are needed — about 4 to 8 urchins per m^2 [44]. This calculation assumes grazing by *Diadema* only. Ideally, herbivorous fish would also be present, and fewer urchins would be required.

Benchmark

Regional average of ~2 urchins/m^2, with more than 50% of surveyed sites showing increasing abundances.

Target

Working target of 2-6 urchins/m^2. More information is needed to determine the optimum number of *Diadema antillarum* to adequately remove algae but not erode the reef framework.

Red Flag

< 1 urchin/m^2.

How Do We Measure It?

Divers normally count the number of juvenile and adult *Diadema antillarum* along belt transects also used to count fish or measure coral cover. AGRRA and MBRS methodologies recommend six transects (each 1 m wide and 10 m long) per site[3,8].

Measurements need to be standardized for the time of day to the extent possible (usually made between 10:00 a.m. and 2:00 p.m.).

Usefulness

Urchin surveys are quick and easy to conduct, and several monitoring programs (e.g., MBRS Project, AGRRA, CARICOMP) include this component.

Because *Diadema* urchins are often cryptic and less active during the day, analysts should be aware that most methods involve daytime counts, which may not capture total abundance.

Status

Prior to the 1983 die-off, *Diadema antillarum* densities in the MAR ecoregion ranged from 4 to 25 urchins/m^2 [42]. Between 1998 and 2001, the regional average was 0.03 urchins/m^2 — about one-fifth the average Caribbean value of 0.15 urchins/m^2 [9].

Urchin populations reportedly declined after the 1998 disturbance events (coral bleaching and Hurricane Mitch). More recent surveys (2004) suggest some populations are recovering, with reported densities between 0.19 and 0.53 urchins/m^2 [9]. Higher abundances are generally observed on reef crests and patch reefs than on fore reefs.

Data Needs

Historical baselines (pre-die-off) are not available for most of the MAR region.

The 2006 comprehensive regional AGRRA survey, in conjunction with MBRS SMP data, will help quantify the distribution and (anticipated) return of this key herbivore. In 2004 The Nature Conservancy compiled a comprehensive database of known MAR *Diadema* occurrences[42].

Future urchin surveys should be accompanied by measurements of associated changes in reef structure — particularly indicators S4, S5 and S6.

Management interventions, such as reseeding programs, could be considered in areas with slower natural recovery or highly imperiled remnant populations of stony corals.

Research is needed to understand the conditions required for sustaining viably productive *Diadema* populations. Of particular interest would be analyses of the potential effects of management (e.g., MPAs) and physical factors (e.g., marine currents) on the recovery rates of urchin populations.

The pathogen responsible for the 1983 die-off has not been identified, and further research is needed — especially on how to respond if another outbreak occurs.


Lisa Carnes

F13 — Priority One: Healthy Reefs for Healthy People

Fleshy Macroalgal Index

Benchmark

A regional macroalgal index of between 20 and 40.

Target

Working target: Macroalgal index <20.

Red Flag

A macroalgal index >40. Site should be evaluated to determine why levels are so high and what actions might lower the index.

What Is It?

Macroalgae are one of three main functional groups of reef algae. (The other two are turf algae and crustose coralline algae.) The *fleshy macroalgal index* is simply a measure of how much fleshy macroalgae is present on the reef.

Macroalgal abundance is usually expressed in terms of percent cover or biomass. A macroalgal biomass index can be calculated as the product of percent macroalgal cover and average algal height. The higher the index, the greater the amount of macroalgae on the reef.

Macroalgae are usually larger canopy-formers (sometimes called "seaweed"). Common reef inhabitants include brown algae (*Dictyota*, *Sargassum*), red algae (*Gracilaria*, *Laurencia*) and green algae (*Caulerpa*, *Microdictyon*). Macroalgae can be either soft and fleshy (e.g., *Lobophora*) or stiff and calcareous (that is, able to deposit calcium carbonate in their tissue; e.g., *Halimeda*).

Macroalgal community structure on tropical reefs is related to the abundance of other algal species, herbivory intensity, and primary productivity (which is in turn controlled by the availability of light and nutrients).

Why Do We Measure It?

Healthier reefs tend to have less fleshy macroalgae. Fleshy macroalgae are tough competitors for corals. In high enough abundances, macroalgae can overgrow stony corals, interfere with coral recruitment and reduce coral survival. A reef "takeover" by macroalgae can potentially lead to the reduction of coral cover, reef structure and functional processes.

Macroalgae are also an important food source for a variety of reef herbivores.

The loss of major reef herbivores through overfishing and the 1983 *Diadema* die-off has led to dramatic increases of macroalgae on the Mesoamerican Reef — so much so that macroalgae have taken over many reefs formerly dominated by corals. Macroalgal dominance is further helped along by the chemical deterrents or structural resistance most macroalgae use to discourage consumption by herbivores.

Increasing nutrient levels (from agriculture, aquaculture, coastal populations and tourism) also fuel macroalgal growth.

How Do We Measure It?

Various methods have been used to measure macroalgal percent cover and biomass in the MAR region (e.g., MBRS, AGRRA, CARICOMP). The same transect measurements of benthic cover that are described in Indicators S4 – Coral Cover and S5 – Coral: Algae Ratio, along with an additional measurement of average algal height (measured in five quadrats along each transect line in the AGRRA protocol), are used to calculate this index.

The fleshy macroalgal biomass index is calculated as the product of the percent macroalgal cover and the average algal height[3].

Usefulness

An increase in macroalgal abundance (easy to measure) may signal an increase in nutrients and/or a decline in herbivory (both of which are harder to measure). The exact cause of macroalgal changes is not usually easily identifiable.

Analysts comparing different data sets need to keep in mind that macroalgal abundance may vary seasonally, by reef type, water depth or wave energy. Apparent differences may also be introduced if different data-collection methods were used.

Macroalgal abundance is easy and inexpensive to measure.

Status

Given the great variety of reefs and communities in the MAR, macroalgal abundance varies greatly over the region. Some local reefs have very high macroalgal abundance. Glover's Atoll (Belize) patch reefs experienced a 315% increase in algae (mostly *Lobophora*, *Dictyota*, *Turbinaria* and *Sargassum*)[45]. Algal production was estimated to be about 8 g (wet) per m^2 per day — very close to the theoretical upper limit of about 9 g per m^2 per day (projected amount of biomass a sugar cane field might produce)[40].

In 1999-2004 AGRRA surveys, the average macroalgal index (i.e., the product of percent macroalgal cover and average canopy height) was higher for Mexico (index = 99) than Belize (62). Both MAR values are lower than the Caribbean average value of 129[9].

The macroalgal index is generally higher on fore reefs than on shallow reefs. In the 1999-2004 AGRRA surveys, the index ranged from 36 to 163 (average = 87) on reef crests and from 25 to 192 (average = 105) on fore reefs in Mexico. In Belize, the index ranged from 13 to 93 (average = 42) for shallow reefs and from 33 to 249 (average = 69) on fore reefs[9].

Shalini Cawich / WWF

Melanie McField / WWF

Data Needs

Fair amounts of data are available for algal cover and average algal height from the AGRRA database, MBRS database and various published studies. No complete synthesis has yet been attempted.

Additional regional AGRRA data on macroalgal abundance were collected across the MAR in 2006. These data, which complement the MBRS SMP data, will help us understand how macroalgal distribution is related to other factors such as coral cover, herbivore abundance and level of protection from fishing (in MPAs).

Additional information is needed on how best to proactively reduce macroalgal abundance or increase levels of herbivory.

Refinements of this target should consider complementary targets for herbivore biomass, *Diadema* densities, coral cover, water quality and level of human alteration.

F14 Fish Bite Rates

What Is It?

Fish bite rates measure how many times herbivorous fish bite a defined area of reef substrate during some specified length of time, or how many times they bite on algal assays that are set out on the reef for a specified time period.

The key functional role of herbivorous fishes on reefs, through their grazing activity, is to keep non-encrusting algae in check, so algae do not outcompete corals for space. High levels of grazing are necessary if corals are to retain a competitive advantage.

Why Do We Measure It?

Fish bite rates give an indication of the intensity of herbivory — which is probably the single most important process influencing reef community structure. Herbivorous fishes, through their grazing and scraping, help constrain the growth of non-encrusting algae and influence algal distribution, abundance and species richness. Their ability to keep algae cropped provides better habitat for corals to recruit and grow. The fish bite rate method can be used to gauge the effect of herbivorous fishes on algal composition.

This fish-bite indicator should not be confused with Indicator F11 – Herbivorous Fish Abundance. That indicator measures fish abundance and biomass as a proxy for herbivory. Measurements of bite rate more directly assess the actual process of herbivory.

How Do We Measure It?

This indicator can be measured in two different ways:

(1) Observation: A diver visually counts the number of fish bites during a specified time and area (e.g., 5 min in a 1-m plot). Grazing rate measurements need to be standardized for the time of day (usually made between 10:00 a.m. and 2:00 p.m.)[46].

(2) Assays: A diver sets out a number of algal assays for a specified period of time (usually 24 hrs) and measures the number of bites on each assay[45]. Assays should contain a common, palatable species of macroalgae and/or *Thalassia* (turtle grass) as a common reference species. At least one such study has occurred in the MAR, although the method has not yet been standardized or widely used in monitoring programs.

Benchmark

To be developed.

Target

To be developed.

Red Flag

To be developed.

Usefulness

The feasibility of using this indicator needs to be assessed across the MAR. If a standardized method can be agreed upon, this indicator has high potential value as a more direct indicator of herbivory than just measuring the abundance of herbivores.

Herbivorous fish guilds are categorized according to how they graze. Scaridae (parrotfish) are scrapers; Acanthuridae (surgeonfish) and *Microspathodon chrysurus* (yellowtail damselfish) are browsers; and other Pomacentridae (damselfish) are denuders. The bite of one species can thus have quite a different effect than that of another species (in terms of grazing efficiency, etc.). The observation method should capture all of these groups, provided they are in the sample area.

The herbivory assay method is biased towards macroalgal feeding species, underestimates herbivory by some groups such as scraping and excavating parrotfish and sea urchins. It also does not measure herbivory for some sucking and scraping species such as grazing surgeonfish.

Some researchers have noted the importance of consistently using neutrally colored lines, clothespins and such to avoid varying the visual attractiveness of the sampling gear for fish.

A combination of the two metrics would provide a more balanced measure of total fish herbivory.

Status

Fish bite rate data are available from only a few sites in the region.

Herbivorous fish grazing rates measured in 2000 at twelve AGRRA sites in Belize ranged from 1.4 bites/minute/m^2 to 13.4 bites/min/m^2 [46]. Fish grazing rates on patch and other shallow reefs generally tend to be higher than grazing rates on deeper fore reefs. Parrotfish can represent over half the fish grazing on a reef.

In Akumal, Mexico, fish herbivory rates were particularly low in 1997, likely contributing to the high abundance of macroalgae found on these reefs.

Approximately 34% of *Lobophora variegata* assays had fish bites (in 24 hrs), and 48% of *Thalassia testudinum* assays were either bitten or eaten, averaged over a one-year study in patch reefs at Glover's Reef (1998/99)[45]. These rates were considered fairly low, particularly for a marine protected area.

Data Needs

Additional fish grazing data are needed at a wider variety of sites in the MAR.

Ideally, both bite rate metrics could be collected in a MAR-wide pilot study, accomplishing a comparison of the metrics and allowing an assessment of their relationship (if any) to other indicators [e.g., Fish Diversity (S2), Coral:Algae Ratio (S5), Fish Abundance (S6), Herbivorous Fish Abundance (F11), Fleshy Macroalgal Index (F13)].

Ultimately, we recommend that a preferred methodology for the region be agreed upon and incorporated into monitoring programs, particularly in MPAs.

F15 Green Turtle Abundance

What Is It?

Green turtles (*Chelonia mydas*) are one of the largest of the sea turtle species and are found globally in tropical and subtropical waters. They are listed as "Endangered" on the IUCN Red List of Threatened Species, due to worldwide population declines over the past three generations. (See Appendix 3). An Endangered species is one that is believed to be facing an extremely high risk of extinction in the wild. The abundance of green turtles may be characterized in terms of (a) numbers of adults, or (b) numbers of nests.

These highly migratory turtles use a variety of habitats throughout their lifetime. Adults nest on sandy beaches; post-hatchlings, small juveniles and migrating adults roam in oceanic zones; and larger juveniles and adults forage in shallow protected waters. Coral reefs or rocky outcrops near foraging seagrass meadows are often used as day- and night-time resting areas. Green turtles are especially susceptible to population declines because of their vulnerability to human impacts during all of their life-stages — from eggs to adults.

Among the greatest threats to green turtles in the MAR are:

- illegal harvesting of eggs and adults at nesting beaches, plus the capture of juveniles and adults at feeding areas; and
- degradation or loss of nesting and foraging areas due to coastal development, dredging in seagrass beds, and incidental catch in fisheries.

Green turtle harvest is illegal in all of the MAR countries (all of whom have signed the Inter-American Convention for the Protection and Conservation of Sea Turtles, IAC)[47]. However, poaching of adults for meat, shells and leather still occurs, along with the harvesting of eggs.

Extensive development in the region, particularly along the Yucatan coast, has destroyed nesting beaches and altered nearshore habitats. Increasing demand for coastal development and a lack of regulation and enforcement continue to be problematic.

Another growing concern is the increasing global prevalence of debilitating tumors that are often lethal to green turtles.

Benchmark

To be developed.

Target

To be developed.

Red Flag

To be developed.

Why Do We Measure It?

One reason for measuring green turtle abundance is simply to keep track of this threatened species. There is a great concern over the historic loss and continued overall decline of the global green turtle population.

The abundance of green turtles may also be a proxy indicator of herbivory in seagrass beds. Historically, these turtles, whose adults feed primarily on seagrasses and macroalgae, have played a functionally important role as a dominant herbivore of shallow seagrass meadows. The turtles help to recycle the nutrients "locked up" in the seagrasses. By quickly digesting and processing consumed grasses, turtles make the nutrients available to other organisms. Green turtles help maintain seagrass beds and make them more productive.

How Do We Measure It?

Nesting surveys are conducted at several locations in the MAR, although methods for data collection and reporting are not standardized regionally[47]. Some tagging studies of adults have been done, but these are often expensive[48].

Many areas in the MAR may be important nursery and foraging areas for green turtles, including those that nest outside the region. Therefore, tracking the number of nests in the MAR may not suffice.

Collaborations with marine tour guides and fishermen are needed to develop a sighting frequency reporting protocol. WWF and the ICRAN MAR Alliance has developed one such activity using the REEF sea turtle identification cards[49].

Current populations of green turtles are thought to be so low that measuring their herbivory rate in seagrass beds would be impractical, although indicative assays might be developed.

Usefulness

This indicator is under development, and the usefulness of green turtles as an indicator of herbivory in seagrass areas needs to be evaluated further.

Manatees are the other megaherbivores of seagrass meadows, and their abundance, measured under Focal Species Abundance (S3) might also be included in this indicator.

Status

The regional status of green turtle populations is difficult to determine because of the lack of regionally coordinated monitoring, the long generation time of green turtles, and the difficulty of tracking early life stages.

Data from one site in Mexico suggest a slight local increase in nesting females.

Globally, the number of nesting females has declined an estimated 48-67%[48].

Current green turtle populations in the Caribbean are believed to be only 3-7% of their historical abundance prior to human exploitation.

Green turtles are protected by a number of laws and treaties. They are listed as endangered by IUCN (EN A2bd) and are listed in Appendix I of CITES, which prohibits their international trade.

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Data Needs

Nesting surveys are conducted annually at a number of nesting beaches in the MAR, and country reports are compiled through the IAC. The Wider Caribbean Sea Turtle Conservation Network (WIDECAST), TNC, WWF and many local NGOs are also currently working jointly to update information about the status of turtles in the Caribbean.

We recommend:

- Development of a standardized method for collecting and reporting regional data, including sighting frequency reports in seagrass habitat;
- Establishment and annual update of a regional database;
- Mapping and analysis of the status of seagrass foraging areas;
- Identification of priority nesting and foraging areas, and integration of these areas into the MPA network; and
- Assessment of the effectiveness of existing regulations and the impacts of illegal harvesting in the region.

Drivers of Change

Drivers of change are human activities and natural events that directly or indirectly influence the integrity and health of the reef ecosystem. While these influences can result in favorable changes, in this guide the phrase "drivers of change" refers specifically to threats or stressors that may negatively impact species diversity, richness and abundance; habitat quality, extent or productivity (including critical habitats such as spawning, breeding and foraging sites); or key ecological processes (such as larval transport).

On regional and global scales, distinguishing the effects of natural disturbances from those of human disturbances is generally difficult. Observed effects may derive from multiple sources with synergistic effects. These combined events and activities may have long-term effects on ecological processes that may enable or hamper a reef's ability to recover and persist.

Disturbances (e.g., waste disposal or predator outbreaks) can profoundly influence coral reef health, and many have increased in scale, frequency, and intensity over the past few decades. Recovery in the wake of disturbances is being delayed or not observed at all on many reefs. Disturbances that were once acute in nature (e.g., coral bleaching or disease outbreaks) are now becoming chronic.

The primary drivers of change that pose the greatest risks to Mesoamerican Reef health are:

- Tourism and coastal development
- Land use and agriculture
- Fishing
- Global climate change.

These activities and threats are the focus of most of the ongoing conservation management interventions in the region. Fifteen indicators associated with these primary drivers of change have been identified (Table 7.c).

Table 7.c. Drivers of Change Indicators.

Attribute	Indicator #	Indicator
Tourism and Coastal Development	D1	Coastal Development Index
	D2	Tourism Development Index
	D3	Tourism Sustainability Index
Land Use and Agriculture	D4	Agricultural Input Rates
	D5	Sediment Delivery Rates
	D6	Foraminifers (FORAM) Index
	D7	Contaminant Accumulation
Fishing	D8	Certified Fisheries Products
	D9	Volume of Production
	D10	Conch Abundance
	D11	Spiny Lobster Abundance
	D12	Protected Fish Spawning Aggregations
Global Climate Change	D13	Photic (Amphi) Index
	D14	Coral Bleaching Index
	D15	Reef Resiliency to Bleaching

Tourism and Coastal Development

Conservation Objective

Mitigate potentially harmful tourism impacts and coastal development influences by planning and managing these activities such that the biological integrity of MAR coastal resources is maintained or improved.

Threats

Unsustainable tourism and coastal development continue to be a problem because of high demand for economic opportunities, increasing population, lack of land use planning and zoning regulations, insufficient enforcement of existing regulations, and inadequate implementation of environmental impact assessments.

Management Actions

- Determine Coastal Development Index (CDI) values for each MAR country.
- Promote and adopt regional "good practice" guidelines, codes of conduct and eco-certification schemes in targeted industries (e.g., agriculture, tourism and aquaculture).
- Adopt regional, sustainable land use and coastal development practices in all four countries in next five years (through integrated coastal zone management).
- Maintain natural coastal vegetation to the extent possible.
- Encourage or require proper sewage treatment facilities.
- Identify land ownership of coastal areas and develop land tenure agreements where needed.
- Encourage landowners to implement habitat conservation activities, through tax- and other incentive programs.
- Enact measures to prevent erosion and water contamination.
- Provide mooring buoys and apply strict anchoring guidelines.
- Promote appropriate eco-friendly certification programs, regulations and other sustainable management strategies.

Tourism is the fastest growing industry in the MAR. According to a regional stakeholder survey taken in 2005, many stakeholders consider unsustainable tourism (and its associated coastal development) to be the single greatest threat to Mesoamerican reefs.

Inappropriate coastal development is a significant threat exacerbated by persistent rural poverty, inadequate enforcement of land use zoning regulations, and a lack of local capacity specifically for coastal development planning. Development practices inappropriate for a coral reef environment include destruction of mangroves and other coastal wetlands, littoral forests and riparian forests, as well marine dredging and beach renourishment.

Increasing population density — especially along the coastline — is likely to exacerbate the already strong pressure for development infrastructure exerted by unsustainable tourism and other coastal activities. Human sewage is often considered a primary stressor to coastal ecosystems, particularly in areas near large population centers and tourism developments. Sewage contamination causes nutrient enrichment, which results in increased susceptibility of corals and other marine life to disease, higher populations of filter-feeding organisms (e.g., sponges), and enhanced bioerosion of the reefs as well as increased occurrence of algal blooms. Other forms of contamination can also accompany coastal development, boat traffic and dredging operations. Heavy metals or pesticides may reduce reproductive and recruitment success in corals, fishes, birds and other organisms.

Indicators selected to track tourism and coastal development are:

D1 - Coastal Development Index

D2 - Tourism Development Index

D3 - Tourism Sustainability Index

D1

Coastal Development Index

What Is It?

The *Coastal Development Index* (CDI) is a proposed indicator envisioned to give a "snapshot" of physical change due to human activities on the coastal landscape. This indicator is being designed to quantify coastal activities that often translate into a commensurate level of environmental degradation. Although a CDI value for the region is not available at this time, the following section describes how a Coastal Development Index can be developed into a useful indicator.

Benchmark

Establish the CDI baseline value for the region and/or per municipality across the region.

Target

Maintain a regional CDI value < 0.5, as an indication of stabilized and sustainable development of coastal areas.

Red Flag

CDI value is ≥ 0.5.

Why Do We Measure It?

Coastal development activities, such as aquaculture, construction or channel dredging, are often associated with economic benefits but also alteration of the physical landscape. In coastal areas, such physical changes can have significant consequences for the marine environment. Natural processes such as freshwater runoff, erosion and sedimentation may be altered or accelerated in ways that surpass the natural tolerance of marine ecosystems.

The proposed Coastal Development Index provides quantitative, concise information regarding the level of coastal alteration, thereby serving as an indicator of development-related pressures on marine ecosystems. Such pressures may require management intervention to mitigate detrimental environmental impacts.

A time-series of index values (that is, a number of index "snapshots" taken over a number of years) also provides a measure of the rate of change of the MAR coastal environment.

How Do We Measure It?

The CDI incorporates three fundamental parameters that represent the most salient development-related pressures on the coastal landscape:

- Coastal population density — number of people per km^2;
- Coastal conversion ratio — average percentage of land per km^2 that is in agricultural use, urbanized, or covered by major infrastructure such as aquaculture farms, airports or ports; and
- Coastal road density — total length of roads per km^2.

The index also incorporates two parameters to indicate rates of change:

- Coastal land conversion rate — average percentage per km^2 converted from a natural state to a specific use over the course of one year; and
- Yearly population growth rate — based on the most recent available estimates.

All five factors are weighted equally within the index. Therefore, 60% of the index value is related to the existing coastal footprint, and 40% is attributed to rate of change.

Information about land cover and road density would be obtained through remote sensing. Population data are available from governmental census reporting.

Coastal Development Index scores range from 0 to 1. A score of 0 indicates an unpopulated, unaltered municipality. A score of 1 indicates an area that is at a maximum level of development, having achieved or surpassed all critical thresholds. The index is proposed to be calculated using the following system that is currently under study.

Index scores can be then compared to a baseline or reference year (to be established) to assess relative change in coastal development pressure.

Usefulness

The Coastal Development Index is a good indicator of development-based pressure on coastal areas because it combines both direct measures and surrogate measures of the impact of human activity. In this regard, it captures the key elements of land-based pressures that can then be used to anticipate associated changes in the coastal marine environment.

The higher the CDI score, the greater the level of alteration and the greater the potential impacts on the marine environment. The design of the CDI is such that it can be used to make assessments both at the regional and local scales based on variations in the Population Growth Rate parameter, which varies significantly across the region. The interpretation of this indicator is most meaningful when combined with coastal development impact indicators such as sedimentation rate, water quality or extent of mangroves. In this regard, the ecological indicators could be useful in validating the CDI results as well as establishing linkages to environmental change.

Status

Coastal Development Index values are not yet available for the MAR. Preliminary results will be drafted in the near future.

Data Needs

Several of the underlying datasets are available, but the Coastal Development Index parameters need to be extracted from various sources and analyzed. At this time, some GIS-based information on coastal land cover is available[2,3].

Additional data are needed regarding: land tenure agreements, specific uses of converted land, land development programs, and coastal emigration and immigration.

Calculating the Coastal Development Index

Index Component	Unit of Expression	Maximum Intensity*	Means of Calculation
Coastal Population Density (CPD)	Number of people per km^2	200 people/km^2	$= \frac{\text{Population Density}}{200/km^2}$ **
Coastal Conversion Ratio (CCR)	Percent of land converted (expressed as a proportion between 0 and 1) per km^2 ***	1 (i.e. all land converted)	Already expressed as a 0 to 1 value.**
Coastal Road Density (CRD)	Meters per km^2	20,000 m/km^2	$= \frac{\text{Road Density}}{20{,}000\ m/km^2}$ **
Land Conversion Rate (LCR)	Ratio (0 to 1)	0.1 km^2/yr	$= \frac{\text{Conversion Rate}}{0.1\ km^2/yr}$ **.
Population Growth Rate (PGR)	Ratio (0 to 1)	Growth rate of 0.15 per year	$= \frac{\text{Growth Rate}}{0.15}$ **
		Final Index Score (Where higher scores indicate higher levels of development)	**CDI Value** $= \frac{CPD+CCR+CRD+LCR+PGR}{5}$

* Maximum Intensity – is defined as the value or level at which development components are at their highest in the MAR.
** Rules for calculating values:
1. CPD > 1 is assigned a score of 1.
2. CCR = 1 means all land has been converted.
3. CRD > 1 is assigned a score of 1.
4. LCR > 1 is assigned a score of 1.
5. PGR > 1 is assigned a score of 1.

*** Example: 20% of land converted is expressed as 0.20.

D2 Tourism Development Index

What Is It?

As with the Coastal Development Index, the *Tourism Development Index* (TDI) is a proposed quantitative indicator of the growth or contraction of tourism as an economic activity. The TDI is calculated for each tourism zone (an area of tourism activity as defined by the tourism agencies of each country) within the MAR region.

Why Do We Measure It?

Tourism is the fastest growing industry in the MAR region[4]. Even conservation strategies often incorporate tourism activities as alternative livelihoods to fishing.

The linkages between unsustainable tourism and environmental degradation are well known. Tourism impacts are generated by two main factors: (a) the sheer volume of tourists that utilize various destinations, and (b) tourism-related infrastructure. Both factors can cause major damage to the physical environment.

Even activities that may be considered "low-impact" have an accumulative destructive effect — due not to intensity, but to frequency as tourist numbers grow. Likewise, the installation of tourism infrastructure (in the form of hotels, resorts, roads, trails and docks) can produce severe alterations in the land- and seascape. These alterations in turn directly impact the marine environment.

The Tourism Development Index is intended to provide a comprehensive measure of the magnitude of tourism in a given area, in a form that can be correlated with other indicators.

How Do We Measure It?

The TDI is a function of five major variables, each calculated at the municipal level:

- Ratio of the average number of daily, non-resident, overnight tourist visitors to the number of residents in the local population — measures the overall magnitude of tourism visitation relative to local population;
- Number of hotel rooms per km of coastline — provides an indication of tourism infrastructure supply and also an idea of coastal pressure exerted by tourism development;

Benchmark

Establish TDI values for each MAR country.

Target

Maintain regional or country-level TDI values between 0 and 70.

Red Flag

TDI values < 71.

- Hotel occupancy rates — provides an indication of the balance between tourism infrastructure supply and demand;
- Annually averaged, daily monetary expenditure by tourists (both overnight and cruise tourists) — a parameter that is normally sensitive to the tourism development cycle and overall environmental quality; and
- Annual cruise ship arrivals — a measure of the overall magnitude and type of tourism visitation in the tourism zone.

Together, these five variables capture the major dimensions of change in tourism growth patterns and local dependence on tourism. All are weighted equally within the index.

Scores range from zero, which indicates no tourism, to 100+. Values close to or over 100 indicate a region with a very high level of tourism dependence and development.

The index scores will be compared to a reference or baseline year set of values (to be established) to determine relative change in tourism development pressure.

Usefulness

The Tourism Development Index provides a composite measure of the level of potential demand by outsiders (tourists) for the use of natural resources within the tourist area. In general, the higher the TDI score, the greater the degree of tourism development, which can be translated into increasing environmental degradation.

The index does not take into account the environmental management practices of tourism enterprises. Recent trends in tourism indicate an increasing valuation of the natural environment, which promotes, in turn, greater protection and management efforts. Ecotourism, for example, is the fastest growing sub-segment of tourism globally and is completely dependent on environmental quality for its competitive tourism offering[5]. By definition, ecotourism destinations must be managed and operated for minimum environmental impacts to maximize the experience of tourists in nature.

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Therefore, this tourism indicator should be evaluated in conjunction with other data. Complementary data would include direct measures of environmental impact (e.g., erosion, sedimentation, water quality) plus contextual information (e.g., regarding the type of tourism being developed, such as eco-boutique establishments marketed exclusively to high-end tourists versus mass tourism operations).

When compared with the baseline-year values, the TDI also provides information on the growth or decline of the tourism sector and the relative dependence of the local economy on tourism activities.

Status

At this time, TDI values are not available for the MAR. Data collection for index parameters is underway.

Data Needs

Data regarding the following are needed: type of tourism development, investment level in tourism, number of tourism businesses participating in voluntary environmental performance improvement programs and number attaining full eco-certification.

Index Component	Unit of Expression	Maximum Intensity*	Means of Calculation**
Ratio of tourist population to local population (RNR)	% Visitor in proportion to Local	100%	$= \frac{\text{Ave. Daily Visitors}}{\text{Local Population}} \times 100$
Total number of hotel rooms per km of coastline (RKC)	Rooms/km	200 rooms/km (level beyond which coastal tourism is considered to be highly developed)	$= \frac{\text{No. Rooms/km}}{\text{200 Rooms/km}} \times 100$
Hotel occupancy rates (HOR)	% occupancy per year	100%	Use the percentage (expressed as a value between 0 and 100%)
Yearly average daily expenditure per tourist (DET)	US$ per day	US$300 per day (adjusted for inflation after base year)	$= \frac{\text{Daily Expenditure per Tourist}}{\text{US\$300}} \times 100$
Yearly cruise ship arrivals (CSA)	Ships per year per port	1500 per year†	$= \frac{\text{Yearly Arrivals}}{1500} \times 100$
		Final Index Score	**TDI Value** $= \frac{\text{RNR+RKC+HOR+DET+CSA}}{5}$

* Maximum Intensity – is defined as the value or level at which development activity is at the highest possible level.
** Any value above 100% is assigned a score of 100.
† Roughly the equivalent of 4 ships per day (above which would be an indicator of very heavy cruise ship activity)
The index scores are compared to a reference or baseline-year set of values (to be established) to determine relative change in tourism development pressure.

D3 Tourism Sustainability Index

What Is It?

The *Tourism Sustainability Index* (TSI) is a proposed indicator intended to measure the degree to which the tourism industry (including the hotel, marine recreation and cruise sectors) has taken steps to ensure that their activities minimize negative environmental and socio-cultural impacts. This index may be calculated for a specific tourist destination, a country or the entire MAR region.

Why Do We Measure It?

Sustainable tourism attempts to reduce negative environmental impacts by minimizing pollution, waste, energy consumption, water usage, landscaping chemicals and excessive nighttime lighting. It also attempts to benefit local residents through hiring practices, community involvement and respect for local cultures and traditions.

In recent years, voluntary environmental good practices programs have been developed to assist travelers in identifying enterprises (e.g., cruise lines, hotels and tour operators) that are environmentally and socially responsible in their day-to-day operations. In this regard, businesses may have to make additional investments to meet the new sustainable tourism guidelines and standards. Sustainable practices are increasingly considered by travelers to be an important indicator of overall visitation quality.

By measuring the cumulative percentage of tourism enterprises with certification credentials, the Tourism Sustainability Index provides a basic measure of the degree to which tourism in a given area meets basic environmental and social guidelines for sustainability.

How Do We Measure It?

The TSI takes into account three major tourism sectors:

- Percentage of rooms that are complying with sustainable tourism guidelines or eco-standards[6],
- Percentage of marine recreation providers (e.g., tour operators or guides) that are complying with sustainable tourism guidelines or eco-standards[7],
- Percentage of passengers arriving on cruise lines that are complying with sustainable tourism guidelines or eco-standards[8].

Benchmark

Establish TSI baseline values for each MAR country for the year 2006.

Increase the number of certified tourism businesses to achieve a TSI value of 30% by 2010.

Target

Achieve a TSI value of 80% by 2030.

Red Flag

TSI value is < 30%.

All three sectors are weighted equally within the index. In areas in which there are no cruise ship arrivals, this element should be left out of the average.

Scores range from 0 (indicating no formal presence of environmentally certified tourism operations) to 100 (indicating that all major tourism operations are certified).

The index scores are intended for comparison to a baseline year (to be established) with which relative change in tourism sustainability can be assessed.

Usefulness

The Tourism Sustainability Index provides a simple measure of the degree to which local tourism enterprises are abiding by standards designed to protect the environment and respect local populations. The higher the index score, the greater the percentage of tourism establishments that are operating according to sustainable management practices and with lesser impacts compared to conventional tourism operations.

Tracking the TSI through time also provides information on the growth or decline of environmentally and socially responsible tourism.

It should be noted that the TSI scores do not represent the overall environmental and social impact of tourism operations. In highly developed tourism zones, for example, the cumulative impact of tourism activities adhering to good environmental business practices may still greatly outweigh the impact in less developed areas where good environmental practices are not being used. Sustainable tourism does not preclude, but also should not be confused with, eco-tourism. (In contrast to conventional tourism activities, eco-tourism focuses on flora, fauna and cultural heritage as the primary attractions.)

The TSI as an indicator should be evaluated in conjunction with other data. Useful complementary information would include the Tourism Development Index and direct measures of environmental impact (e.g., erosion, sedimentation, water quality). Contextual information, such as the type of tourism being developed (e.g., eco-boutique establishments marketed exclusively to high-end tourists versus mass tourism operations) should also be included.

Status

Tourism Sustainability Index values are currently not available.

Information regarding certified marine recreation providers is being gathered from the ICRAN-CORAL project[7]. Information on hotels participating in voluntary performance improvement programs is being obtained from Conservation International's Center for Environmental Leadership in Business and from the Rainforest Alliance[6]. Conservation International and the MBRS project have produced several resources

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to guide the development of sustainable tourism for the cruise industry[8]. See Appendix 3 for information and links.

Data Needs

Other types of data to complement this indicator would include: type of tourism development, Tourism Development Index values, and returns on investment on certification efforts in terms of occupancy and revenues. Database of marine recreation service providers would also be useful.

Index Component	Unit of Expression	Maximum Value	Means of Calculation
The total number of hotel rooms that are in hotels participating in voluntary environmental performance improvement programs and attaining certification as a percentage of all rooms in a given area (TCR)	%	100%	No. of Participating Rooms X 100 Total No. of Rooms
The number of tour operators and guides (marine recreation providers) that are participating in voluntary performance improvement programs as a percentage of total operators (TCO)	%	100%	No. Participating Operators X 100 Total No. of Operators * see note
The number of cruise ship arrivals per port (CCA) that are from cruise lines participating in voluntary performance improvement programs	%	100%	No. of Passenger Arrivals from Participating Cruise Ships X 100 Total No. of Cruise Ship Passenger Arrivals
Final Index Score * If data become available on the annual volume of tours handled by each operator, this metric could be weighted by volume (as in the other components) for greater accuracy Note: Cruise sector % should not be included in the index for areas in which there are no cruise ship arrivals.			Total Sum/3 (for areas that receive cruise ships) = TCR+TCO+CCA 3 Total Sum/2 (for areas that do not receive cruise ships) = TCR+TCO 2

Land Use and Agriculture

Conservation Objective

Minimize the negative impacts of agriculture and other land uses by implementing environmentally sound and sustainable management practices.

Threats

Threats associated with inappropriate land use and poor agricultural practices include direct loss of habitat, increased sedimentation, and contamination of fluvial and marine ecosystems with fertilizers, pesticides, metals and hydrocarbons. These land-based impacts are a result of inadequate land use planning, lack of regulatory enforcement, unsustainable and intensive agricultural use, uncontrolled runoff and use of toxic chemicals and pesticides.

Management Actions

- Promote the adoption of eco-certification guidelines and low-impact management practices for major agro-industries and aquaculture.
- Develop and enforce the implementation of environmental regulations under the Central American Free Trade Agreement (CAFTA).
- Reduce the use of known toxic pesticides and harmonize rules on pesticide use and imports.
- Implement in all four countries the Protocol on Marine Pollution from Land-based Sources and Activities (supplement to the Cartagena Convention).
- Assess the extent of direct habitat loss, and determine whether reefs or related ecosystems are being exposed to rates of sedimentation or concentrations of pollutants that are above acceptable limits.
- Determine whether agrochemicals, pesticides or other contaminants are accumulating in indicator organisms and monitor for subsequent physiological stress responses.
- Reduce sediment discharge rates to levels that minimize negative impacts to MAR marine ecosystems.
- Minimize the entry of agrochemicals and other pollutants into the marine ecosystem through minimizing their use and implementing mitigation measures such as closed irrigation systems, treatment of wastewater and use of physical barriers to contamination.

Agriculture is perceived as the main driver of land-based threats in the Mesoamerican region, but urban and industrial development, aquaculture discharge, and atmospheric deposition of nutrients and other contaminants are significant as well. Industrial and agricultural activities located a great distance from coastal areas can still impact downstream estuaries, lagoons, seagrass beds and reefs.

Changes in land use (e.g., deforestation, agriculture, aquaculture, and dredge and fill operations) often result in increased erosion. Sediment transported out to sea decreases water clarity, which can decrease coral growth rates. Increased nutrient levels from sewage and fertilizers result in highly productive waters that may exacerbate the proliferation of fleshy algae, non-calcifying invertebrates and bioeroding organisms — all of which harm coral reefs. Toxic chemicals also adversely affect the growth, reproductive success and overall fitness of marine organisms.

Indicators selected to track the impacts of land use and agricultural practices are:

D4 - Agricultural Input Rates

D5 - Sediment Delivery Rates

D6 - Foraminifers (FORAM) Index

D7 - Contaminant Accumulation

Jose Vasquez/WWF

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D4 Agricultural Input Rates

What Is It?

Agricultural input rates are estimates of the quantities of fertilizers and pesticides applied to crops (per unit time) in order to maintain their economic productivity. These inputs will vary greatly depending on the crop being cultivated, the intensity and productivity of the agricultural system, and the management practices of each farm.

Benchmark

Develop an inventory of actual agricultural input rates by watershed and crop.

Target

Reduce agricultural input rates by at least 30% over the next 15 years.

Red Flag

Any annual increase in agricultural input rates.

Why Do We Measure It?

The delivery of agrochemicals — in the form of insecticides, fungicides, herbicides and fertilizers — to marine waters represents one of the most significant and persistent direct threats to the marine environment. Establishing mitigation strategies requires an understanding of the nature, volume and sources of agricultural inputs within a given watershed, as well as the impact of runoff on the marine environment.

Estimates of agricultural input rates help identify watershed areas that represent a current or growing source of agrochemical contamination. This information can be used to pinpoint critical areas of intervention where alternative management practices and technologies could be introduced to reduce the use of agrochemicals and mitigate potential threats to marine ecosystems.

The amount of agrochemicals applied in a given area is influenced by crop type, soil type, the intensity of the cropping system and general farm management practices. Different types of crops require different kinds and quantities of agricultural inputs. Large areas of agricultural production such as citrus groves, banana plantations or rice fields may also indicate the presence of high-intensity agricultural systems. Other considerations include substrate type, irrigation and weather impacts.

How Do We Measure It?

Data on fertilizer and pesticide use, if given in terms of national totals, are first converted to watershed totals, based on estimated percentages of agricultural lands within each watershed. For example, a final result would be presented as "kg of fungicide per year per hectare of banana plantation in watershed A."

It is recommended that a simple, GIS-based model be used to estimate agricultural inputs in the different watersheds of the MAR region. Land use coverage can be used to pinpoint the agricultural areas at the watershed scale by extent and crop class. These data can then be summarized into an estimate of total input per hectare within the watershed, based on the crop-specific land cover data and maps.

This type of model could be useful for providing agricultural input estimates to NOAA's Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) runoff model[9]. Flow accumulation, marine dispersion or other similar models could also be used to estimate the flow and dispersion of agriculture-derived pollutants into coastal and marine areas.

Estimates of agricultural inputs can be verified in the course of direct work and interventions to develop better management practices in collaboration with agro-industries.

Usefulness

Estimates of agricultural inputs are useful when agriculture-based activities have been identified as a critical threat to marine ecosystems and mitigation strategies to alter inputs (types or levels) are being considered. In such cases, the indicator provides direct information about which watersheds should be targeted for agrochemical reductions. Estimating agricultural input is most effective when using accurate, GIS-based (i.e., spatially explicit) information.

Clearly many factors affect the percentage of agrochemicals that actually end up in the marine environment (e.g., slope, riparian buffers, timing of use and method of application). Some of these issues are captured in the Sediment Delivery Rates indicator (D5).

Better management practices should produce a desired effect at a local level but, in conjunction with other efforts, contribute to the overall reduction of pollutants reaching the marine ecosystem.

The usefulness of this indicator will be enhanced if complementary testing is conducted to measure marine-based concentrations of agrochemicals or their by-products. When combined with oceanographic models of water flow from river mouths to reefs and other coastal areas, these datasets can help identify correlations between agricultural practices and observed or postulated ecosystem impacts.

Status

The figure below shows a summary of fertilizer input rates for each MAR Country. These rates vary significantly largely due to the kind of agriculture being practiced but also due to the scale at which these inputs are being applied.

Data Needs

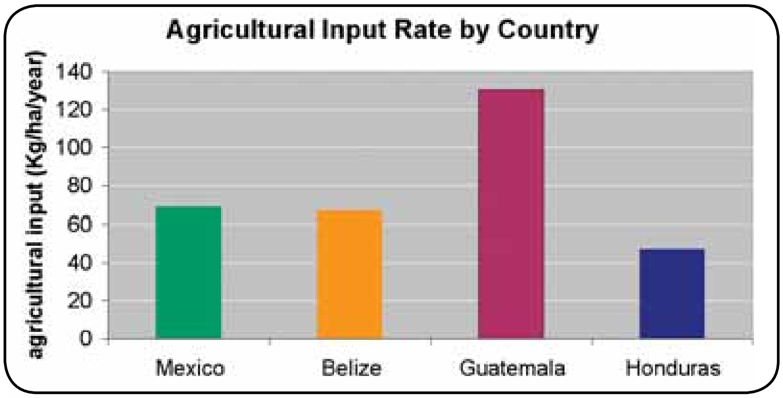
Data on fertilizer and pesticide use are available at a national scale for all four countries. WWF is compiling such data at the watershed scale in Honduras and Belize. Some watersheds have been completed[11].

Estimates of agricultural inputs per crop cycle can be obtained from groups working on agricultural practices (e.g., WWF and Rainforest Alliance), or by using standard United Nations Food and Agriculture Organization (FAO) estimates by crop type.

Jose Vasquez/WWF

GIS-based spatial information is needed for agriculturally productive areas that drain into the marine environment. Crop-specific land-use data are needed to develop a regionally consistent classification scheme for agricultural systems.

The physio-chemical processes affecting contaminant mobilization and deposition vary with different agrochemicals, so the strategies needed to reduce them also differ. Thus, the identification of which chemicals have the greatest negative impact on marine organisms and ecosystems is of paramount importance.



Data Source[10]

D5 Sediment Delivery Rates

Benchmark

Maintain (modeled) annual sediment delivery rates at current (2003/2004) levels.

Target

A 5% reduction in sediment delivery by 2025. Higher reductions (~10% could be achieved if appropriate agricultural management practices are adopted).

Red Flag

Any increase in modeled or measured sediment delivery rates.

What Is It?

Sediment delivery rate refers to an estimate of the amount of suspended solids that reach a river discharge point within a specific period of time. This rate indicates the extent of erosion occurring upstream, mobilizing sediments that will eventually be deposited in coastal and marine environments.

Why Do We Measure It?

Transport of soil into rivers and eventually coastal waters is a major concern, particularly for nearshore environments. Sediment erosion and deposition are naturally occurring processes to which marine ecosystems are adapted. However, land disturbances that increase sedimentation can impact marine ecosystems in several ways — some deleterious.

Increased water turbidity reduces the amount of light reaching the seafloor, thereby reducing photosynthesis (and growth) of seagrasses and corals. In severe cases (usually on nearshore reefs), corals and seagrasses can be literally smothered by sediment. In extreme cases, sedimentation can completely change the composition of the marine benthic community and alter shorelines.

Estimating, or modeling sediment delivery rates at river mouths provides information about which watersheds are likely contributing the majority of sediments to the coast. This information can be used to guide interventions. Management efforts then aim to maintain or reduce sediment discharge rates to levels that minimize disturbances to marine ecosystems.

How Do We Measure It?

Ideally, sediment delivery rates would be measured directly at each river mouth. Alternatively, sediment delivery can be estimated using GIS erosion and sediment delivery models, based on watershed characteristics such as land cover, precipitation, soil characteristics and slope.

Usefulness

Modeled sediment delivery rates are helpful for identifying potentially harmful levels of erosion on a spatially explicit basis. This indicator also provides the possibility of looking back in time, as delivery rates can be modeled for earlier times when the land cover was in an unaltered, "pristine" state.

Causes of observed or modeled increases in sediment delivery rates are not readily attributable to specific activities. It is impossible to determine (solely from a model) whether elevated delivery rates are being caused by (for example) agriculture, ranching, deforestation, general infrastructure development or climatic changes.

Therefore, it may be difficult to identify a point of intervention to address erosion issues. Repeated model iterations, incorporating refinements such as different agricultural management practices or more specific land cover classes, may prove helpful.

In addition, current models do not have the capacity to account for reduced sediment delivery for watersheds with hydroelectric dams (reservoirs of sediments) or those that are adopting better management practices to reduce erosion. Hopefully, future model versions will be able to accommodate these site-based adjustments.

Modeled delivery estimates must be validated at a range of river mouth sites (from actual measurements of sediment delivery rates). Observations of reef sedimentation rates and community structure, coral recruitment, and current flow patterns are also needed to identify potential impacts of sediment delivery on reef health.

Status

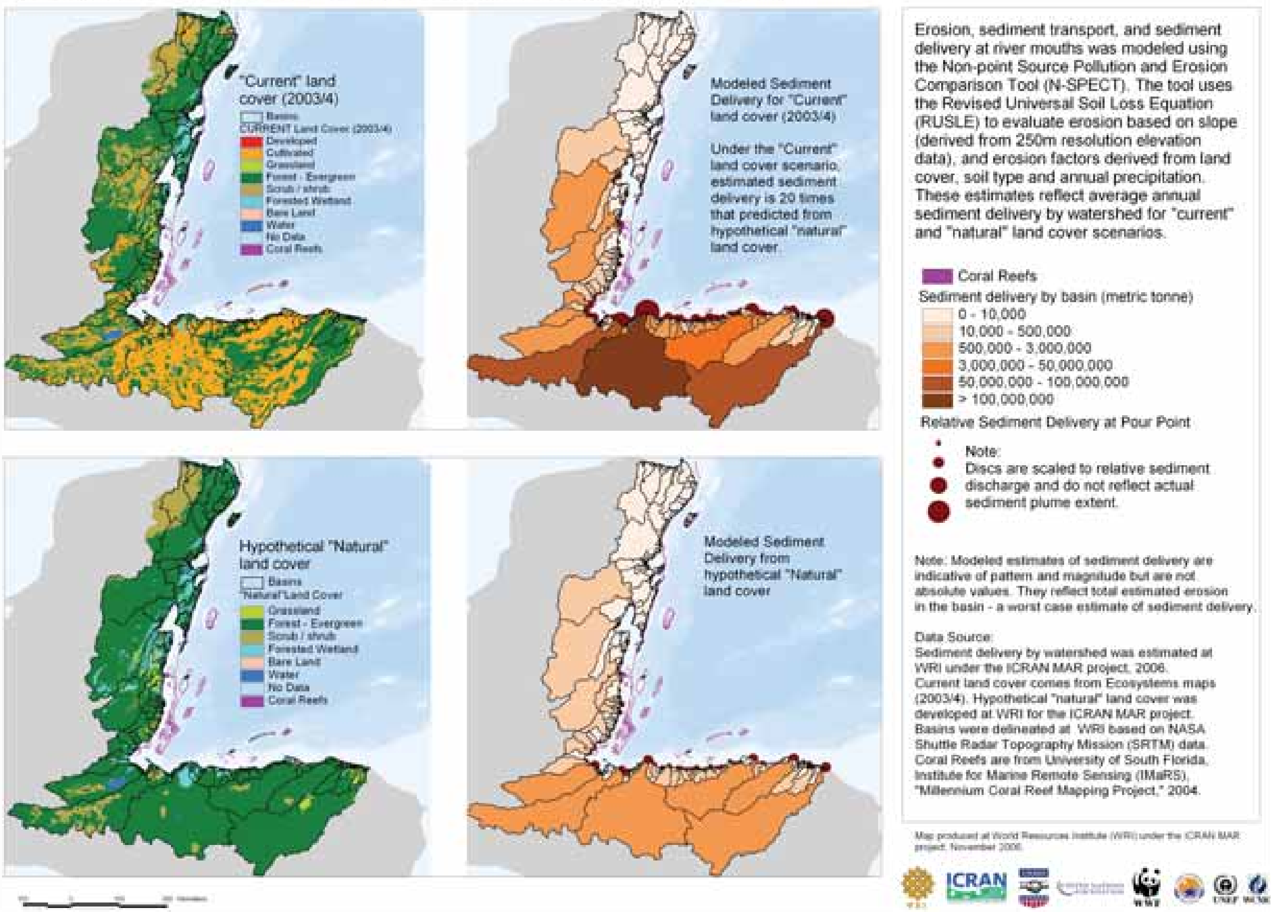
NOAA's Nonpoint Source Pollution and Erosion Comparison Tool (N-SPECT) estimates sediment delivery at river mouths draining into marine areas proximate to the Mesoamerican Reef[9]. This model was used to estimate and compare sediment delivery for two land cover scenarios: "natural" versus "current" (i.e., 2003/2004)[12].

The model results indicate that, on average, at a regional level, current rates of sediment delivery may be over 20 times that of natural (no development) conditions. The model also indicates that sediment delivery rates deviate most severely from hypothesized natural conditions in the southern MAR watersheds of Guatemala and Honduras. In the northern MAR watersheds (Quintana Roo and Belize), discharge rates remain much closer to hypothesized natural conditions. Completely natural land cover conditions have not existed in the MAR for the last few millennia, since before Mayan agricultural civilizations.

Data Needs

Measurements of sediment delivery rates at a variety of river mouths are needed to assess the accuracy of modeled estimates. New model versions could include a variety of agricultural management practices, to help evaluate the sediment-delivery impacts of different land management approches.

Human Impact on Annual Sediment Delivery from Watersheds (comparison of current verses hypothetical "natural" land cover)



Comparison of Regional Results for Annual Model Runs for Current and Natural Land Cover

Scenario	Freshwater Discharge (m^3)	Sediment (mt)†
Current (2003/2004)	60,088,829,077	431,129,480
Natural (no development)	34,501,909,421	19,115,006
Ratio of Current / Natural	1.74 (174%)	22.55 (2255%)

Date Source[12]

Note: Sediment delivery represents an upper-bound estimate for the region, as sediment attenuation due to redeposition en route to the river mouth is not accounted for. The values reflect overall erosion within the region and are indicative of the overall magnitude of sediment delivery, but should not be regarded as absolute values. The relative relationship between the scenarios is valid.

† mt=metric tonnes

D6 Foraminifers (FORAM) Index

What Is It?

Foraminifers (forams) are microscopic, shelled protists (one-celled organisms with a nucleus and other internal structures) belonging to a variety of species that inhabit a wide range of environmental conditions.

The *FORAM Index* (Foraminifers in Reef Assessment and Monitoring: FI) evaluates water quality (primarily nutrient loads). The index value is calculated according to the relative abundances of different benthic foram functional groups found in surface sediments of reef-associated environments.

Pamela Hallock

Why Do We Measure It?

Foraminifers with algal symbionts have similar water quality requirements to reef-building, zooxanthellate corals. Since coral reef communities are sensitive to a variety of stresses, it is critical to have an indicator of water quality conditions that can be measured even in the absence of healthy coral populations following mass mortality events (e.g., disease outbreaks or severe bleaching). Foraminifers can indicate whether water quality conditions (particularly nutrient concentrations) will likely support coral recovery from disturbances or not.

Benchmark

FI > 4: Physical environment suitable for reef growth with potential for recovery.

Target

FI > 6: Physical environment conducive for reef growth and recovery.

Red Flag

2 < FI > 4: Physical environment marginal for reef growth and unsuitable for recovery.

FI < 2: Physical environment unsuitable for reef growth.

Populations of larger foraminifers are immune to coral-specific diseases, and they recover more quickly from physical impacts than do long-lived coral populations. They may also be less sensitive to the effects of overfishing because they have less direct contact and fewer competitive interactions with macroalgae for reef substrate. Thus, they are less responsive to changes in herbivory levels and can be used to discriminate between the influence of water quality factors (like nutrient concentrations) and ecological controls (like herbivory levels) with regard to declines in reef quality.

The utility of the FORAM Index has been well established based on formal U.S. Environmental Protection Agency (EPA) evaluation guidelines for ecological indicators.

How Do We Measure It?

First, samples of seafloor sediment from reef-associated environments are collected using small plastic jars or film canisters[13]. Next, in a laboratory, the foraminifers are separated from the sediment samples and identified according to functional group:

- Symbiont-bearing,
- Stress-tolerant, or
- Small, heterotrophic.

The distribution of samples within each group is recorded on a spreadsheet, and the FORAM Index is calculated using simple equations that require only limited computer capabilities (see Appendix 3).

Usefulness

The tremendous taxonomic diversity and widespread occurrence of foraminifers make them potential bioindicators for different types of pollution. Their hard tests (shells) are readily preserved and can record evidence of environmental stress over time.
Foraminifers make ideal bioindicators because:

- They are widely dispersed in marine environments;
- They live on and in sediment, which can act as a sink for pollution;
- They are relatively small and abundant, permitting statistically significant sample sizes to be collected quickly and relatively inexpensively, ideally as a component of comprehensive monitoring programs; and
- Their relatively short life span, as compared with long-lived colonial corals, facilitates differentiation between long-term water quality decline and episodic stress events.

Therefore, the FORAM Index provides a tool for assessing whether water quality in the environment is adequate to support the symbiotic feeding strategy (mixotrophy) found in corals and some foraminifers[14].

The collected foraminiferal shells can also be subjected to morphometric and geochemical analyses in areas of suspected heavy-metal pollution. FORAM Index datasets can be used with other monitoring data in detailed multi-dimensional assessments.

Use of this index requires some training on identification of foraminiferal assemblages. However, a key advantage is the reliance on functional groups, which are recognizable worldwide, thus minimizing the need for local taxonomic specialists.

Status

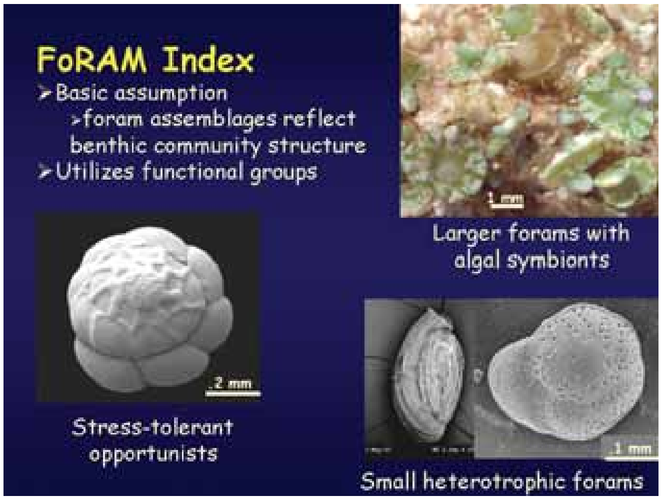
FORAM Index values for most areas in the region are not available at this time. However, as an example, in 1999, FORAM Index values for Glover's Reef Atoll, Belize, ranged from 1.8 to 3.2 with an average of 2.2[15]. These values indicate that the nutrient concentrations are higher than would be expected in this offshore atoll, and that the water conditions are marginal for reef growth and are not conducive to recovery (see red flag). Some unpublished nutrient measurements and analysis of ocean color images of fluvial plumes on the Honduran shelf offer some support for this interpretation[16,17].

A study of the same location 25 years prior found a greater abundance of symbiont-bearing taxa and a lower presence of heterotrophic taxa, specifically stress-tolerant heterotrophs[18]. Comparisons of the 1975 and 1999 datasets suggest a decrease in FORAM Index values at Glover's Reef Atoll in the last 25 years, indicative of declining water quality (increased nutrient availability).

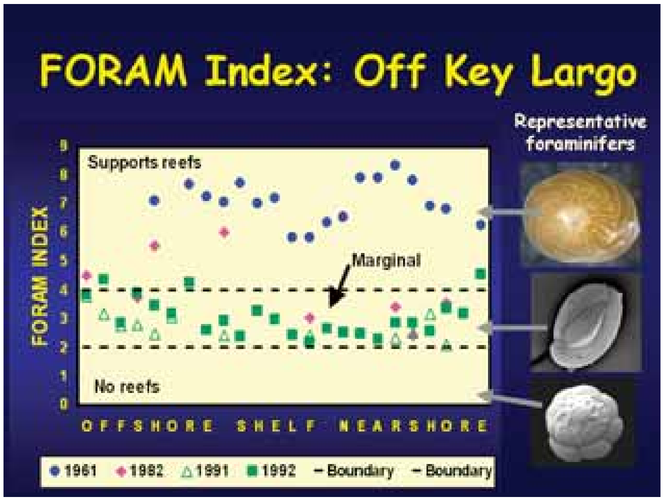
Data Needs

FORAM Index baseline values need to be established for coral reef systems throughout the MAR and Caribbean. Earlier studies with adequate foraminiferal assemblage data and archived sediment samples can be utilized to help provide historical context.

Pamela Hallock



Pamela Hallock



D7 Contaminant Accumulation

PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

What Is It?

This indicator is a direct measure of the types and quantities of chemical compounds (particularly agrochemicals) accumulating in the tissues of marine organisms and the sediments of marine environments.

Some contaminants found in the marine environment are associated primarily with agricultural activity (e.g., many fungicides and herbicides). Others (insecticides such as chlorpyriphos, malathion, or heavy metals) are also associated with golf courses, mosquito control programs and urban runoff.

Why Do We Measure It?

Although corals and other reef organisms have been the subject of few ecotoxicology studies, they are generally thought to be highly sensitive to chemical perturbations (particularly in larval development and settlement phases)[19]. Many chemical products used for inland applications (e.g., pest control) can be transported via rivers to the sea, where they eventually accumulate in sediments or the tissues of marine organisms. As a result, even chemicals applied far inland may have imperceptible but significant consequences on the condition and persistence of coral reefs.

Some compounds bind to sediment or organic matter that settles out in coastal environments. Others are lipophilic (fat-loving) and quickly become incorporated into plankton, invertebrates, and fish through the process of bioaccumulation through food webs. Others remain dissolved in the water for long periods, more slowly being incorporated into filter feeders and other marine life.

There is some recent evidence that coral bleaching can occur at lower temperatures if the coral is stressed by either agrochemicals or sediments[20]. Other recent studies have shown detrimental effects to coral planula survival and settlement success when exposed to low concentrations (~ 5 ppb) of some agrochemicals (e.g., chlorothalonil and Irgarol)[21].

How Do We Measure It?

Agrochemicals and other contaminants can be measured directly from tissue samples and sediments. A sampling protocol recently developed by WWF/ICRAN describes field and laboratory methods for analyses of mustard hill coral (*Porites asteroides*), queen conch (*Strombus gigas*), white grunt (*Haemulon plumierii*) and surface sediments[22]. The MBRS Synoptic Monitoring Program also contains a protocol for sediment collection and analysis of fish tissue for biomarkers of stress associated with chemical contaminants[23].

Benchmark

Establish baseline values of "current" levels for different species and areas,

Determine short-term benchmarks for contaminant reductions.

Target

Reduce contaminant levels in sediments and marine organisms to acceptable limits (to be determined).

Red Flag

Any increase in contaminant concentrations from (current 2006 levels) in marine organisms or sediment samples.

Usefulness

The accumulation of contaminants is a strong indicator of agricultural activity (and, to some extent, general coastal development). Some of these chemicals are carcinogens, others endocrine disruptors, and others may interfere with neurological development or other physiological processes. The potential impacts of chemical contaminants are of concern to both marine life and the human populations that consume these marine organisms (measured in indicator SW1 – Contaminants in Breast Milk). When considered in conjunction with coastal development and agricultural input indicators, the linkages between these activities and potential health implications can be identified more readily.

While some chemicals of concern (e.g., chlorothalonil) may be fairly specific to certain agricultural crops (e.g., bananas), other chemicals (e.g., malathion) also have non-agricultural uses. Furthermore, complex cross-shelf sampling schemes (from rivers out to reefs) would be needed to help pinpoint the origin of chemicals found in reef organisms. Therefore, caution and prudence must be exercised in interpreting bioaccumulation results, which must be placed in the appropriate context in order to be understood and acted upon properly.

It is important to remember that the mere presence of these chemicals in marine life and sediments is only a *potential* problem, with ecotoxicological tests needed to determine the physiological or ecological significance of different concentrations.

Great care and attention must be taken in field sampling protocols to avoid cross-contamination and subsequent contamination of samples. Likewise, strict laboratory procedures and controls are required to ensure consistent and accurate results.

Craig Downs

Status

Few data on contaminant accumulation in reef organisms are available, although work is currently underway by WWF and partners. Preliminary data indicate that the most prevalent compounds in reef organisms are chlorothalonil, imidacloprid, malathion, DDT, mancozeb, deltamethrin, fipronil, propanil, lindane, and aldrin. Contaminant concentrations in marine organisms range from non-detectable to relatively high ~ 2 ppm (mg/kg)[24].

Top-level predator fish species are more likely to have the highest concentrations of highly persistent chemicals. Other species (like the white grunt) have been found to contain the widest range of compounds in rather high concentrations, probably due to their variety of food sources.

The MBRS Synoptic Monitoring Program has collected some data on chlordane and hexachlorocyclohexane (HCH). Both pesticides have been banned or severely restricted in the MAR region, but, due to their persistence, traces still remain in the environment. Maps of summarized data are available at the MBRS website (www.mbrs.org.bz)[25].

Data Needs

Further sampling is needed to establish baseline values for a variety of chemicals and locations throughout the MAR. Data from ecotoxicology studies using a variety of marine organisms are needed, including those on sensitive larval and settlement phases. A variety of marine organisms (e.g., corals, crustaceans, mollusks, echinoderms, and fishes) need to be evaluated because the response and physiological pathways of chemical exposure vary among these organisms.

Fishing

Conservation Objective

Achieve region-wide sustainable levels of fishing in the MAR, thus supporting traditional livelihoods and avoiding the ecological consequences of overfishing. Maintain or improve the biological integrity and economic viability of commercially valuable marine resources by increasing the population abundances of commercial species, improving and restoring habitats, increasing the effectiveness and enforcement of fishing regulations, and implementing effective eco-certification schemes.

Threats

Unsustainable fishing practices such as overharvesting, illegal fishing and destructive fishing practices are serious threats in the MAR. At greatest risk are fisheries-targeted species such as grouper, conch, and lobster. The condition and recovery of highly degraded reef habitats are also affected by unsustainable fishing practices. Management actions to reduce these threats need to consider the existing status of commercial species, availability and connectivity of intact habitats, and management regulations (e.g., seasonal closures, size and weight restrictions, and fishing methods). High food demand, lack of coordinated regional management, and lack of effective certification programs also hinder the sustainable management of fisheries resources.

Management Actions

- Eliminate illegal fishing and destructive fishing practices in the region.
- Implement coordinated, standardized regional assessments of commercial fish species, conch and lobster. Surveys should include species abundance, size, habitat use, reproduction and dispersal, catch per unit effort (CPUE) and management effectiveness.
- Implement harmonized management of shared fisheries resources.
- Promote the development of certification (or eco-labeling) programs for the major fisheries in the region to provide sustainable seafood.
- Locate and protect important conch mating grounds.
- Implement and enforce conch and lobster size, season and gear restrictions.
- Establish baseline and target values for commercial fish population densities and spiny lobster abundances; establish estimates of maximum sustainable yields.
- Identify spawning aggregations in lesser-known but potentially significant areas.
- Maintain the viability of fish spawning aggregations through coordinated protection strategies.
- Limit total volume of harvest (local and export including the allocation of spatial concessions and fishing rights) so as not to exceed estimated maximum sustainable yields established for the most significant commercial species.

Many scientists consider overfishing to be one of the primary causes of coral reef ecosystem decline in the MAR. The problem with overfishing is simple: humans are overly successful as an apex predator and are now fishing at all levels of the food web.

As a result of overfishing, fish populations have suffered a decline in population abundance (particularly of the larger/older individuals), reduced species diversity, loss of key functional groups and local extinctions of species. Key coral reef processes such as coral recruitment and herbivory have likely been altered as well due to overfishing. The longstanding and dramatic loss of megavertebrates (e.g., sea turtles and manatees from fishing and poaching) has resulted in significantly reduced grazing on and productivity of seagrasses, reduced predation on sponges, loss of production of adjacent ecosystems, and alteration of the structure of food webs. Overall, unsustainable fishing practices also result in the disruption of energy flows and the natural interactions that confer resilience to the reef ecosystem.

Overfishing in the MAR affects not only targeted species. It has reached a disturbing level that encompasses the entire ecosystem, resulting in major changes in natural processes and phase shifts to alternative community types when key herbivores are affected. Overfishing is often not readily apparent due to a time lag between the time of overexploitation and the time when disruptions in ecological processes become evident. The ecological mechanisms for cascading effects from the loss of top predators to key herbivores are not fully understood.

Species at greatest risk in the MAR today include the groupers and snappers, queen conch and spiny lobster and secondary value reef fishes, including key herbivores like large parrotfishes that help maintain clean settlement space for coral recruits.

Snappers and groupers have formed the basis for commercial and recreational fisheries in the region for decades. Traditionally exploited during spawning periods, their populations have declined dramatically from historic levels, and several historical aggregations have disappeared in the MAR region. Declines in fish abundance and catches are attributed to lowered populations, overexploitation, changing economic circumstances, illegal fishing, destructive fishing methods (e.g., the use of gill nets) and lack of regulatory enforcement.

Throughout the MAR, queen conch (*Strombus gigas*) and spiny lobster (*Panulirus argus*) have important economic, social and cultural value. Nevertheless, overexploitation, illegal fishing, poor regulatory enforcement and lack of transboundary management over the last 30 years have resulted in declining populations and decreases in catches. Management of these fisheries varies throughout the region. Illegal fishing is common throughout the region and transboundary issues are largely ignored.

Indicators selected to track overfishing are related to the presence or absence of fisheries management interventions, fishing practices, production volumes and resulting impacts on natural populations of the target species populations, and include:

D8 - Certified Fisheries Products

D9 - Volume of Production

D10 - Conch Abundance

D11 - Spiny Lobster Abundance

D12 - Protected Fish Spawning Aggregations

Note: Fish are considered under Fish Abundance (S6) and Herbivorous Fish Abundance (F11), and these indicators can also be used to evaluate the effects of fishing on commercial species.

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D8 Certified Fisheries Products

What Is It?

Fisheries certification encompasses a variety of eco-certification or eco-labeling plans that generally serve to distinguish products that have been produced in accordance with certain environmental standards designed to achieve both sustainable resources and a sustainable ecosystem. In some cases, certification also requires that production techniques minimize secondary environmental impacts.

One of the most well-known organizations in marine product certification, the Marine Stewardship Council (MSC), defines a certified fishery as: "*Fisheries that achieve certification demonstrate management operations that maintain healthy populations of targeted species, protect the integrity of ecosystems, and balance biological, social and commercial interests*[26]." Certified fisheries are entitled to use the distinguishing MSC logo for identification in the marketplace and are well poised to meet the growing demand for sustainable seafood.

This indicator is applied to economically valuable marine species in danger of reaching critically low population densities due to fishing pressure. Assuming rigor in testing and certification standards, this indicator is a measure of how much of the total marine harvest on the market is taken in a sustainable manner.

Benchmark

At least two fisheries or marine product exports (potentially including farmed shrimp) are eco-certified.

Target

30% - 50% of total marine product exports are eco-certified.

Red Flag

No fisheries or marine product exports can meet the criteria for eco-certification.

Why Do We Measure It?

Long-term resource sustainability is of great concern to producers and consumers alike. In many cases, market demand for marine resources has demonstrated that consumers are willing to pay more for the assurance that the goods they are consuming are harvested in a way that ensures the long-term viability of the resource.

There are several marine product certification programs with strict standards that producers must meet in order to receive a seal of approval[26,27]. Eco-labels enable consumers to identify seafood that has come from a sustainable source. Although the methods may differ, the end goal of resource sustainability and minimal environmental damage remains a common thread across the various certification mechanisms.

The volume of certified fisheries products, expressed as a percentage of all production, therefore, can be used as an indicator of the extent to which sustainable fishing practices have penetrated the fishing industry as a whole. Species abundance data can be used to evaluate the success of certified sustainable fisheries management programs in maintaining the overall viability of species populations.

Certification or eco-labeling also provides a venue for which proper documentation of harvesting regimes and actual extraction data substantiates the certification process. The underlying assumption here is that the higher the percentage of certified fisheries products, the more sustainable the fisheries sector is over the long term. However, it must be noted that some uncertified operations may, in fact, be employing sustainable fisheries practices but simply have not undergone the certification process.

How Do We Measure It?

At this time, the major demand for certified marine products resides in the international markets of the United States and Europe, where consumers can afford the higher price of certified seafood products. However, in the MAR, sustainable seafood options can be offered to tourists who, over time, can create a local demand for certified seafood. This indicator is measured by both the number of fisheries in the region that become certified (e.g., lobster in Sian Ka'an, conch in Belize) and as the ratio of exported certified marine products to the total volume of exported marine products.

The certification agency (e.g., Marine Stewardship Council or MSC) keeps track of the volume of certified production, which can then be compared to governmental or FAO records of total production. National export records can be used to calculate the percent of exports from certified suppliers. Each fishery certified covers a particular species (e.g., spiny lobster) in a particular place (e.g., Belize). The size of the area contained in that fishery depends on the species population dynamics and on the data used to demonstrate sustainable management.

Usefulness

This indicator can be considered a proxy for the likelihood of successful, sustainable management of the primary fisheries in the region, with an increasing percent of eco-certified fisheries indicating an increased likelihood of successful management. By comparing the trends in fisheries certification to trends in population abundance (e.g., D10 — Conch Abundance and D11 — Spiny Lobster Abundance) and fisheries yields (D9 — Volume of Production), the effectiveness of certification as a strategy for sustainable marine resource use can be evaluated.

However, fisheries production is not a closed system. Products sold in local markets go largely unmeasured — in terms of both volume of production and total monetary value. Conservation efforts within marine protected areas can also contribute to improved viability of the species. Therefore, the attribution of success to the certification scheme must be balanced against these other factors that also influence the long-term viability of the species and sustainability of fisheries activities.

Status

The largest marine export products in the region are lobster, conch and shrimp. Although export production volumes for these species are well documented, no eco-certification programs have yet to be established in the MAR.

A feasibility study was conducted by WWF for the Banco Chinchorro, Mexico, lobster fishery[28]. This study highlighted some difficulties for attaining MSC certification for any relatively small area in the Caribbean due to the long larval stage of lobster and the wide range of the meta-population. However, continuing research on larval connectivity is reducing the spatial envelope of connectivity, and now similar certification efforts are underway with the Sian Ka'an Biosphere Reserve lobster fishery (also in Mexico).

An example of a certified lobster fishery (outside the MAR but in Mexico) is the Gulf of California lobster fishery, which was recently certified by the MSC. As an alternative to the requirements of full MSC certification, several organizations have supported regional efforts to establish "better management practices" in the lobster and conch fisheries as a first step toward potential certification within the MAR[29].

Sergio Hoare / WCS

As the queen conch is listed under the CITES convention, conch exports are allowed only by countries that demonstrate adequate management of their stocks. Thus Mexico and Belize have demonstrated some degree of adequate management of their conch fisheries, although the requirements for CITES are much less stringent than actual eco-certification schemes developed by the MSC. Honduras was banned from exporting conch in 2004 due to concerns of overexploitation (including citations related to illegal and undersize harvesting).

Wild-caught shrimp are an unlikely candidate for eco-certification due to the ecological damage and by-catch resulting from shrimp trawling. One exception exists for the very small-scale artisanal shrimp harvest using cast nets. However, appropriately sited and well-managed shrimp aquaculture does have the potential for some type of eco-certification, with two such efforts now underway in Belize (through WWF and Environmental Defense).

Data Needs

Information needed to define certification data parameters include the following:

- Natural population abundance (densities) over time,
- Catch per unit effort over time,
- Minimum size and weight requirements for extraction,
- Prescribed harvesting seasons,
- Restricted fishing zones, and
- Accepted fishing gear and methods.

D9 Volume of Production

Benchmark

No increase in volume harvest (from 2005 levels) until total sustainable volume harvest is determined.

Target

Total volume of harvest (local and export) should not exceed estimated maximum sustainable yield established per species. Volume of production should remain stable or increase over time (on average, given natural population fluctuations).

Red Flag

Consistent declines in the total harvest volume over a 3 to 5 year period.

What Is It?

The *volume of production per species* is an estimated measure of the volume of resource being taken out of existing fisheries populations. Through additional calculations, total volume of harvest can be converted to an approximation of the number of individuals depleted from wild populations through fishing. For most MAR countries species-level production data are available only for spiny lobster and queen conch, with all fish species being aggregated.

Why Do We Measure It?

Knowing the volumes of marine resources being extracted is critical for estimating each species' capacity to support viable fishing activity. The proportion of the population that is being depleted through fishing is estimated by comparing the number of individuals harvested against their estimated abundance. Fishing is then controlled through regulations to ensure that harvest volumes do not exceed the theoretical rate at which the population replenishes itself.

How Do We Measure It?

Data for annual production of key indicator commercial species for the Western Central Atlantic Region are extracted from the FAO FishStat dataset (see Appendix 3 for details)[30]. This database provides nominal catch data for a variety of marine species or taxa [e.g., spiny lobster, queen conch, fin fish (all species combined) and stromboid mollusks] taken for commercial, industrial, recreational and subsistence purposes. Data should include all recorded quantities caught and landed, including products for both human consumption and animal feed but excluding discards. FAO reports that their totals frequently underestimate the real catch of the individual species due to numerous factors. For example, much of the fisheries production in rural areas of the MAR may be sold in local markets and not recorded in any national databases (also not reported to FAO). The FAO data can be cross-referenced with various national fisheries reports.

Lisa Carnes

The volume of the marine resource is expressed as live weight in metric tonnes (mt). This value can then be converted to an estimated number of individuals harvested, which can be compared to population abundance data and maximum sustainable yield estimates.

Usefulness

Estimating the production of each major fishery resource is one way to determine fishing mortality. It is also a key factor in the resource sustainability equation — one that can be controlled directly through regulatory means.

A major limitation of this indicator is the lack of data on unreported production that is consumed locally in some of the MAR countries. Export estimates do not reflect total catch but are sometimes used for estimating total production (assuming some percent is consumed locally and not recorded). In this regard, production volume is most accurate if data on fisheries products sold in local markets (both formal and informal) are also collected annually.

Additional information on catch per unit effort (CPUE) would greatly enhance the value of this indicator, although collecting these data over the entire region would be difficult. Mexico routinely monitors CPUE in a number of fisheries, but the other Mesoamerican countries appear to undertake less systematic collection of CPUE data.

Status

The FAO data indicate annual variation in the production of spiny lobster and strombid conch in the 1995 to 2004 period, but do not show a clear overall trend during that 10-year period (see figures below)[30]. The data for Honduras and Mexico include areas that are outside the MAR ecoregional boundary (Figure 1.a. Section 1) but are all within the Caribbean and Gulf of Mexico.

Additional species data from national reports follows:

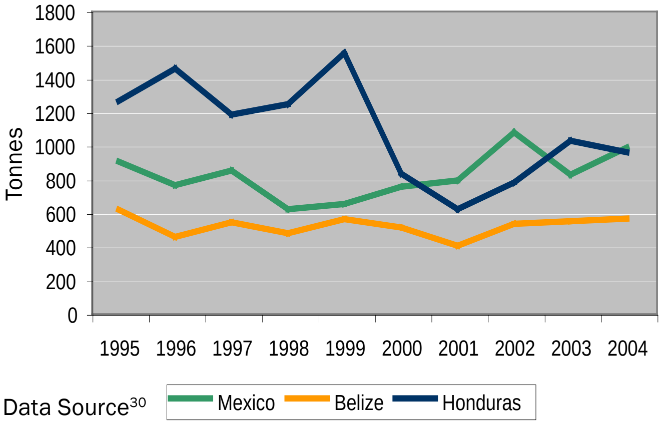
- Mexico exported 1.4 metric tonnes (mt) of conch in 2002[31]. Quintana Roo exported 30 mt of conch[32] in 2005, responding to the increased quota after some populations recovered from a no-fishing moratorium (see D10 Conch Abundance).
- Belize produced 241 mt of conch meat in 2003[33]. Based on historical data, a maximum sustainable yield of 324 mt has been determined, while a harvest quota of 280 mt has been set[34].
- Honduras exported 1,330 mt of conch meat to the US in 2001, almost double its 1998 exports of 750 mt[2].
- Lobster production declined 11% in Mexico (Caribbean) between 1990 and 2001[30]. Quintana Roo contributed 248 mt to overall production[32].
- Belize lobster production has remained fairly stable at about 171 to 272 mt per year over the last five years[33].
- Honduras experienced a significant decline of a little more than 50% from 3000 mt of lobster in 1991 to 1300 mt in 1998[35].

Data Needs

Actual harvest production volumes (including exports and local markets) need to be collected per species for different fishing zones, MPAs, or other well-defined subregions within the MAR. Spatially comparable CPUE data are also needed for target species (e.g., lobster, conch), possibly with quotas developed for key species based on modeled maximum sustainable yield per species. Regional standardization of fisheries data collection protocols and reporting procedures (including both exports and total production) would result in an improved understanding of the regional trends in fisheries production.

Caribbean Spiny Lobster Production by Country (for the Caribbean and Gulf of Mexico)

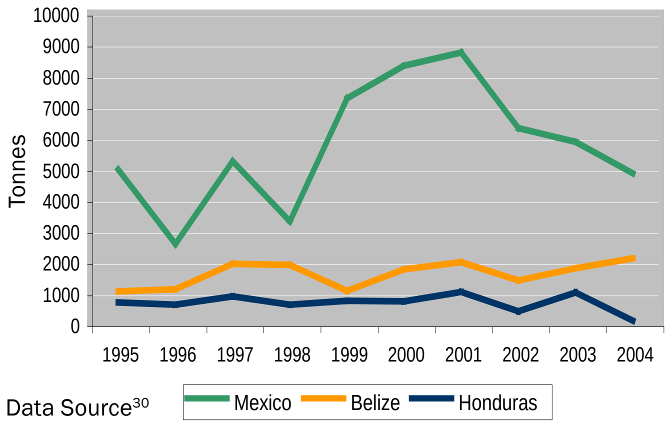
(Live weight in Tonnes)



Data Source[30]

Stromboid Conch† Production by Country (for the Caribbean and Gulf of Mexico)

(Live weight in Tonnes)



Data Source[30]
† All species

FISHING
D9

D10 PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

Conch Abundance

What Is It?

Queen conch (*Strombus gigas*) are large, herbivorous marine mollusks usually found in shallow sandy areas with seagrass-algal meadows or mixed coral communities. Throughout the MAR region, the queen conch has important economic, social and cultural value — for which reasons it is a targeted commercial species. The *conch abundance* indicator is measured as the number of individuals per hectare (i.e., density).

The queen conch has been listed in CITES Appendix II since 1992, which means that CITES permits must be issued for all exports. Exporting nations must demonstrate that their stocks are stable and well-managed. This requirement has spurred research and documentation of stocks in the region.

Benchmark

Adult conch populations of 50-300 individuals per hectare (depending on habitat and management zone) within the next 5-10 years.

Target

Adult conch populations of 300-800 individuals per hectare within the next 20-25 years.

Red Flag

Any consistent (3-4 year) reduction in average density, particularly when correlated with a drop in production (indicator D9).

Why Do We Measure It?

Queen conch have an important ecological role as herbivores, as well as a socioeconomic role as an important fishery in the region. Conch populations in the MAR are considered important to the wider Caribbean and may include both "source" and "sink" populations (both providing and receiving recruits) for areas outside the MAR.

The density of conch (number of adult individuals per hectare) is a significant indicator of population status, as scientific studies have demonstrated that densities lower than 50 conch/ha result in reproductive failure[36,37]. More recent studies indicate that the critical threshold for reproductive success may be as high as 200 conch/ha[38]. Equally important are data on essential nursery grounds, which are often defined by specific abiotic and biotic characteristics (e.g., water circulation, food availability, benthic community, and sediment type).

Overexploitation, illegal harvesting of undersized animals, poor regulatory enforcement, and lack of transboundary management over the last 30 years have resulted in declining conch populations and decreases in catches. Moreover, the complex biology of *S. gigas* does not lend itself well to recovery after populations have been heavily depleted. The result has been local extinctions and economic collapse of the fishery in some areas.

How Do We Measure It?

The most significant parameter to measure the status of conch populations is overall abundance (measured as their density or number of individuals per hectare), which is surveyed by using belt transects to count the number of conch in a spatially defined area. Population structure is estimated by taking direct measurements of shell size and lip thickness to estimate age.

Usefulness

Conch abundance is a good indicator as it provides immediate feedback regarding overfishing impacts and is responsive to management strategies.

This indicator also has high ecological relevance as conch are important herbivores associated with sandy seagrass habitats. Comparing field-based abundance data to production (catch) volume from the same area (e.g., fishing zone or MPA) provides enhanced understanding of the fishing effects and production capacity of each area.

Data collection methods for assessing conch abundance are usually simple and inexpensive. Collecting data on larval dispersal may require more fieldwork and expertise, but such data are essential in understanding connectivity of populations and effectiveness of management actions. The usefulness of the data can be improved by standardizing collection and reporting methods in the region.

Status

Data on natural population abundances (density measures) are often lacking. The majority of natural conch abundance monitoring occurs within MPAs. It is important that such monitoring also includes control areas outside the MPA boundaries.

The status of queen conch in the Mesoamerican Reef region varies significantly throughout the region. Following the decimation of Yucatan, Mexico, conch populations in the 1980s, a ban on conch fishing was put in place there. Quintana Roo enacted a ban in 1991, although Banco Chinchorro and Banco de Cozumel are now open to conch fishing[37] because populations increased after the ban on fishing. In Cozumel, conch density was reported at 89 conch/ha in 1989 and increased to 830 conch/ha in 1995[39]. In 1999, an average density of 0.14 conch/m^2 (or 1,400 conch/ha) was recorded for four sites in Banco Chinchorro[39]. Both these areas have a limited conch quota set each year.

In Belize, analysis of conch density inside versus outside marine protected areas illustrates the potential of reserves to increase densities to levels that are reproductively viable — thereby serving as reseeding areas. Data from Glover's Reef Marine Reserve taken in 2001 (four years after full enforcement of the reserve) found almost 900 adult conch/ha in the "no-take" zone compared to just over 200 adult conch in the "general-use" zone[40]. Subsequent monitoring (summer 2004 to 2005) at Glover's found 1100 adult (> 110 mm) conch in the "no-take" zone, while 500 conch/ha were found in the "general-use" zone[41].

The Belize national conch survey (conducted for CITES) found an average density of 44 conch/ha in open fishing areas (including the "general use" areas of marine reserves) and an average of 266 conch/ha in the "no-take" zones where no fishing is allowed[34]. In 1996, overall conch density was reported at 14.9 conch/ha, increasing to 43.95 conch/ha in 2004[34].

In 2003, at the request of CITES, Honduras agreed to halt all export of conch until further notice and to increase efforts to better survey and regulate the fishing industry[42]. In 2006, Honduras requested the CITES ban be lifted so that exports could resume. One of the only studies available documenting conch density in Honduras is for Cayos Cochinos (a protected area), which reported 14.5 conch/ha in 1998[35].

The only areas that approximate the target of 300 – 800 conch/ha are protected areas or those that have recovered from a fishing moratorium. The Cozumel and Banco Chinchorro abundances remain relatively high despite the limited fishing activity. The remainder of the region's fishing areas (outside of MPAs) appears to have fairly low abundances. The average abundance for Belize is in the low range of the benchmark, and updated information is needed from Honduras, which appears to have the overall lowest population abundance.

Data Needs

A regionally comparable assessment on conch abundance, size, and habitat classification is needed, with particular attention to nursery areas, habitat occurrences and the role of marine protected areas. Other data needs include: reproductive and dispersal studies, information on different management mechanisms throughout the region, data on illegal fishing and transboundary issues, potential impact of pollution on reproductive fitness (based on impacts observed in inshore Florida populations), local consumption and production, and connectivity among populations (especially shallow-water and deepwater populations, including reproductive/mating banks).


Mito Paz

D11 Spiny Lobster Abundance

What Is It?

The spiny lobster (*Panulirus argus*) is a large crustacean that occurs throughout the Caribbean. Spiny lobsters are distinguished by their long, thick, spiny antennae and complete lack of claws. They often live in crevices of coral reefs, mangrove prop roots or seagrass beds, emerging at night to forage for food.

In the MAR region, lobster is the most valuable marine export product and is, therefore, of great importance to coastal livelihoods (see below). *Spiny lobster abundance* is measured in terms of their density (number of individuals per hectare) in specified lobster habitats.

Why Do We Measure It?

Spiny lobster fishing is a key activity that supports marine-based livelihoods in the MAR region. Measuring the natural population density provides a results-based indicator of fisheries management efforts. Although each country implements regulatory measures to protect the species from unsustainable exploitation, the fishery has experienced significant declines in production. As such, the viability of populations in the wild that support the lobster fishery is of particular concern. Major declines in the abundance of this species (and its valuable commercial fishery) would produce economic hardship for fishers.

Lobster populations in the MAR are considered important to the wider Caribbean and may include both "source" and "sink" populations (both providing and receiving recruits) for areas outside the MAR.

How Do We Measure It?

Spiny lobster stock assessments are usually conducted by divers using belt transect methods to measure occurrence over a specific area and calculate lobster density.

In the region, various monitoring efforts are underway; however, the data are often specific to select marine protected areas. There is no routine regional stock assessment or standardized methodology for the region. Production data by country are consistently collected throughout the region (see Indicator D9 Volume of Production).

Benchmark

Increase average spiny lobster abundance by 7% in each country by 2011.

Establish baseline values for spiny lobster abundance in the MAR region, using no-fishing zones to indicate optimal "natural" densities.

Target

Increase average spiny lobster abundance by 30% in each country by 2025.

Red Flag

Any consistent (3-4 year) reduction in average density, particularly when correlated with a drop in production.

Usefulness

Measuring population abundance or density directly characterizes the status of wild spiny lobster stocks in the MAR region. It also helps estimate whether populations are able to sustain the current level of extraction, or if the level of extraction exceeds the natural replenishment. It also serves as a signal for managers to take action when abundance levels decrease below established viability thresholds.

Status

Currently there are limited data on the overall regional abundance or density of spiny lobster in the MAR. Data from several MPAs in Belize include the following:

- Data from Glover's Reef Marine Reserve taken in 2001 (four years after full enforcement of the reserve) found almost 90 adult lobster/hectare in the "no-take" zone versus about 25 adult lobster/ha in the 'general-use" zone[40]. From summer 2004 to summer 2005, average lobster densities were five times higher in the "no-take" zone (50 lobster/ha) than in the "general-use" zone (10 lobster/ha)[41].

- Laughing Bird Caye National Park (fully a "no-take" zone) reported 200 lobster/ha inside the park compared to 100 lobster/ha outside in 2002 surveys[43]. Results for nearby Gladden Spit Marine Reserve found fewer than 10 lobster/ha for both "general-use" and "no-take" zones, although this "no-take" zone had only been enforced for about one year (relative to this 2002 survey)[44].

Some areas, particularly in Punta Allen, Mexico (Sian Ka'an Biosphere Reserve), have exemplary regulations and enforcement and are thought to be in stable condition. Other areas, particularly in Honduras, have widespread unsustainable fishing practices, including the use of SCUBA gear for fishing deep populations.

Data Needs

Region-wide standards for monitoring lobster abundance need to be established, including the timing (months) for assessments, lengths and numbers of transects per site, and size ranges for adult versus juvenile comparisons.

In general, more information is needed regarding the following:

- Spiny lobster population abundance or density,
- Volume of local consumption,
- Level of fishing pressure (number of fishers, fishing methods, CPUE), and
- Connectivity among different populations.

Melanie McField/WWF

D12 Protected Fish Spawning Aggregations

Benchmark

Identify spawning aggregation sites in Honduras and fully protect 20-30% of the known sites in Honduras and Mexico by 2015. Implement management of all protected SPAGs in Belize.

Target

Protect at least 50% of all known SPAG sites in each country in the MAR region through the implementation of 'no-take' zones and active management of sites.

Red Flag

No increase in the current (2006) percent of SPAGS that are fully protected.

What Is It?

Fish spawning aggregations (SPAG) are large groupings of fish that tend to form in a defined area (e.g., near reef promontories or sharp reef projections) strictly for the purpose of breeding. Aggregations of various fish species, including groupers, snappers and jacks, have been observed on many promontories in the MAR region throughout different times of the year. "Protected" aggregations refer to those within marine protected areas (MPAs).

Individual fish travel long distances along the MAR reef to gather at a specific site for spawning. Depending on the species, aggregations can number in the thousands (as with snapper) or in the hundreds (as with grouper).

Because large variations exist among aggregations in the region (in terms of aggregation size, seasonality, location and spawning behavior), a simple measure of the percentage of known aggregations that are under some form of protection is used as a surrogate measure of spawning success.

Why Do We Measure It?

This aggregation phenomenon is a critical stage in the life cycle of various fish species. It is also a stage in which populations are most vulnerable to fishing for the following reasons:

- Aggregations are predictable in space and time, so that fishing pressure is concentrated during known seasons (generally November to February for grouper, and May to July for snapper);
- Aggregations are large groupings that are easily targeted for fishing;
- General fish behavior can be more aggressive during spawning, leaving fish more susceptible to fishing at this time; and
- Aggregations are composed mostly of the adult breeding individuals that are large in size and, therefore, represent greater catch returns per unit effort of fishing.

In many cases in Asia, the Pacific, the Caribbean and several cases in the MAR, aggregations of fish have been known to stop forming because of the severe decline in fish numbers due to harvesting activities.

High levels of fishing, both within and outside of the spawning seasons, are contributing to the continued decline in the abundance of fish at the spawning sites — even for some sites with full protection.

The MAR region is believed to contain some of the Caribbean's most viable fish aggregations for economically valuable species. One example is the Nassau grouper, which has undergone local extinctions throughout the Caribbean.

Although protection of these aggregations encompasses only one phase of their full life cycle, it is the most critical in terms of preventing overfishing during a time of increased vulnerability. Such protection allows the optimization of spawning events, which helps ensure the persistence of future generations.

How Do We Measure It?

Fish spawning aggregations have been identified in Mexico, Belize and Honduras using a combination of traditional knowledge of fishers in the region and scientific information (e.g., bathymetry, currents, and temperature signals of upwelling). Some of these spawning grounds have now been placed under a certain level of protection against overharvesting.

This indicator is calculated by identifying the number of protected spawning aggregations, then expressing that number as a percentage of the total known aggregations.

Usefulness

This indicator is useful as an overall measure of the level of protection afforded to various species that form spawning aggregations, but does not necessarily evaluate the effectiveness of the protection. This characterization is based on the assumption that greater protection and regulatory efforts regarding the exploitation of fish spawning aggregations translate to greater potential for the spawning success that maintains overall population viability.

However, because aggregations are highly differentiated based on species and breeding population, this indicator is very generalized. It does not provide any information on the status of individual aggregations or individual species. In addition, this measure assumes that all spawning aggregations are equal, which is not necessarily the case. To a fisher, Nassau grouper aggregations generally represent a higher economic value than snapper aggregations.

Although monitoring and protection of known spawning sites is relatively straightforward, what they represent in terms of total spawning activity and breeding success in the region is not known (i.e., including potential aggregations that have not yet been identified). Therefore, the assumptions made in interpreting the results of this indicator must be carefully balanced out with more detailed site-specific monitoring of the abundance of fish at each of the spawning aggregations.

Status

To date, Belize has the highest percentage of its known spawning aggregation sites protected (11 of 32 sites). Belize also has a seasonal fishing closure for Nassau grouper (December – March) throughout the country.

Many aggregation sites have been identified in Mexico (approximately 36), but only one has been placed under full protection. Only one site has been identified in Honduras. None are known in Guatemalan waters.


Wolcott Henry

A regional assessment of spawning aggregations was recently conducted by the MBRS Project. There is a need for harmonized regulations, including the protection of SPAG sites and the concurrence of closed seasons in all the countries.

Data Needs

Additional information is needed regarding the following:

- Status of spawning aggregations (numbers of fish at each site) per species at all identified SPAG sites;
- Further work to identify potential spawning aggregations in Honduras;
- Level of fishing pressure at each aggregation; and
- Effectiveness of existing regulations at protected aggregations.

Priority should be given to obtaining data and protection for highly endangered species such as the Nassau grouper.

Summary of the Protected Status of Spawning Aggregations in the MAR Region per Country

Country	Total SPAG Sites Identified to Date	Total Protected	% Protected
Belize	32	11	34%
Guatemala	NA	NA	NA
Honduras	1	0	0
Mexico	36	1	3%

Data Source[45,46]

NA = not applicable

Global Climate Change

Conservation Objective

Promote the ability of coral reefs to withstand the effects of global climate change by identifying and protecting (within MPA networks) areas of high resilience or resistance to coral bleaching, and developing strategies to minimize human disturbances in these areas, particularly during times of stress (e.g., elevated temperatures and ultraviolet radiation). A longer-term goal is to maintain or restore coral abundance to levels sufficient to maintain reef accretion (or net accumulation of calcium carbonate).

Threats

The main ecological threats associated with global climate change (GCC) are potential increases in the frequency and severity of coral bleaching events, hurricanes, coral disease outbreaks, increased ultraviolet radiation, sea-level rise, and a decrease in coral growth and reef accretion (related to increased acidification due to increased CO_2). Of particular concern is the synergistic effect of these threats occurring at the same time. Global climate change may also affect human well-being by causing weather extremes (e.g., more hurricanes or droughts), increasing the transmission of infectious diseases, and affecting food productivity and water availability.

Management Actions

- Develop an early-warning network for coral bleaching events in the MAR (e.g., like the BleachWatch Program in the Florida Keys) and a regional program to respond with rapid monitoring to measure the extent of bleaching (and non-bleaching) and any resultant mortality.
- Identify reefs that are most resilient and resistant to the main global climate change impacts.
- Implement protection and management strategies in at least 50% of resilient and resistant reef areas.
- Restrict access to reef areas during coral bleaching events to reduce human impacts.
- Re-evaluate MPA design to ensure resiliency is incorporated into planning.
- Implement environmentally-sound agricultural and land use practices to reduce sediment and pollution runoff to the marine environment.
- Increase awareness of GCC impacts and educate the public through school programs and outreach activities on ways to reduce activities that contribute to GCC.
- Invest in alternative energy and high-efficiency technologies, including solar and wind power generation, four-stroke boat engines and high-efficiency vehicles.
- Galvanize and encourage large regional industries (e.g., hotel chains, cruise lines) to adopt “green” energy practices.

Perhaps the most widespread driver of change in the MAR is associated with global climate change. Many scientists have expressed concern that the recent large increase in atmospheric CO_2 is contributing to rapid warming of the Earth and acidification of its oceans[47,48]. Global warming is expected to have broad environmental and socioeconomic impacts. The possibility of more frequent and intense coral bleaching events are of particular concern for the Mesoamerican Reef. Computer models that predict sea surface temperature suggest that the recent warming trends will continue and that bleaching events will become more frequent and more extreme in magnitude during the next 100 years[47].

The ecological consequences of global change for the MAR could include:

- Increased coral susceptibility to bleaching and disease,
- Lower coral growth and reef accretion rates,
- Increased bioerosion,
- Loss of reef structure due primarily to stronger and more frequent hurricanes, and
- Sea level rise causing flooding of coastal habitats.

The main GCC-related impacts that have been observed in the MAR include:

- Coral Bleaching: Corals are highly sensitive to changes in water temperature, and increases of only 1 to 2°C can have potentially lethal effects[47]. The MAR region has experienced several large-scale bleaching events (e.g., in 1995 and 1998), causing significant coral mortality in some areas. Human-induced global warming is widely believed to be responsible for increases in global sea surface temperature. Coral bleaching may be a good early-warning indicator of climatic changes.

- Diseases: Coral disease outbreaks are one of the single most devastating disturbances to coral reefs in the Caribbean and MAR in the recent past[49]. Disease has always been a natural process in regulating populations, but the recent increased magnitude of disease and resultant mortality may be unique in the last several thousand years. Disease organisms tend to thrive in higher temperatures, and some may also benefit from increased ultraviolet (UV) radiation. Both stressors (temperature and UV) may render host organisms more prone to disease. In addition to these effects related to global climate change, diseases have also been linked to elevated nutrients (especially from sewage), sedimentation and runoff[50]. Little specific information is available, however, as it is usually difficult to identify the exact disease pathogen. Similar to humans, corals seem to be more prone to disease when affected by other stressors.

- Powerful Storms: Powerful storms and hurricanes are naturally occurring events to which corals have adapted over evolutionary timescales. Storms can be both beneficial and detrimental to reefs. The MAR region has a long history of hurricanes damaging the coral reefs. One projection of global climate change models involves the predicted increase in the frequency, intensity and duration of large storms fueled by warmer seas[51]. This effect could prevent corals from having sufficient recovery time between disturbance events. Secondary impacts — such as storm-associated runoff of low-salinity waters laden with nutrients, sediments and pollutants — are an additional concern. Hurricanes will continue to be a major driving force of coral reef condition in the MAR. The concern is whether corals will be able to maintain resilience in light of their already degraded condition and the likelihood that global climate change will alter the pattern of this and other natural disturbances.

Global climate change may also affect human health and well-being in different ways and to different degrees. Direct impacts to human well-being may include greater exposure to weather extremes (e.g., more hurricanes or droughts), an increase in the transmission of infectious diseases (especially through water and food), and a loss of food productivity and drinking water availability. Climate change is likely to cause changes in the frequency or distribution of human diseases (i.e., insect vector diseases like malaria, waterborne diseases like cholera). For example, malaria and dengue cases increased in Honduras after Hurricane Mitch in 1998[52]. Poor populations will be at the greatest health risk because of the lack of public health services and lack of financial resources or infrastructure to minimize health risks. Managers, scientists, and policy makers are encouraged to develop mechanisms to address the link between the ecological and social implications of global climate change (see Indicators SW2 — Safe Water and Sanitation and SW3 — Cholera and Other Diseases).

Managers in the MAR can do little to alleviate the root causes of GCC or even to prevent impacts (e.g., bleaching, hurricanes) on a local scale. But they do need tools to evaluate the extent of these GCC impacts. More importantly, effective, proactive management is needed to protect the coral reefs from additional anthropogenic stress, which compounds the synergistic effects of global climate change, prevents recovery from acute disturbances, and further increases the likelihood of significant loss of ecosystem structure and function. Reefs that may be naturally less susceptible or more resilient to bleaching and other disturbances need to be identified and incorporated into MPA conservation zones.

Indicators selected to track the ecological effects of global climate change are:

D13 - Photic (Amphi) Index

D14 - Coral Bleaching Index

D15 - Reef Resiliency to Bleaching

D13 Photic (Amphi) Index

What Is It?

Amphistegina is a genus of relatively large (1-3 mm) foraminifera (microscopic one-celled organisms with a shell) with symbiotic zooxanthellae (algae that produce oxygen and remove wastes for the host). The *Photic (Amphi) Index* is based upon densities and visual characterization of populations of *Amphistegina*. This is an indicator of general environmental suitability for calcifying organisms with algal symbionts and an indicator of light stress (especially UV radiation). Unlike the FORAM Index (D6), which measures general environmental water quality particularly with respect to nutrient availability, this indicator looks at a stress response primarily associated with light levels affecting the host-symbiont relationship (similarly to some coral bleaching responses).

Benchmark

Density > 103 #/m^2. Bleaching < 25%. Juveniles 30-80% (varies seasonally). Damaged tests 5-15%.

Target

Density > 104 #/m^2. Bleaching 0%. Juveniles 30-80% (varies seasonally). Damaged tests < 5%.

Red Flag

Density < 103 #/m^2 or bleaching > 40% or % Juveniles < 40% in early summer or damaged tests > 20%.

Why Do We Measure It?

Amphistegina are abundant and widely distributed foraminifera (shelled protists), whose shelled bodies (both alive and dead) are commonly found in the sediments on "healthy" reefs. Since the early 1990s, population densities have decreased and bleaching (loss or reduction of symbiotic zooxanthellae) has become prevalent in populations of *Amphistegina* worldwide. Bleaching is often associated with increases in microbial infestations, shell breakage due to predation, reproductive failure and shell deformities.

Amphistegina are known to be sensitive to water quality deterioration and to bleach in response to excess radiant energy, but not in response to temperature stress. Thus, this index provides a quick and sensitive way to discriminate the extent of photo-oxidative stress resulting from intense UV radiation. While most coral bleaching events correlate more closely with temperature stress, light (particularly UV) also plays a contributing role. Comparing the values of the Photic (Amphi) Index (D13), the Coral Bleaching Index (D14) and extent of Coral Bleaching (F7) during a bleaching event enables an estimation of the relative contributions between ultraviolet radiation and temperature stress in the reef environment for any given bleaching event.

Pamela Hallock

How Do We Measure It?

Amphistegina populations are analyzed by collecting reef rubble in areas of concern. The reef rubble is scrubbed in seawater using a soft brush. The resultant sediment slurry is rinsed free of most of the loose organic matter by decanting, and the sediment is placed in a dish (e.g., large petri dish) overnight. Live *Amphistegina* will crawl to the surface and can be picked from the sediment. Using a stereomicroscope at 10-20x magnification, *Amphistegina* are counted, measured or "sized" (juveniles are <0.5 mm), and characterized by their appearance according to symbiont color and degree of breakage[53].

The "health" of the population is based on an evaluation of densities, size distributions, and prevalence and severity of bleaching and shell damage.

Usefulness

Amphistegina makes an ideal bioindicator because:

- They require similar environmental conditions to zooxanthellate corals,
- They are an easily identifiable, widely distributed genus that is abundant in healthy reef environments,
- They have relatively short life spans and are sensitive to changes in environmental conditions over days to weeks, providing an early warning signal of declining water quality or episodic stress events, and
- Statistically-significant sample sizes can be collected quickly and relatively inexpensively with minimal impact on reef resources.

High densities of adult and juvenile *Amphistegina* with low percentages of bleaching and breakage are representative of optimal reef conditions. Absence of *Amphistegina* or low densities with some juveniles but few to no adults are indications of water quality unsuitable for maturation and successful reproduction of *Amphistegina.* The assumption of the index is that such conditions will not support other reef-building organisms either.

This index is most suitable for assessing reef environments between approximately 6 and 30 m depth. However, it is not suitable for assessing the condition of nearshore reef environments that contain silty sediments. Comparisons should be made among similar reef types and depths due to natural variability.

Suggested sampling periods include late spring or early summer (May to June), when highest densities will be observed in healthy populations and when photic stress (bleaching) will be most prevalent in impacted populations, and in late summer (August to September) when shell damage will be most prevalent under chronic stress.

The equipment needed to take actual UV radiation measurements on the reef are relatively expensive and require frequent measurements. In lieu of expensive direct UV measurements, the Amphi Index provides a time-integrated response to UV stress that also has relevance for corals due to the synergistic effect of UV stress affecting corals exposed to elevated temperatures.

Status

Data on the density of MAR *Amphistegina* populations are not currently available, but the index has been well developed for the Florida Keys. Historically, *Amphistegina* were abundant in reef sediments with densities > 10^4 #/m^2 and exhibited 0% bleaching and <5% damage[54]. However, bleaching in *Amphistegina* populations was observed in samples from Montego Bay, Jamaica, in 1992; at Glover's Reef, Belize, in 1998; and in Roatan, Honduras, during several years since 1995[55].

Data Needs

Formal evaluation of the Photic (Amphi) index by EPA standards is not yet complete. The index is currently being assessed using large data sets from throughout the Florida Keys spanning the early 1990s to the present. Data collection in the MAR should be conducted in coordination with the collection of other climate change indicators at the same sites.

Gradient of bleaching from normal (upper left) to bleached (lower right).

D14 Coral Bleaching Index

What Is It?

The *Tropical Ocean Coral Bleaching Indices* provide near-real-time information about thermal stress — a key cause of coral bleaching — at 24 reef sites around the world, including Glover's Reef Atoll in Belize.

This web-based system, developed by NOAA Coral Reef Watch, uses satellite data to estimate sea surface temperature and other bleaching-related indices[56]. The program includes a system for generating bleaching alerts that enable real-time monitoring of bleaching events. Given the projections for increasing ocean temperatures and coral bleaching events, this is one of the most important indicators of global climate change (GCC) for coral reefs.

Why Do We Measure It?

Coral bleaching can be attributed to many causes. However, in recent decades a correlation between elevated sea surface temperatures (a key impact of global climate change) and the occurrence of widespread bleaching events has become evident. With improved understanding of bleaching thresholds and satellite technology, it is now possible to predict bleaching events on a global scale by studying the changing patterns of sea surface temperature. This Coral Bleaching Index warns managers of imminent bleaching events and allows them to initiate monitoring even before bleaching actually begins.

Although local managers can do little to prevent bleaching events, monitoring their occurrences is particularly useful in identifying highly susceptible areas, as well as areas resilient to thermal stress (see D15 – Reef Resiliency to Bleaching for definitions). Appropriate management actions can then be initiated such as reef restoration or protection from localized human-induced stresses that can lower reef resistance to bleaching.

How Do We Measure It?

The Coral Bleaching Index is a function of three key variables:

- Sea surface temperature (SST),
- HotSpot – the difference between SST and the climatological maximum monthly mean temperature (a measure of thermal stress intensity), and
- Degree Heating Week (DHW) - an indication of the thermal stress experienced over the preceding 12-week period (a measure of the duration and strength of thermal stress).

For methodological details, see the NOAA Tropical Ocean Coral Bleaching Indices webpage[56]: http://coralreefwatch.noaa.gov/satellite.

Benchmark

No increase in the frequency of NOAA Bleaching Watches issued for the MAR region. No increase in mortality percentages associated with bleaching events.

Target

Reduction in the frequency of NOAA Bleaching Watches issued for the MAR region. Reduction of subsequent mortality associated with these events. Protection of naturally resistant or resilient areas.

Red Flag

Increase in the frequency of NOAA Bleaching Watches issued for the MAR region.

NOAA defines five status levels of thermal stress:

Stress Level	Variable Definition	Interpretation
No Stress	HotSpot $\leq$ 0	No Thermal Stress
Bleaching Watch	0 < HotSpot < 1	Low-Level Thermal Stress
Bleaching Warning	1 $\leq$ HotSpot and 0 < DHW < 4	Thermal Stress is Accumulating
Bleaching Alert Level 1	1 $\leq$ HotSpot and 4 $\leq$ DHW < 8	Bleaching Expected
Bleaching Alert Level 2	1 $\leq$ HotSpot and 8 $\leq$ DHW	Significant Bleaching Expected

Data Source[56]

Usefulness

The use of SSTs, HotSpots and DHW has proven to be effective in describing conditions under which bleaching is likely to occur. This indicator provides a useful tool for monitoring efforts and management strategies that attempt to mitigate climate change impacts.

This indicator is particularly useful when combined with other related indicators like F7 – Coral Bleaching (to measure the extent of actual bleaching as predicted by this Index), along with subsequent monitoring of F5 – Coral Mortality, F6 – Coral Disease and S4 – Coral Cover (to measure the actual impacts of the bleaching). Comparison with D13 – Photic (Amphi) Index allows the potential discrimination between temperature and UV light (both widespread stressors capable of causing bleaching events). The synthesis of this information allows the ranking of reef resiliency to bleaching presented in D15. Calibration of the satellite-derived temperatures with *in situ* temperature measurements (within S8 – Water Quality) is also important to understand local-scale bleaching patterns.

A limitation of the tool is that the one MAR monitoring site, Glover's Reef, is not necessarily representative of the entire MAR region. However, once an alert for Glover's Reef (or anywhere in the Caribbean) is sent out, reef managers throughout the MAR can visit the website to look at sea surface temperature anomalies and DHW for their particular reef area.

Status

Due to the coarse scale of the available data, the information from Belize can act as a surrogate for the MAR region.

Looking back to the major bleaching event of 1998, the latitudinal variation in DHW can clearly be seen in the following image taken from the NOAA website.

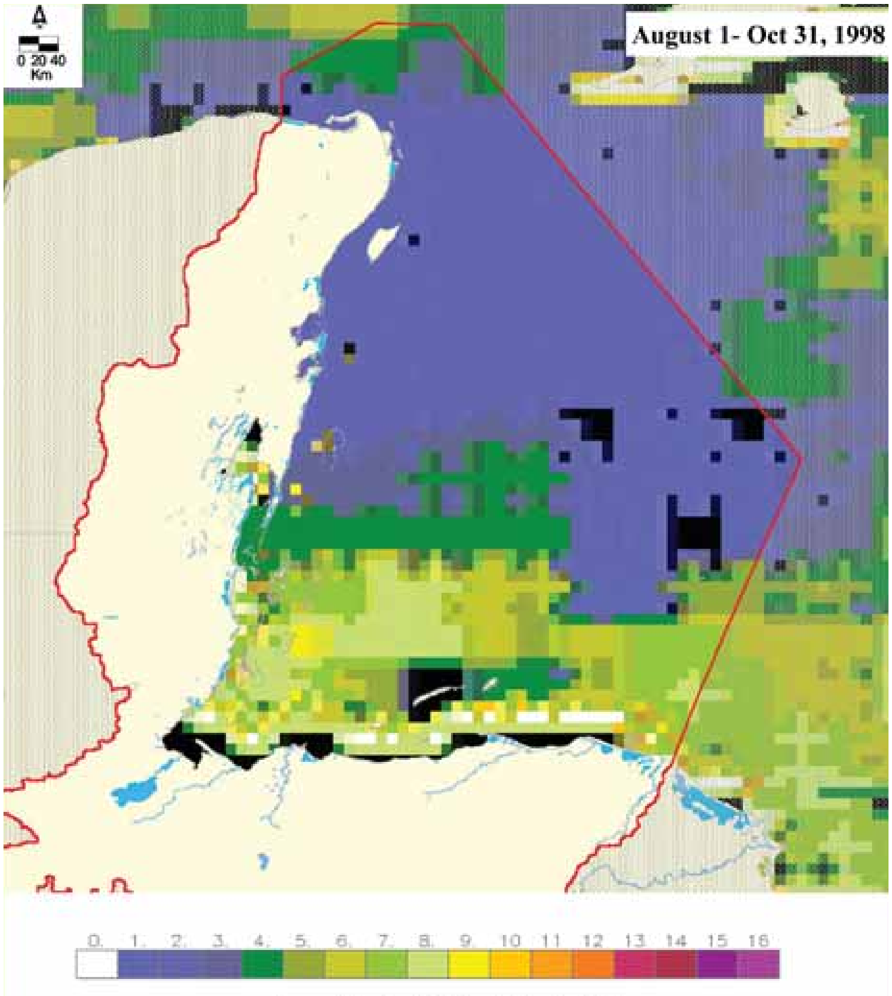
Degree Heating Weeks Index (DHW)
One DHW is equivalent to one week of sea surface temperatures one degree Celsius warmer than the expected summertime maximum. Two DHWs are equivalent to two weeks at one degree above the expected summertime maximum OR one week of two degrees above the expected summertime maximum.

A reef assessment in the summer of 1999 found coral mortality following this same latitudinal gradient. This 1998 bleaching event was the most severe event recorded in the MAR. The 1995 and 2005 events did not have as high mortality of corals.

Data Needs

Additional information is needed regarding the following:

- Inclusion of more areas in the MAR for automated bleaching alerts,
- Incorporation of other environmental data into the model (e.g., UV radiation levels, wind speeds),
- Compiled data on historical bleaching events (extent and environmental conditions during the event),
- Extent and severity of subsequent mortality (including coral disease outbreaks), and
- Identification of reef areas that are particularly susceptible or particularly resistant or resilient to bleaching.



Source: Reference 1 of the introductory section references (see Section 11)

D15 Reef Resiliency to Bleaching

Benchmark

Initiate some management changes (e.g., boundary changes in existing MPAs or creation of no-disturbance zones) based on the classification of resiliency.

Target

At least 50% of the total extent of resilient and resistant coral reef under protective management.

Red Flag

No net increase of resilient and resistant coral reef areas under protection.

What Is It?

The ability of a coral reef ecosystem to withstand or avoid the effects of bleaching exemplifies reef *resistance*, while the ecosystem's ability to recover from bleaching and other disturbances is an example of *resilience*.

The *Reef Resiliency to Bleaching* indicator is a measure of the spatial extent of MAR coral reef areas that have known resilience and/or resistance properties with respect to coral bleaching stress, or that demonstrate the potential for these properties.

Why Do We Measure It?

Resistance and resilience are considered the most salient factors to the long-term survival of coral reef ecosystems facing increasing and intensifying threats. This indicator provides information on the geographic location and extent of coral reef areas that possess resilience or resistance properties to bleaching stress.

While bleaching events cannot be mitigated through direct interventions to address the threat (primarily that of rising sea surface temperatures associated with climate change), the identification of particularly resistant and resilient areas allows appropriate management strategies to be implemented in a highly targeted fashion. By targeting these resilient reefs for additional conservation and management efforts, managers maximize the likelihood of survival and long-term viability of these reefs in light of the projected sea surface temperature increases and associated increases in the number and severity of future bleaching events.

How Do We Measure It?

Physical features that facilitate the identification of reefs likely to be resilient or resistant to bleaching include[59]:

- Areas of upwelling — areas through which colder, often nutrient-rich currents flow,
- Areas of rapid current — areas through which currents flow at a fast rate producing a cooling and flushing effect,
- Areas of shading — areas that are in the shadow of physical structures (e.g., land promontory, reef overhang) and are therefore protected from direct sunlight and heat, and
- Areas of screening — areas that are in a naturally turbid state in which particulates act as screens to UV exposure.

With the use of GIS-based information, field data, direct observations and local knowledge, these areas (or probable areas) can be located and estimates of their extent can be made.

MAR reefs can be classified according to the following scheme:

Categories of Reef Resiliency to Bleaching

Resiliency Type	Condition Definitions
Type 1 Resiliency (Resistance)	No historical or current bleaching reported
Type 2 Resiliency	Historical or current bleaching with no mortality
Type 3 Resiliency	Historical or current bleaching with mortality and subsequent recovery
Type 4 Resiliency	Historical or current bleaching with mortality and no recovery

Data Source[60]

The areal extent of bleaching-resistant and resilient coral reefs in the MAR region can then be calculated. MAR reefs can also be ranked according to this prioritization scheme, which helps to identify reefs that warrant more or immediate protective management action.

Conservation Prioritization of Bleaching-Resistant and Resilient Coral Reefs

Conservation Priority	Areal Extent	Condition
Very High	≥ 1000 m²	Type 1 and Type 2 Resiliency
High	700 m² – 1000 m²	Type 1 – 3 Resiliency
Medium	300 m² – 700 m²	Type 1 – 3 Resiliency
Low	≤ 300 m²	Type 1 – 4 Resiliency

Data Source[60]

A comparison of the bleaching-resilient/resistant areas and existing marine protected areas will reveal the proportion of resilient and resistant reef area already under some form of protection. Such a comparison will also facilitate the development of management strategies for unprotected resilient and resistant areas.

Usefulness

This indicator provides a means of estimating location and size of MAR coral reef areas that are potentially resilient or resistant due to favorable abiotic or biotic features. This measure provides important information for understanding the overall capacity of the coral reef system to tolerate global climate change impacts. From this perspective, this indicator is very useful for integrating management strategies, including MPA delineation.

It must be noted, however, that this indicator focuses on bleaching attributed to thermal stress and not necessarily from other stressors (including pollution, breakage and UV exposure). Resistance and resilience to other stressors are influenced by a variety of other factors and would not necessarily have the same response patterns. Therefore, resilient and resistant reef areas identified through the process above will also have to be assessed for overall condition of health to ensure that protection strategies are maximized. In addition, coral reefs need to be managed for their overall survival, which also depends on other factors such as reproduction, genetic diversity and structural integrity.

For further discussion of this indicator see references[60,61].

Status

A MAR regional assessment of coral reef resilience and resistance areas has not yet been conducted. However, there are various unconsolidated reports of areas that have been particularly damaged from bleaching, with fewer reports of reefs that did not bleach in bleaching years.

The Nature Conservancy has conducted training sessions in the MAR region based on their Reef Resilience toolkit. A preliminary effort for ranking all of Belize's reefs was conducted in 2004, with the result for Glover's Reef shown below[62].

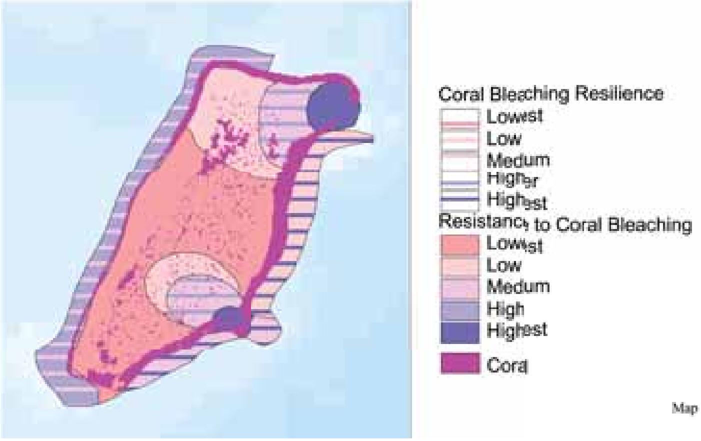
Data Needs

Additional information or analysis is needed in the following areas:

- Regionally consistent MAR reef habitat maps (see S11 Coral Reef Areal Extent);
- Historical data or knowledge regarding past bleaching events and a thorough analysis of historical data; and
- Real-time, coordinated bleaching response surveys to identify and track coral bleaching events (e.g., similar to the Florida Keys) BleachWatch Program[57]).

Glover's Reef Resiliency to Bleaching: Expert Mapping

Local stakeholders and scientists identified coral bleaching, physical damage recreation (anchors and snorkelers), and overfishing (both local and non-local fishers) as key threats to the reef during a threat analysis and mapping workshop hosted by the Wildlife Conservation Society (WCS) in February 2004 and reported by WRI[62].



In evaluating the threat of coral bleaching, areas of high to low resistance and high to low resilience were mapped. High resistance areas are less likely to bleach because of depth, openness and faster water movement. High resilience areas are more likely to recover quickly because of factors promoting recovery, such as the availability of coral larvae.

The areas were mapped using a combination of local knowledge of past bleaching patterns and theoretical expectations based on the environmental conditions in different areas of the atoll.

Source[62]

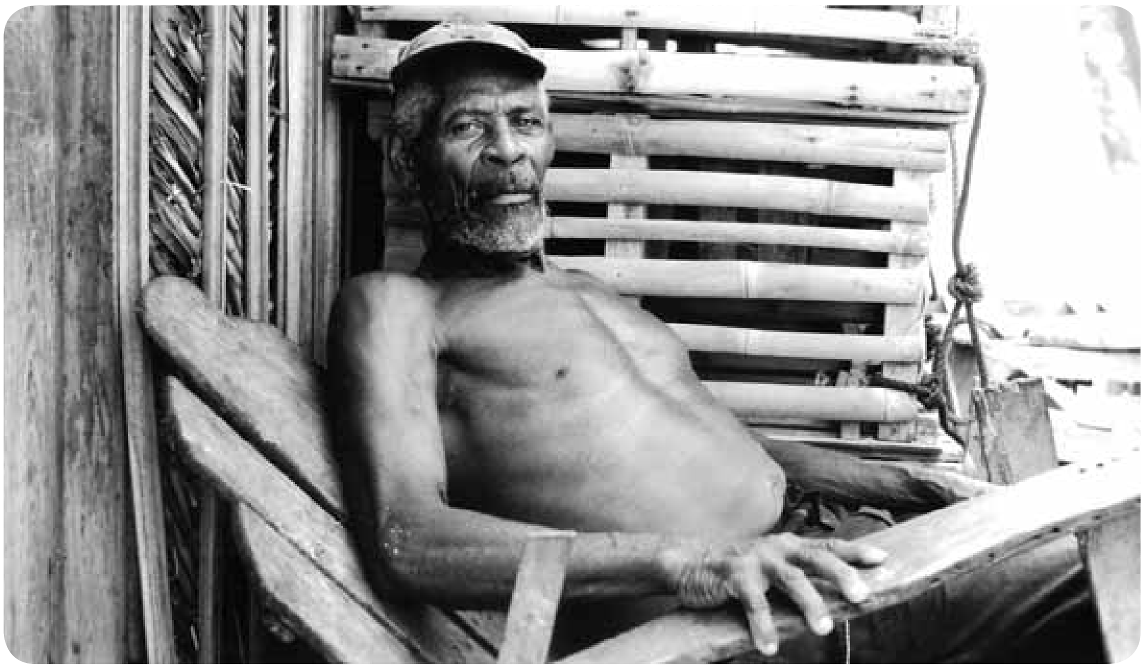
Social Well-being and Governance

Indicators of social well-being and governance are included in recognition of the role that the environment plays in sustaining people's livelihoods, health and culture, as well as the potential positive and negative effects of human activity on the ecosystem. Human values and stewardship play a dominant role in sustainable ecosystem management.

We have identified 15 indicators of Social Well-being and Governance, grouped into four themes (Table 7.d).

Table 7.d. Social Well-being and Governance Indicators

Attribute	Indicator #	Indicator
Human Health	SW1	Contaminants in Breast Milk
	SW2	Safe Water and Sanitation
	SW3	Cholera and Other Diseases
Economy	SW4	Poverty
	SW5	Economic Contribution of Marine-related Activities
	SW6	Adjusted Net Savings Index
	SW7	Human Development Index
Culture	SW8	Ethno-languages
	SW9	Gender and Employment
	SW10	In-migration
	SW11	Environmental Perceptions
Policy	SW12	Environmental Sustainability Index
	SW13	Marine Area within MPAs
	SW14	MPA Effectiveness
	SW 15	World Bank Governance Indicators



Toni Parras

Human Health

Conservation Objective

Improve water quality in coastal waters and reduce the risk of human illnesses by reducing direct input of sewage, pesticides and other contaminants; enforcing water quality standards; and increasing public awareness.

Threats

Human health is compromised by poor environmental conditions such as improper sanitation (e.g., sewage contamination), contaminated drinking water (e.g., excessive coliform bacteria, nitrates, or heavy metals) and exposure to pesticides and other contaminants through poor agricultural practices.

Management Actions

- Increase public awareness about proper sanitation, health concerns and linkages between poor water quality and human illness. Publicize methods for decreasing risk of waterborne disease (e.g., filtering or boiling water).
- Identify areas of direct sewage contamination and develop ways to reduce or eliminate direct contamination of coastal waters (e.g., through adequate collection and treatment of wastewater).
- Work with hotels and housing developments to ensure proper sanitation and waste control.
- Coordinate with health officials to track waterborne diseases, illnesses related to seafood consumption (e.g., ciguatera), and other illnesses associated with degraded ecosystems.
- Implement water quality testing and health safety reporting at public beaches.
- Implement, track and enforce water quality standards in coastal waters, rivers and groundwaters.
- Coordinate with watershed managers to track toxic pesticides and harmonize regulations on pesticides throughout the region.
- Work with agro-industries to develop better management practices which minimize the use of the most toxic pesticides.

The relationship between the health of coastal ecosystems and humans has not received much attention within the MAR, although the same environmental conditions responsible for waterborne illnesses, namely poor sanitation and human sewage contamination, also have led to ecosystem degradation. Likewise, chemical contaminants found in reef organisms as a result of agricultural and industrial activities have also been found in humans.

Tracking indicators of human health can improve our understanding of the linkages between human and ecological health. Human health indicators are used to identify adverse public health events associated with environmental exposures and provide an opportunity to incorporate information into public health interventions and environmental regulations. A variety of health indicators (e.g., hazard, risk, or exposure indicators) can be used, but few data are available in the MAR region and few have been linked directly with marine environments.

Useful human health indicators for the MAR region include the occurrence of cholera, which is associated with human sewage contamination that also affects the reef. In addition, ciguatera fish poisoning — the most common marine toxin disease reported in the world — results from eating reef fish such as barracuda, snapper, and grouper that have ingested toxins produced by marine microalgae (dinoflagellates), and may be linked to physical disturbance of the reef (such as dredging, blasting and breaking of corals).

Some illnesses related to women's reproductive health (such as molar pregnancies, or fibroids and tumors on reproductive organs) are a growing concern in the MAR and may be linked to toxins acting as endocrine disruptors or otherwise affecting the hormonal system. These same endocrine disruptors are now being linked to disruptions in wildlife, such as the feminization of male alligators in Florida lakes, or gastropods in the Caribbean. A major constraint in studying similar effects in the Mesoamerican region is the lack of systematic recording of such illnesses and defects.

The indicators selected to track human health are:

- SW1 Contaminants in Breast Milk
- SW2 Safe Water and Sanitation
- SW3 Cholera and Other Diseases


WWF-Canon / Nigel DICKINSON

SW1

Contaminants in Breast Milk

What Is It?

This indicator is a measure of the levels of potential contaminants (such as pesticides) found in human breast milk. In recent years, health and environmental scientists have documented the occurrence of numerous synthetic chemicals in breast milk[1,2]. Use of some of these chemicals is now restricted or banned; and, as environmental concentrations have decreased, so have concentrations in breast milk. However, some chemicals persist in the environment and in the human body long after application or exposure. Such chemicals—as well as many in current use—continue to show up in mothers' breast milk.

Of particular concern is a class of long-lasting chemicals known as persistent organic pollutants (POPs). Examples include the insecticides chlordane and DDT, dioxins and furans (inadvertently produced through the burning of plastics and other materials), plus polychlorinated biphenyls (PCBs), once widely used in hundreds of commercial applications. Widely used agrochemicals have also been raised as a particular concern in the Mesoamerican Reef region.

The metric presented here is contaminants in breast milk, but additional development of this and other human health metrics linked to environmental contamination is encouraged.

Why Do We Measure It?

Human health indicators, such as contaminants in breast milk, can provide early detection of potential marine-based contaminants, thus identifying marine ecosystem degradation and ultimately reducing associated human illness. Identifying potential linkages between contaminants found in the environment and in humans also helps raise awareness and garner support for mitigation measures.

Crop-protection and pest-management contaminants have been found in subsistence fish and invertebrates from the Mesoamerican Reef. Establishing the connection between agrochemical contamination of reef organisms and contamination of human breast milk with these same agrochemicals provides a straightforward yet poignant example of the linkage between eco-health and human health. Environmental contamination originating from the burning of medical and municipal waste is also a potential source of contamination in humans (e.g., mercury, dioxins, furans).

Benchmark

Complete a regional baseline of contaminants in breast milk and establish a routine screening program.

Target

Maintain average human breast milk contaminant levels within or below World Health Organization Allowable Daily Intake Levels (ADI).

Red Flag

Any breast milk contaminant levels above the ADI.

Goals associated with the breast milk indicator include:

- Determine the composition and concentration of environmental contaminants, including agricultural biocides, in breast milk;
- Determine the potential sources of contamination (food, drinking water, cisterns, waste incineration and landfills);
- Determine the relative risks of the contaminants to infant health and development; and
- Incorporate findings into public health interventions and environmental mitigation strategies.

How Do We Measure It?

Most basic health indicator data (demographic and mortality data, for example) are collected by the Pan American Health Organization (PAHO) as well as several national agencies in the MAR countries. But few data are available for health indicators with specific links to marine ecosystems, especially on levels of contaminants in human tissues or bodily fluids.

To fill the data gap, a study of approximately 200 women in Belize was begun in late 2006, through a partnership between Haereticus Environmental Laboratory and the Smithsonian Institution, in contribution to the Healthy Reefs for Healthy People Initiative. The study will cover a wide range of potential contaminants and will include a food consumption survey.

Usefulness

Contaminants in breast milk are a telling indicator of the level of contamination in the food chain and in the environment. In general, most chemicals that are detrimental to marine life are also detrimental to humans, with a variety of associated pathologies documented in the medical and scientific literature.

The simplicity of the argument that "many things that are bad for the reef are also bad for us humans" adds to its value as an indicator. Establishing such direct linkages has great potential for mobilizing public and political support for conservation and better management of activities leading to environmental contamination.

Ultimately, the usefulness of this indicator depends on the amount of data that is collected, the strength of any correlations between contaminants in humans and marine life, correlations between diet (particularly seafood consumption) and human contamination, the feasibility and costs of reliably collecting these data, and the degree to which public awareness campaigns can lead to successful mitigation strategies.

The sampling methodology is straightforward, although sample storage, shipping and analysis are costly.

Status

Consumption of fish with high concentrations has been hypothesized to be one avenue leading to contaminant accumulation in women's breast milk. Several of the pesticide residues that Mesoamerican people are exposed to are known mutagens (potential carcinogens) and teratogens (i.e., substances that may cause congenital birth defects or result in developmental abnormalities).

One of the pesticide residues found in the MAR at unsafe consumption concentrations is malathion, or its more toxic breakdown product, malaoxon, which is a documented teratogen. This high exposure could be resulting from fish consumption, residues on fruits and vegetables, or drinking water sources, particularly rainwater vats located in residential areas sprayed in mosquito control programs.

Few data are available on contaminants in human breast milk. No comprehensive study covering a wide range of potential agrochemical contaminants and including a food consumption survey has been conducted on lactating women in the Mesoamerican Reef region (or many other regions).

Sample Concentrations of Pesticide Residues from Two MAR Women

Chemical	Concentration in breast milk	Times higher than ADI
Malaoxon*	49 ppb†	49,000 times higher
Endosulfan	2.4 ppb	12 times higher
Mirex**	9 ppb	15,000 times higher
DDT**	91 ppb	65 times higher
Aldrin**	2.2 ppb	8 times higher

†ppb = parts per billion; ADI = Allowable Daily Intake for a 2.8 kg infant. The concentration of a given contaminant (in mg/ml) is multiplied by the average daily milk consumption of an infant (in ml) to produce the estimated daily intake (in mg) which is compared to the ADI[4].

** Malaoxon is a breakdown product of malathion and is ~ 10,000 times more toxic.*

*** POPs (Persistent Organic Pollutants / Stockholm Convention)*

A global compilation of more than 130 records of DDT in breast milk found the highest value worldwide in rural women in Guatemala in 1971 at 76,800 micrograms of DDT per kg of milk fat[3]. (One microgram per kg is equivalent to one part per billion). In general, women from Latin American countries demonstrated relatively high DDT values due to the pesticide's continued use in the region into the late 1990s. Now that DDT use has been banned throughout the Central American region, concentrations are expected to decrease when compared to previous studies. Reductions in average milk content of 11-21% per year were seen in women in the U.S. and Canada after the product was banned in those countries (by 1975)[3].

Data Needs

Our current information on human exposure to a wide range of potential contaminants is limited, and our understanding of the risks that such chemicals pose to infants is even more limited. The Belize study should be completed by 2008. Similar studies need to be conducted in other MAR countries. Diet and demographic surveys need to be conducted to determine potential sources of exposure. Other studies have shown that lifelong consumers of sports fish can have body burdens of some pesticides of two to five times higher than the general population[5].

SW2

Safe Water and Sanitation

What is it?

Safe water refers to "improved" (i.e., clean) drinking water sources. According to international standards, safe water sources could include piped, public tap, borehole or pump, protected well or protected spring water, as well as rainwater. Each one of the four MAR countries has established their own standards regarding "improved" water sources. Access to safe water means that a population has regular and easy access to that water. Sustainable access requires that water quality be maintained within acceptable limits for human consumption and that safe yield is ensured to prevent future declines in the resource.

Improved *sanitation* services are provided by facilities that hygienically separate human excreta from human, animal and insect contact. These facilities include sewers or septic tanks, poor-flush latrines and simple pit or ventilation-improved latrines[6].

Access, again, means consistent and easy access. Sustainable access to safe sanitation requires that financial and administrative mechanisms be in place to maintain functionality and prevent degradation of the existing improved sanitation facilities into the future.

This indicator tracks the proportions of the population with (a) sustainable access to an improved water source, and (b) access to improved sanitation.

Why Do We Measure It?

Both indicators are included among the official list of United Nations (UN) Millennium Development Goals indicators. Lack of access to clean water and basic sanitation is the main reason diseases transmitted by feces are so common in developing countries. As water demands increase in association with tourism enterprises and growing urban populations, fair water allocation and greater efficiency are needed to balance the limited supply with rising demand.

How Do We Measure It?

Data regarding access to safe water and sanitation are obtained from household and population censuses (every 10 years), as well as national multi-purpose household surveys.

Benchmark

Reduce by one quarter the proportion of people without sustainable access to safe drinking water and basic sanitation. The following levels should be met for each country: Safe Water: Belize (85%), Guatemala (89%), Honduras (89%), Mexico (93%); and Basic Sanitation: Belize (94%), Guatemala (87%), Honduras (80%), Mexico (88%).

Target

Halve, by 2015, the proportion of people without sustainable access to safe drinking water and basic sanitation (consistent with Millennium Development Goal 7). The following levels should be met for each country: Safe Water: Belize (90%), Guatemala (93%), Honduras (93%), Mexico (95%); and Basic Sanitation: Belize (96%), Guatemala (91%), Honduras (87%), Mexico (92%).

Red Flag

No improvement (or a decline) in the percent of people without sustainable access to safe drinking water and basic sanitation.

Usefulness

These two indicators track access to safe water and sanitation—the lack of which increases human illness and morbidity, contributing to ongoing poverty. These indicators also provide information regarding need for water and sanitation facilities and services. Lack of safe water and basic sanitation also indicates water- and sewage-management issues that may lead to contamination problems known to negatively impact marine ecosystems, particularly coral reefs.

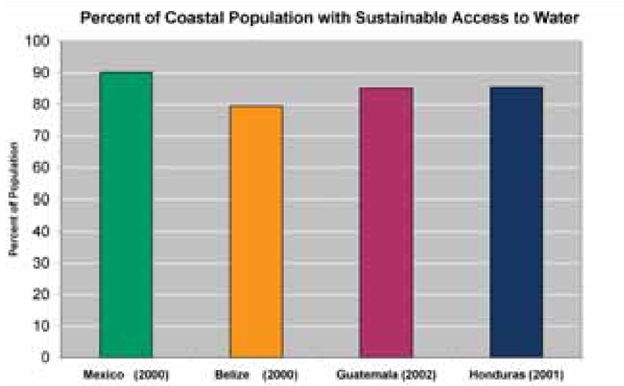
Status

The four MAR countries provide more than three-quarters of their coastal population with sustainable access to improved water or sanitation. Belize currently provides the greatest access to basic sanitation. Mexico provides the highest level of sustainable access to safe water in the municipalities along the MAR coastal region.

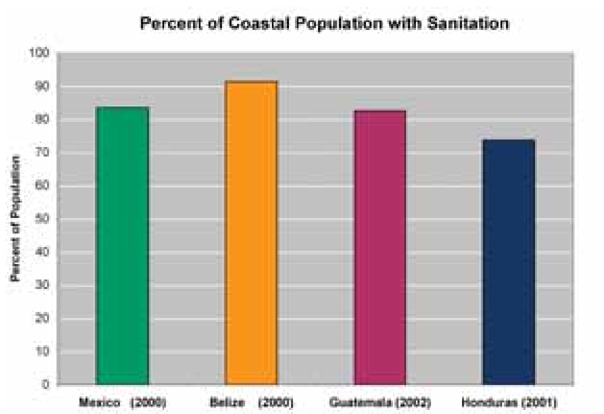
Data Needs

Data on sustainable access to water and sanitation are available for all MAR countries at the municipal level. Data for each municipality are in Appendix 3.

Data for these two indicators typically rely on reports of the physical facilities that provide improved water and sanitation. Additional data from tests of actual water quality would be a valuable addition. For example, piped water sources can become contaminated. Likewise, use of septic tanks and pit latrines can still result in *Escherichia coli* and other harmful disease agents contaminating natural (e.g., riverine or coastal) waters. Expanded testing and consolidated, publicly accessible reporting of drinking water parameters (e.g., total suspended solids, nitrates) and ambient water quality (e.g., *E. coli*) could help validate and refine the indicator statistics.



Data Source: [21,22,48,47]



Data Source: [21,22,46,47]

Cubola Archives

HUMAN HEALTH

SW 2

SW3 Cholera and Other Diseases

What Is It?

Cholera is a serious water-borne disease caused by the bacterium *Vibrio cholerae*, which thrives in polluted waterways. Localized outbreaks are often associated with water pollution and unsanitary conditions caused by human activities, particularly improper treatment of human sewage. In some areas, scientists have found a significant correlation between cholera incidence and elevated sea surface temperature (SST)[7].

Other diseases associated with habitat destruction, destabilization of natural wildlife populations and global climate change may become an increasing problem in the MAR region. Emerging diseases of concern include hantavirus pulmonary syndrome, Lyme disease and avian flu. This indicator will be further developed as more data are collected concerning these emerging diseases and their relationship to environmental health.

Why Do We Measure It?

Cholera outbreaks among coastal communities can be used as an indicator of the overall health of the population and their general living conditions. Due to the correlation between the cleanliness of waterways and the occurrence of cholera, cholera outbreaks can be used as an indicator of water quality and sanitation. Cholera can also be transmitted through uncooked fish or shellfish in which *Vibrio cholerae* have accumulated. Cholera outbreaks also occur when ocean surface temperatures increase. The bacteria, *V. cholerae*, live in marine ecosystems by attaching to zooplankton. Zooplankton depend on eating phytoplankton, and when ocean temperatures increase, phytoplankton bloom, allowing for both zooplankton and *V. cholerae* to increase.

How Do We Measure It?

This indicator is expressed in terms of the number of confirmed cases of cholera recorded in coastal communities annually and in recent history (past 5–10 years). It can also be expressed as the prevalence rate (per 1000 people) to account for the different sizes of coastal populations. A disease outbreak can be recognized by a rapidly growing incidence rate (i.e., number of new cases within a given time frame) within a specific geographic location.

Benchmark

Maintain current conditions of no cholera cases over the next 5 years. Identify and assess risk to other diseases linked to environmental health.

Target

Remain cholera-free over the next 10 years. Reduce human exposure to diseases by improving environmental conditions.

Red Flag

Any reported cases of cholera or outbreaks of other environmentally linked diseases.

Usefulness

Tracking the prevalence of cholera and other diseases that are linked to environmental health is an important measure of ecosystem health for the MAR. Cholera cases and outbreaks are generally indicative of poor sanitary and water quality conditions that contribute to reef degradation. It is assumed that the more numerous or frequent the outbreaks, the poorer the water quality and the less sanitary the living conditions—and the more likely reef quality is to be poor.

Status

With the exception of Belize, all countries in the MAR region experienced significant cholera outbreaks in the 1990s. Nevertheless, by 2004 the Pan American Health Organization (PAHO) declared Central America to be cholera-free. Belize reported its last case of cholera in 1999; Honduras and Mexico, in 2001; and Guatemala, in March 2002. According to PAHO, the lone Guatemalan case in 2002 was the last recorded case of cholera in the Central American isthmus. Note that these data are reported as number of cases, rather than as a prevalence rate or number of outbreaks [8].

Cholera cases in MAR countries 1995 to 2004

Country	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Belize	19	26	2	28	12	0	0	0	0	0
Honduras	4717	708	90	306	56	15	1	0	0	0
Mexico	16430	1088	2356	71	9	5	1	0	0	0
Guatemala	7970	1568	1263	5970	2077	178	13	1	0	0

Data Source[8]

Ygnacio Rivero

Data Needs

Additional data are needed on the co-occurrence of climatic events associated with cholera such as storms, hurricanes or unusually strong and prolonged wet seasons that tend to trigger disease occurrences or exacerbate conditions for outbreaks. Investigations are needed to review other diseases that may be more sensitive to ecological condition, habitat disturbance, or contamination. Data on these diseases need to be collected and standardized through a common reporting mechanism (e.g., PAHO, World Health Organization).

Economy

Conservation Objective

Sustainably manage marine resources such that they contribute to human well-being by providing economic opportunities based on fishing, tourism and supporting industries.

Threats

Overfishing, environmental degradation, poor environmental regulation and planning, increased population growth and coastal development, and inadequate investment in education and social programs negatively impact local and regional economic viability.

Management Actions

- Strengthen the environmental impact assessment (EIA) process for reviewing ecological impacts of coastal developments, and encourage sustainable development and minimization of damage associated with coastal development.
- Work with local, regional and national government agencies to encourage the use of tourism tax revenues to support equitable social and ecological programs.
- Continue to monitor the percentage of the population engaged in marine-related activities.
- Implement and enforce fishing regulations to ensure the economic viability of fisheries and marine-based livelihoods.
- Encourage policymakers to adopt an integrated coastal zone management approach and to include environmental resources as an important asset in economic planning and cost-benefit analyses for coastal developments.
- Improve employment opportunities for women, access to education and health care, and conservation of cultural values and other elements that support a high quality of life.
- Investigate the relationships among adjusted net savings index and the condition of marine resources and management effectiveness.

Economic viability in the MAR region relies greatly on the quality and availability of coastal marine resources. Economic activity is a powerful driving force that exerts both positive and negative influences on reef health. The ecoregion's major economic activities include tourism, agriculture, fishing, aquaculture and manufacturing, most of which are largely dependent on maintaining a healthy reef ecosystem. With population growth and coastal development projected to increase in the MAR region, the unsustainable use and unregulated extraction of marine resources may be expected to increase as well—with increasing negative economic impacts on local communities. Thus, in order to sustain strong national and local economies in the MAR region, we must maintain reef ecosystem health.

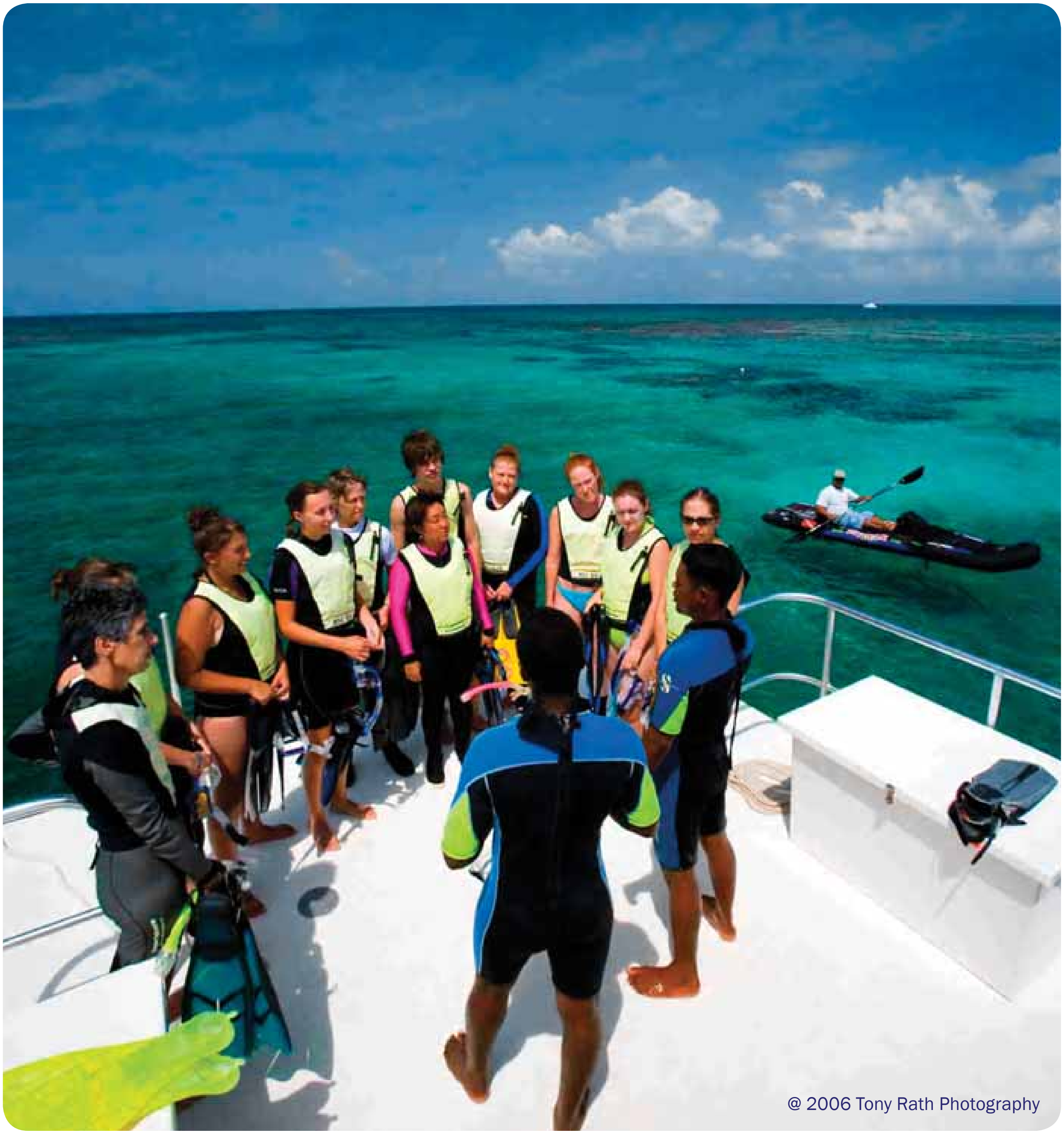
The economic indicators presented here examine the economic role and importance of marine resources for coastal communities in the Mesoamerican region. These indicators help us understand how dependent people are on reef ecosystems, how human activities are impacting reef ecosystem health, and how the condition of reef resources are affecting the social well-being and livelihoods of people. Some indicators provide feedback at the local community level, while others show how national and regional economies influence how people use marine resources.

Increases in gross domestic product (GDP), for example, may signal economic progress for a developing country, but it may also signal escalating pressure on natural ecosystems, as environmental costs continue to be externalized. Much attention has been given to the impact of high poverty on ecosystem health, but increased wealth and development may also lead to greater ecological disruption. While income derived from marine-related activities may or may not negatively impact the ecosystem, the wealth they create may not reach the most impoverished sections of society.

Thus, the stratification of wealth — the degree to which the "rich get richer while the poor get poorer" — is a relevant economic indicator, with increasing poverty signaling a dysfunction in the socioeconomic system. Similarly, the affluence or poverty (including natural assets) of a country can be assessed by the measures included in the Adjusted Net Savings Index. The positive and negative aspects of development are measured in the Human Development Index.

The indicators selected to track sustainable economic growth are:

- SW4 Poverty
- SW5 Economic Contribution of Marine-related Activities
- SW6 Adjusted Net Savings Index
- SW7 Human Development Index



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Poverty

What Is It?

Poverty rates are expressed as the proportion of the total coastal population living in conditions of poverty. Poverty conditions are generally measured through two methods: (a) the poverty line method, and (b) the unsatisfied basic needs method.

The *poverty line* method defines poverty based on household expenditures relative to the cost of acquiring a basic food basket in the country. The *unsatisfied basic needs* (UBN) method defines poverty based on the extent to which individuals are deprived of one or more basic needs. Basic needs include adequate shelter, water and sewage services, and access to education and health services.

No one poverty indicator is strictly comparable across the four MAR countries. At present, the development of poverty measures is in different stages in each country. It is likely that increased standardization and improved poverty measurements will be available in the near future.

Benchmark

Reduce poverty by 25% in each of the coastal municipalities.

Target

Reduce poverty by 50% in each of the coastal municipalities (consistent with Millennium Development Goal 1).

Red Flag

No reduction in poverty rates over current levels.

Why Do We Measure It?

Poverty rates in coastal communities provide an overall view of the economic status of the coastal population relative to the rest of the nation and coastal region. Poverty can also indicate the levels of livelihood opportunities and sustainable resource use in coastal communities. For example, in fishing-dependent communities, high levels of poverty may indicate decimation of the fishery while lower levels of poverty may indicate more sustainable fishery management. Higher local poverty rates may also indicate a greater likelihood of unsustainable pressures on available natural resources.

How Do We Measure It?

Poverty line estimates are generated using either household income and expenditure surveys or similar specialized Living Standards Measurement Study (LSMS) household surveys. A disadvantage of these surveys is that the sample size generally permits inferences to be made regarding poverty rates at the national and regional but not local (provincial and municipal) levels. Furthermore, although national censuses provide detailed data on all households, they are conducted only once per decade, and they generally do not gather the income and consumption data required to generate poverty line information.

UBN poverty rates are generated from population and household censuses. These estimates are sometimes updated in intercensal periods with models using population projections and the results of annual multi-purpose household survey samples to project census data percentages to current dates.

Usefulness

Assessments of poverty are useful in determining whether the local economy, including marine-based activities, is providing the population with livelihoods that ensure a reasonable standard of living for the population. In general, if direct or indirect marine-based economic activities are profitable and there is relatively equitable access to and distribution of resources, then poverty line levels should be lower among coastal communities dependent on the marine environment for livelihood, so long as the resources are maintained.

For example, assuming a lack of widespread economic alternatives in other livelihoods, it may be expected that if commercially valuable species such as lobster and conch become scarce or if reef health deteriorates significantly, then these declines will result in a rise in poverty.

Status

Districts, municipalities and departments with high levels of coastal tourism development — such as Benito Juarez (Cancun), Isla Mujeres, Solidaridad

(Riviera Maya), Belize district (San Pedro), and the Bay Islands (Roatan, Utila) — display significantly lower poverty rates than municipalities in other areas of the countries that have lower tourism levels. Coastal poverty rates also tend to be slightly below national averages in most of the coastal municipalities, suggesting that economic advantages accrue from living in near proximity to the MAR coast as a result of the presence of economic alternatives such as tourism, ports, and fishing. In contrast, coastal municipalities and departments with particularly high poverty rates — such as Felipe Carrillo Puerto in Mexico, Toledo District in Belize, and the Gracias a Dios department in Honduras — tend to be characterized by the predominance of small-scale agriculture, little to no tourism or other available economic alternatives, and relatively large indigenous/ethnic populations.

Data Needs

These additional data are needed for a comprehensive assessment of MAR coastal poverty:

- Comprehensive poverty line data for the municipalities of Quintana Roo,
- Poverty rates based on UBN for Mexico and Belize,
- Municipal-level poverty line data for Honduras, and
- Marine resource viability and availability and relationship to poverty in coastal communities.

Mexico[9]

Coastal Locales in the MAR	Poverty Rate (poverty line method), % of individuals
Mexico: Country	34.8
Benito Juarez	18.0
Cozumel	n/a
Felipe Carrillo Puerto	43.0
Isla Mujeres	28.0
Othon P. Blanco	30.0
Solidaridad	25.0

Honduras[12]

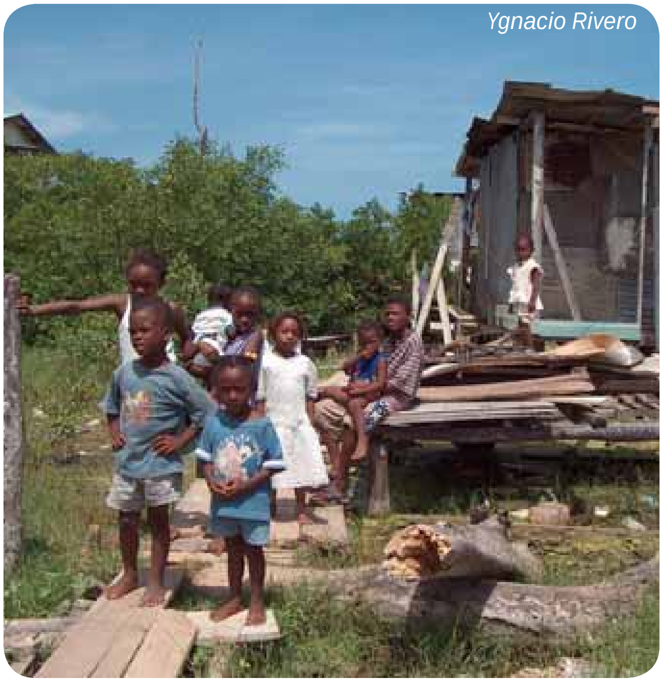
Coastal Departments in the MAR	Poverty Rate (poverty line method), % of individuals	Poverty Rate (UBN method), % of individuals
Honduras: Country	64.5	56.9
Atlantida	61.5- 73.8	47.7
Colon	73.8-78.1	62.9
Cortes	58.2 - 61.5	38.0
Gracias a Dios	73.8 - 78.1	89.4
Isla de la Bahia	58.2 - 61.5	36.0

Belize[10]

Coastal Districts	Poverty Rate (poverty line method), % of individuals
Belize: Country	33.5
Belize	24.8
Corozal	26.1
Stann Creek	34.8
Toledo	79

Guatemala[11]

Coastal Department (MAR coast)	Poverty Rate (poverty line method), % of individuals	Poverty Rate (UBN method), % of individuals
Guatemala: Country	56.0	60.0
Izabal	47.9	62.0


Ygnacio Rivero

SW5 Economic Contribution of Marine-related Activities

What Is It?

The *Economic contribution marine-related activities* — is expressed as the percentage of the economically active population whose main economic activity is either fishing or tourism-related activities that directly or indirectly depend on marine resources.

Why Do We Measure It?

This parameter provides a relative indication of how much of a coastal community's income is derived from marine activities, as well as the community's level of dependence on marine ecosystems for livelihood, by providing information on the number of individuals whose direct economic activities are related to tourism and fishing. However, it is not a comprehensive indicator of the number of individuals whose livelihoods depend directly or indirectly on marine-related activities, due to the fact that it does not include activities indirectly related to tourism and fishing nor marine-dependent activities such as ports and shipping.

Benchmark

Develop community-based targets for a sustainable number of people employed in different marine-related activities (i.e., how many tour guides, hoteliers, or fishers can a local reef sustain?).

Target

Meet marine-based employment targets (as established in the benchmark) that balance economic benefits and ecological sustainability.

Red Flag

Employment in marine-related activities continues to be market-driven with no consideration of environmental sustainability.

This indicator measures only the main activity reported by individuals in population surveys. However, occupational multiplicity (i.e., an individual engaging in various different economic activities to generate income) is a common practice within coastal communities. In the MAR region, this practice is evidenced by individuals who engage in fishing, tourism, agriculture and/or other trades in the same year, shifting from one to the other on a seasonal, weekly or even daily basis.

This indicator therefore provides one measure of the economic importance of reef resources for coastal communities in the MAR. The assumption is that the degradation of the resources will have a negative socioeconomic impact by reducing employment opportunities and economic benefits for local populations. Considered in combination with SW4 – Poverty and SW7 – Human Development Index, this can be a telling indicator of the long-term sustainability of marine-resource-based livelihoods.

How Do We Measure It?

The indicator is based on the economically active population (EAP), which includes all persons above a specified age (based on national standards) who supply labor for the production of economic goods and services during a specified time period. This group generally includes all individuals engaged in work for cash or in-kind income during a specific reference period (usually one hour in the week prior to the census or survey); individuals with a formal attachment to a job (even if they did not work during the reference period); and individuals without work but who were available for and seeking work during the reference period.

The labor surveys and household and population censuses request information on the primary income-earning activity for each household member in the week before the survey. Survey results are then coded by using standardized employment classifications. However, EAP statistics still may not be strictly comparable from country to country, due to slight differences in the ways that individual countries apply the classification systems to define labor participation and occupational categories. Furthermore, although in the coastal municipalities some fishing activity may take place in non-marine areas and some tourism activities are terrestrial-based (e.g., jungle and archeological tours), it can be reasonably assumed that the vast majority of activities related to the fishing and tourism economic sectors in nearshore areas are directly or indirectly marine-dependent.

Standard sources for EAP and occupation data include the national population censuses carried out approximately every 10 years, multi-purpose household surveys, and labor surveys usually carried out once or more per year. In most countries, census data provide the only information for the economically active population representative at the level of municipalities. The annual labor surveys focus on urban populations and are usually statistically representative only at national and regional scales, meaning that the random sample applied in the survey is designed to estimate EAP at a national scale within a reasonable margin of error but the samples are too small to make meaningful EAP estimates at the township, municipal or department/state levels.

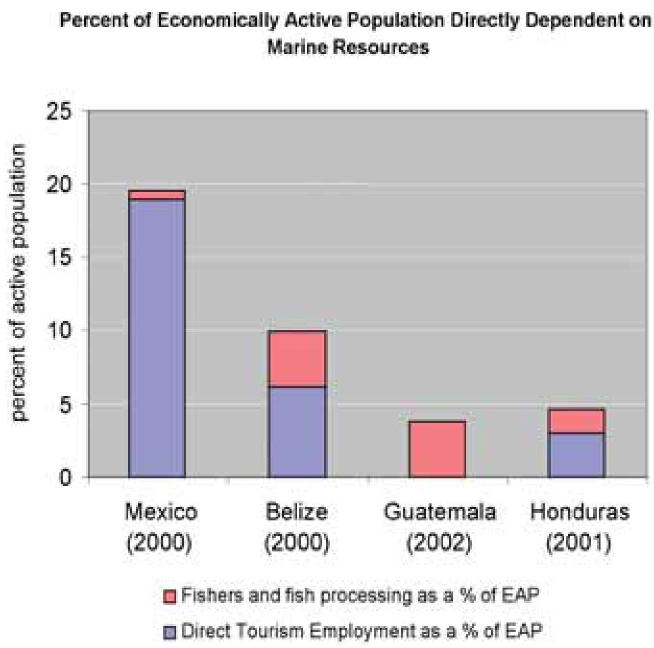
Usefulness

This indicator provides information regarding the extent to which the economic success of coastal communities depends upon marine resources. To understand the relationships among this indicator, local economic success and resource conservation, it should be interpreted within the context of the economic drivers and opportunities motivating the economically active population. It would be overly simplistic, for example, to say that the greater the percentage of the EAP involved in marine-derived livelihoods, the more value the population places on marine resource conservation. It would also be overly simplistic to state that marine activities provide an economically viable livelihood, based exclusively upon a high percentage of the EAP being involved in marine-derived activities. The key to appropriate use of this indicator is to interpret results in conjunction with other social and economic indicators that influence the overall economic well-being of coastal communities.

Status

The state of Quintana Roo, Mexico, and especially the municipalities in the northern part of the state, are the areas in the MAR in which the population is most highly dependent on marine-based activities, due to the overwhelming importance of tourism-based employment. The populations of the coastal communities of Belize and Guatemala are the most highly dependent on fishing and fish processing, due to the fact that a higher percentage of the EAP in those areas rely on fishing as a main activity. However, the northern Honduras coast has the largest numbers of fishers overall.

The data presented in the graph below are not exactly the same across countries, due to different interpretations of the employment classification system. The EAP data for tourism in Belize, Mexico and Honduras only includes the individuals involved in direct tourism employment (hotel, restaurant, tour agents, operators and guides). It can also be assumed, however, that for every individual directly employed in tourism there are two or three individuals who are employed in activities that indirectly depend on the tourism economy (construction, transportation, and other services). This multiplier factor was not applied to the data in the following graph.



Data Source[13,14]

Thus, our existing data on tourism employment only includes activities directly related to the hotel, restaurant and tour service provision sectors. It does not include activities indirectly dependent on the tourism economy.

Data Needs

A regionally standardized interpretation system is needed to capture the full employment derived from tourism (direct and indirect). Additional information is also needed regarding:

- More specific EAP data for the hotel and restaurant sectors of Guatemala;
- Occupational multiplicity (supplemental sources of income);
- Coastal community decision-making processes; and
- Employment opportunities in coastal communities.

SW6 ADJUSTED NET SAVINGS INDEX

BENCHMARK

Develop national targets for adjusted net savings that improve environmental sustainability.

TARGET

Achieve national targets for adjusted net savings levels that improve environmental sustainability.

RED FLAG

No improvement (or any decrease) in adjusted net savings in any of the MAR countries.

What Is It?

The World Bank's *Adjusted Net Savings Index* (ANS), formerly called "genuine savings," measures the "true rate of savings" in a country's economy after considering investments in human capital, depletion of natural resources and damage caused by pollution. For this indicator, we report on the ANS values already calculated and readily available from the World Bank[15].

Why Do We Measure It?

Economic growth often occurs at the expense of natural resources, either through resource depletion or excess pollution loads. The ANS considers the importance of managing natural resources and reducing pollution through regulations and incentives. The ANS is based on the concept of "green" accounting, where the goal is to shift economies away from their present emphasis on infinite economic growth and toward a greater focus on sustainable human well-being and reduction of environmental degradation.

The ANS indicator provides a useful way to incorporate environmental and natural resources issues into financial and economic planning. It provides decision-makers with a clear, relatively simple indicator of how sustainable a country's investment policies are, and it helps guide sustainable development. ANS also helps to raise awareness of these issues. In some cases, the adjusted net savings can be reflective of the loss of an important economic natural resource.

How Do We Measure It?

Net savings or assets accounts in monetary units provide a yardstick for measuring development prospects. The ANS is based on an integrated framework that allows the weighting and aggregation of various elements of the economy and environment. As an aggregate indicator, it allows for comparisons across groups of countries either by region or by income. Additional information on how the World Bank calculates the ANS is available on their website[15,16].

Usefulness

The World Bank's ANS is a well-respected, standardized global index that the World Bank calculates regularly. This indicator, which takes into consideration the condition of natural marine resources, can provide an impetus for promoting sustainable or green economic growth. The World Bank's ANS has several advantages including:

- Serves as an indicator of sustainability
- Presents resource and environmental issues within a framework familiar to finance and development planning ministries
- Reinforces the need to boost domestic savings (and sound macroeconomic policies)
- Highlights fiscal aspects of environmental and resource management (since resource royalties and pollution taxes are basic ways to raise development finance and ensure efficient use of the natural resources)
- Makes the growth–environment trade-off quite explicit, since countries planning to grow today and protect the environment tomorrow can be identified by their depressed rates of adjusted net savings

Decreasing ANS values imply that total national wealth is in decline. Policies leading to persistently negative adjusted net savings are policies that can not be sustained for the long-term.

To be more indicative of marine environmental sustainability, the ANS should be considered in conjunction with biophysical indicators (e.g., mangrove areal extent, fish biomass).

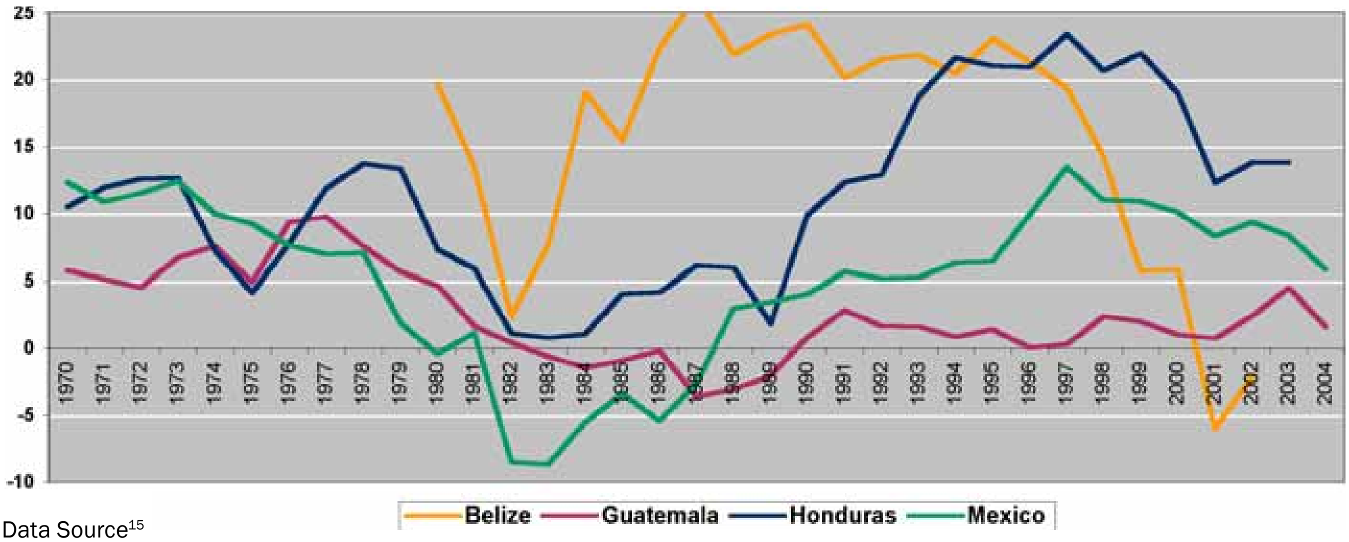
Status

Over the past decade, the ANS of Belize and Honduras declined from the highest in the region to the lowest in the region. Mexico and Guatemala have remained fairly stable with Mexico having somewhat higher values than Guatemala, but all falling below the global average. Of particular concern is the negative ANS value displayed by Belize in 2001. The adjusted net savings in the region have likely been affected by a number of factors including an overall decline in fisheries production, increased levels of environmental degradation, and reduced investments in education and social programs. Data are available for most countries spanning back to the 1970s. Additional analyses are needed to quantify the relationship between the ANS and marine resources. The overarching objective is to ensure that economic growth and social development investments are not offset by depreciation of non-renewable resources or overexploitation of renewable resources.

Data Needs

Additional data are needed to identify how marine natural resource capital has changed, especially in relation to increased tourism and coastal development in the region. ANS data should be updated annually.

Adjusted Net Savings values for MAR countries, 1970 – 2004



Data Source[15]

ECONOMY

SW 6

SW7 Human Development Index (HDI)

Benchmark

Compile necessary data to routinely calculate HDI at the coastal municipal level and investigate the relationship between increasing HDI and environmental stewardship.

Target

Improve health and education infrastructure so there is a measurable increase in HDI (with target values to be developed between governments and community organizations). Demonstrate a positive correlation between increasing HDI and increased levels of environmental stewardship.

Red Flag

Any decline in HDI (potentially with an associated decline in environmental stewardship).

What Is It?

The *Human Development Index* (HDI) is a composite index that provides a measure of human well-being. The index takes into account average achievements in three basic areas: longevity, knowledge, and standard of living. This index was developed by the United Nations Development Programme (UNDP) and is typically applied to countries or sub-national political administrative units.

Index values range from 0 to 1. Countries with an index score greater than 0.8 are considered to be at a high level of development. HDI scores between 0.5 and 0.799 indicate middle human development. Countries with HDI scores below 0.5 are considered to have low human development [24].

Why Do We Measure It?

The HDI is a standard indicator used to measure general economic and social development. The indicator takes into account factors other than standard economic variables to measure human well-being. Since the indicator is standardized across countries, it can be readily used for regional or global comparisons.

How Do We Measure It?

The HDI takes into account four variables:

- Life expectancy at birth;
- Adult literacy rate;
- Combined primary, secondary, and tertiary gross enrollment ratio (the percentage of individuals in the population within the age group corresponding to school level that are enrolled in school); and
- Gross domestic product (GDP) per capita (purchasing power parity in $US).

These variables are transformed into three indices, each with a value between 0 and 1: a Life Expectancy Index; an Education Index (the average of an adult literacy index and a gross enrollment index); and a GDP index. The HDI then represents the average of these three general indices:

$$\text{HDI} = \frac{\text{Life Expectancy Index} + \text{Education Index} + \text{GDP Index}}{3}$$

Usefulness

The HDI is a widely accepted indicator of social well-being. It is easy to measure, replicate and compare among countries. The HDI is more strongly linked to social issues than to environmental issues, but there is a tendency for countries with healthier, better-educated and higher-income populations (i.e. higher HDI values) to have higher levels of environmental protection.

It is also probable that HDI levels among coastal communities dependent on the marine environment for their livelihoods will be higher when reef resources are abundant and marine activities are profitable. A decline in HDI trends in coastal municipalities may be an indicator of a decline in resource abundance and reef health.

Status

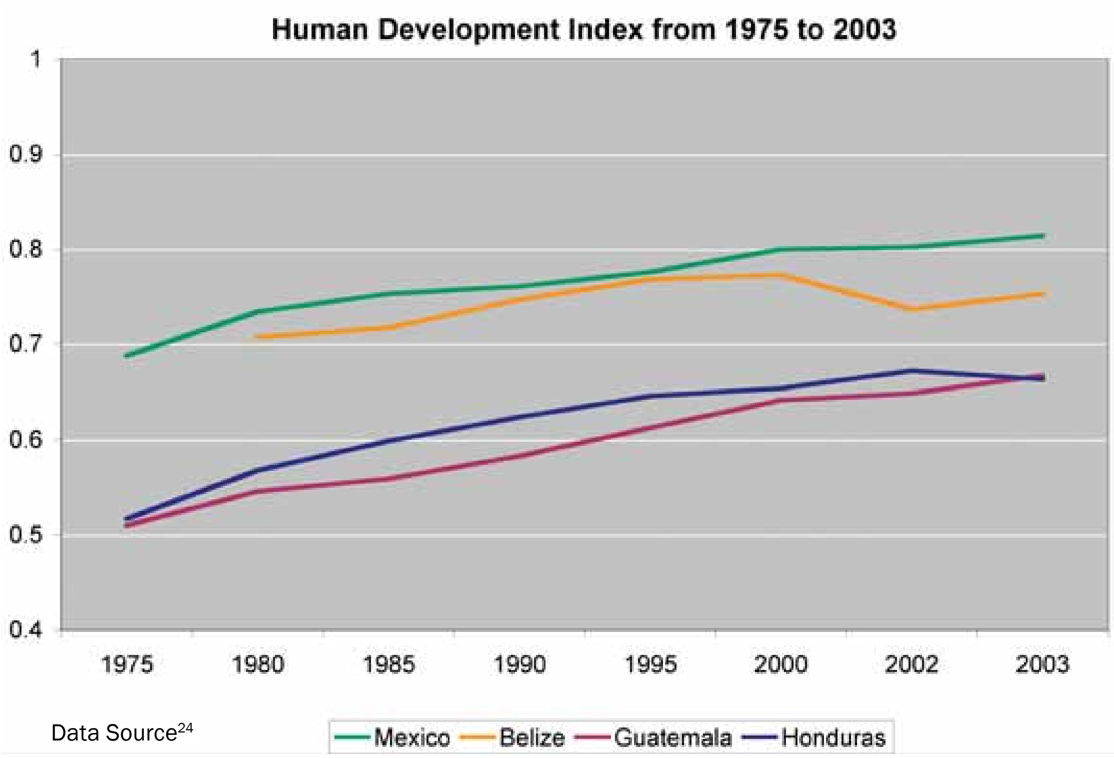
As of 2003, Mexico was at a relatively high level of human development. Belize, Honduras and Guatemala all fell within the medium category of human development. National indicators show an overall HDI score increase in all countries over the last 20 years. Only Belize shows a recent downward trend in HDI scores [25].

HDI values have also been calculated for individual municipalities within Honduras, Mexico and Guatemala (Appendix 3). These data display significant variation in HDI scores in coastal municipalities at national and sub-national levels. Similar to the poverty rates, HDI scores are higher for those municipalities with high levels of tourism development. For example, Benito Juarez (Cancun) and Cozumel in Mexico and the Bay Island municipalities in Honduras display human development scores that indicate a high middle or high level of human development compared to other municipalities in Honduras such as Balfate and Arizona that display low middle development scores [26,27].

Data Needs

Data needs relevant to measures of human development include: HDI calculated to the municipal level for Belize and updated calculations of HDI for all countries.

Further research is needed into the relationship between national and municipal HDI values and levels of environmental protection and stewardship.



Note: The human development index values in this table were calculated using a consistent methodology and data series. They are not strictly comparable with those in earlier Human Development Reports.

Country-Level HDI rankings for 2003

	Mexico	Belize	Honduras	Guatemala
Human Development Index (HDI) value 2003	0.814	0.753	0.667	0.663
HDI Overall Rank (out of 177 countries)	53	91	116	117

Culture

Conservation Objective

Sustainably manage marine and cultural resources while balancing the preservation of cultural traditions with the emerging opportunities of the global marketplace. Achieve a higher quality of life in the region.

Threats

Economic growth, coastal development, tourism expansion, migration patterns, education level, and quality and availability of marine resources are changing the Mesoamerican region's cultural identity. The loss of ethno-languages, oral history, traditional cultural practices, and respect towards elders threatens traditional cultural integrity and values.

Management Actions

- Develop a better understanding of cultural attitudes toward marine resources at the local community level.
- Investigate the effects of economic growth, coastal development and migration on traditional cultures.
- Encourage programs promoting traditional cultural values or sustainable cultural use of reef ecosystems.
- Encourage work programs that promote gender equity in employment and education, and support sustainable development or use of coastal marine resources.
- Promote awareness of non-material benefits of reef ecosystems.
- Integrate cultural values and services of reefs into decision-making, particularly in the EIA planning process.
- Develop coastal zone management (CZM) plans that incorporate projected in-migration rates, social infrastructure

Inclusion of cultural indicators in discussions of ecosystem health is a fairly new endeavor. Incorporating traditional knowledge and indigenous people's relationships with the natural ecosystem may provide an approach to resource management different from that found in strictly economic or ecological approaches. Cultural beliefs, values and behaviors may have both positive and negative consequences on the reef ecosystem and are tied to economy, governance, environment and human health.

Cultural indicators are helpful for identifying how stakeholders value reef resources in non-monetary terms and for generating effective advocacy tools for protecting the reef environment. Cultural indicators track how indigenous or local communities have changed in association with changing reef health or management, particularly in relation to resource extraction and availability. Too often policies are developed without considering important cultural concerns, resulting in less-respected and less-effective implementation. Cultural indicators with direct ties to the environment can help insert cultural priorities into policy development.

The indicators selected to track cultural integrity are:

SW8	Ethno-languages
SW9	Gender & Employment
SW10	In-migration
SW11	Environmental Perceptions


Sergio Hoare / WCS

SW8

Ethno-languages

What Is It?

The term *ethno-languages* refers to traditional or indigenous languages remaining in active use by a population. This indicator is a measure of the numbers of individuals who continue to speak ethno-languages within specified coastal municipalities.

Benchmark

No decline in proportion of individuals that speak the ethno-language of their ethnic or cultural group.

Target

Maintain or increase the proportion of individuals that speak the ethno-language of their ethnic or cultural group.

Red Flag

A reduction in the proportion of individuals that speak the ethno-language of their ethnic or cultural group.

Why Do We Measure It?

The use of ethno-languages is an indicator of a population's adherence to their traditional lifeways and cultural identity[17,18,19]. Outside influences and the encroachment of a modern lifestyle act against the preservation of traditional practices and values which, in turn, are strongly linked to the use of traditional languages. Because a direct correlation is suspected between cultural and linguistic diversity, biological diversity, and the stewardship of natural resources, the disappearance of cultural practices and the loss of ethno-languages may indicate both a deterioration of the socio-cultural context and the weakening of sound natural resource stewardship.

How Do We Measure It?

The indicator measures the percentage and absolute numbers of individuals that report the ability to speak an ethno-language. The question used to obtain the indicator is slightly different for each country. The Mexican and Guatemalan censuses report the number of individuals in the population that speak an indigenous language. The Belize census reports the main language that individuals speak in their homes. In contrast, the census in Honduras does not request information on languages but rather on ethnic identification. Although it is likely that many individuals identifying themselves with a non-ladino (i.e., mainstream) ethnic group speak the traditional language associated with that group, ethnic self-identification is a different indicator of ethnic diversity and should not be strictly compared with data from the other three countries, although it may have some comparative value.

Usefulness

Language uniquely encodes culturally-specific forms of knowledge and values and the decline or disappearance of language use therefore provides one of the most salient signs of culture loss. Both cultural and biological diversity constitute part of the rich heritage of the MAR region. Some conservation-based studies have noted a relationship between cultural diversity, local knowledge, resource stewardship and biological diversity. Many traditional groups around the world that have strong historical ties to local land and marine areas maintain traditional practices and values that support the conservation and sustainable management of the resources upon which they depend for their livelihoods. Further study is required to determine whether this correlation holds true for different groups in the MAR region.

Furthermore, the relationship between the growth of tourism and the persistence of traditional cultures is of particular interest because of the accompanying exposure to foreign cultures. Tourism can be a force that provokes rapid cultural change, including loss of local identity and values. At the same time, tourism can boost the preservation and transmission of cultural and historical traditions. For example, Garifuna entrepreneurs in Hopkins, Belize, offer drumming and dance classes, folkloric performances, and traditional medicinal services to tourists.

Status

The main ethno-languages spoken in the Mesoamerican reef communities include a wide variety of pre-Columbian indigenous languages as well as Creole and Garifuna that emerged during the colonial period. The highest percentages of individuals that speak ethno-languages occur in central Quintana Roo (municipality of Felipe Carrillo Puerto) where Maya is the dominant ethno-language;[20] in central Belize with Creole and Garifuna speakers; in southern Belize (Toledo District) as a result of Maya K'etchi, Maya Mopan and Creole speakers;[21] and in the municipality of Livingston in Guatemala as a result of the presence of Maya and Garifuna speakers.[22] The southern municipalities of the northern Honduran coast also display a high percentage of individuals that identify themselves with an indigenous or traditional group with the preponderance of Miskito and Garifuna ethnicities.[23]

Data Needs

Additional information is needed regarding:

- The use of ethno-languages in Honduras;
- Changes in the use of traditional socio-cultural practices (e.g., dance, ethnobotany, oral history);
- The loss of cultural practices that include traditional resource uses and management practices.

Percent and Numbers of the Population that Speak Ethno-Languages per Municipality

Country	State/ Department/ District[1]	Municipality/ District	Percentage that speak ethno-language	Numbers that speak an ethno-language
Belize	Belize	Belize	65.0	41,017
	Corozal	Corozal	12.1	3,911
	Stann Creek	Stann Creek	62.3	15,238
	Toledo	Toledo	73.5	16,981
Guatemala	Izabal	Livingston	49.1	23,857
		Puerto Barrios	4.4	3,759
Mexico	Quintana Roo	Benito Juarez	11.9	50,936
		Cozumel	12.8	8,062
		Felipe Carrillo Puerto	72.3	40,996
		Isla Mujeres	13.4	1,300
		Othon P. Blanco	11.4	21,940
		Solidaridad	21.7	19,915
Honduras[2]	Atlantida	La Ceiba	8.7	11,107
		Tela	8.7	6,762
	Colon	Santa Fe	51.3	2,873
		Santa Rosa de Aguan	39.5	1,497
	Gracias a Dios	Brus Laguna	91.3	8,647
		Puerto Lempira	82.9	19,332
	Islas de la Bahia	Jose Santos Guardiola	49.6	3,774
		Roatan	26	4,538

Data Source[20, 21, 22, 23]

[1]The largest political administrative unit in the country is variously called a state (Mexico), district (Belize), and department (Guatemala and Belize). In Belize, the next largest administrative unit is the village or township level. These are very numerous within districts and generally represent very small populations. For that reason, the district level in Belize has been used as the equivalent of the municipalities in the other countries.

[2]For Honduras the data represent the numbers of individuals that identify their ethnicity as that of an indigenous or traditional group, not ethno-language speakers per se. The table only includes the top two municipalities in each department in terms of the percentage of individuals reporting affiliation with a traditional ethnic group. The full table is available in Appendix 3.

SW9 Gender and Employment

Benchmark

Promote a gradual increase in the female labor force participation rate in the MAR region of each country.

Target

Increase the overall LFPRs in Honduras and Guatemala to 50%. View a notable increase in female LFPRs in the MAR region of each country.

Red Flag

Any decrease in overall and female LFPRs at the municipal or country level.

What Is It?

Male and female labor force participation rates (LFPR) constitute an important indicator of gender roles within households and communities. One sign of economic development is the overall participation of working-age individuals in the workforce. Low levels of economic participation are an indicator of an underutilized workforce and a population that is likely under economic stress. It is also important to compare workforce participation by gender—that is, the relative levels of men of working age and women of working age that participate the workforce. In more traditional societies, women normally display low levels of workforce participation in comparison to males as their roles are relegated to household activities. In contrast, modern economic development is usually characterized by the rapid incorporation of women into the workforce. This is often accompanied by shifts in gender roles within households and societies that change the relative status of women as decision-makers within households and communities.

Why Do We Measure It?

In the MAR region, new opportunities in the workforce have increased more dramatically for women than men, especially in areas where tourism development has taken place. For example, in Hopkins and Placencia, Belize, census data indicate that tourism development has brought a rapid increase in the participation of women in the workforce and a dramatic decline in 'home duties'[28]. Similarly, a recent study carried out in the community of Punta Allen, Mexico, indicates that tourism has brought an increase in the numbers of women who are small business owners, members of tourism cooperatives, owners of boats and salaried workers — and that women are now earning as much as or more than males from tourism activities[29].

Traditionally low levels of female workforce participation in comparison to men probably (but do not necessarily) indicate high degrees of gender inequality within households and communities. Furthermore, as their labor force participation increases, women may take on an increased burden as they assume responsibilities as income earners in addition to their traditional household roles. However, over time increased female labor force participation is likely to be accompanied by a gradual shift in traditional gender roles. As women become more independent economic agents within society, their relative autonomy and status within the family and communities vis-à-vis male members are often enhanced and they become more active participants in family and community decision-making. In many parts of the MAR region, women are increasingly visible in the workplace as professionals and in leadership roles in government departments, non-governmental organizations (NGOs) and community-based organizations. Throughout the world, the increased participation of women in the labor force is also strongly correlated to a decrease in total fertility rates (TFRs). A decrease in TFRs will reduce the potential pressure on MAR resources in the future from natural population increases.

How Do We Measure It?

The overall labor force participation rate represents the percentage of the working-age population in a specified area that is economically active. Similarly, male and female labor force participation rates represent economically active males as a percentage of the total working-age male population and economically active females as a percentage of the working-age female population. Official cut-off ages for the working-age population are based on national standards (age of 7 and over in Honduras and Guatemala, 12 and over in Mexico, and 14 and over in Belize). "Economically active individuals" generally includes all individuals engaged in work for cash or in-kind income for at least one hour in the week prior to the census or labor survey (reference period) used to measure the labor force, as well as individuals with a formal attachment to a job (even if they did not work during the reference period), and individuals without work but who were available for and seeking work during the reference period.

Usefulness

Male and female participation in the overall labor force provides a means of establishing the relationship between specific economic trends (e.g., tourism development or duty-free zone establishment) with associated changes in the labor force that are likely to involve changing family structures, values, gender roles, education levels for women and fertility rates. The specific impact of increased involvement of women in the labor force will also depend on factors not included in this particular indicator, such as prevailing values, gender-based division of labor, and traditional patterns of female leadership within communities. These vary significantly amongst the different ethnic groups represented in the MAR region. Availability of quality education, government policies supporting women's equal access to political positions, land and other legal rights, as well as the rate and specific nature of local economic development, will also play a significant role.

Status

Labor force participation rate data are available at the national and municipal levels for all MAR countries [30]. The data are not strictly comparable across countries because different countries use different age ranges to define "working age" (see above). A table summarizing LFPR and LFPR per gender within coastal communities per country is provided below. Detailed data for the municipal level are provided in Appendix 3.

The baseline data show higher overall participation rates in Mexico and Belize and extremely low overall labor force participation rates in Guatemala and Honduras, indicating that more traditional patterns of economic and social organization continue to prevail in these areas. They also demonstrate much higher male than female LFPRs in all countries, with female LFPRs being especially low in Honduras.

Data Needs

Additional information is needed regarding historical trends in labor force participation rates, the types of jobs occupied by women in the MAR region, male and female income, and the relationship between LFPRs, gender equality and empowerment and environmental protection or resource extraction.

Courtesy of Belize Medical Associates
© 2006 Tony Rath Photography

Country	Labor Force Participation Rate, %	Male Labor Force Participation Rate, %	Female Labor Force Participation Rate, %
Belize	65	78	46
Guatemala	37	55	19
Honduras	36	56	18
Mexico	58	79	36

Data Source[30]

SW10 In-migration

What Is It?

In-migration refers to the movement of persons into a given community or municipality from another department/district/state or country. Persons who make such a move are called in-migrants. (Immigration and emigration, in contrast, refer specifically to a move from one country to another.)

Two indicators are commonly available from census data to track a given area's in-migration patterns: (a) the percentage of the population born in the department or district in which they currently reside (i.e., as of most recent census), and (b) the percentage of the population 5 years of age or older who did not live in the municipality five years prior to the most recent census.

The first indicator provides information about historical in-migration patterns, while the second one provides information on recent in-migration patterns.

Benchmark

Develop coastal zone management (CZM) plans that incorporate projected in-migration rates, social infrastructure and environmental conservation needs for all coastal areas in the MAR.

Target

Implement CZM plans that incorporate projected in-migration rates, social infrastructure and environmental conservation needs for all coastal areas in the MAR.

Red Flag

Any coastal area with high in-migration rates or levels. No progress in developing CZM plans.

Why Do We Measure It?

The negative social and environmental impacts of rapid and uncontrolled in-migration are easily observable throughout the MAR region, especially along the outskirts of cities and towns along the coast. Commonly, existing services and infrastructure are unable to accommodate rapidly growing in-migrant populations. New, spontaneous settlements are created without access to proper sanitation facilities, clean potable water sources and power lines. Existing educational and health services are overwhelmed. Green areas may be cleared and paved over to accommodate new shacks and houses. The resulting situation increases health risks for the population, provokes deterioration in environmental quality and poses the potential for overexploitation of local natural resources.

In-migration may also impact established patterns of resource conservation and use. The "newer" the population in a coastal area, the less likely there is to be strong identification with the conservation of local resources and resource use patterns based on long-time identification and experience with the area. It might also be expected that newer populations are less socially cohesive and less willing and able to make conservation investments today to ensure future benefits. Newer populations may also introduce new natural resource uses and management practices that conflict with local practices and increase pressure on existing resources. One such conflict in the MAR region involves the increasing involvement of new fishers from Guatemala and Honduras into Belizean waters. Although these immigrant fishers often have legal fishing licenses, the Belizean fishers complain that they use fishing techniques that display a lack of respect for and understanding of laws and customary and sound fishing practices. They express the concern that these practices are placing increased pressure on the country's already delicate fishery resources [28].

How Do We Measure It?

The data required to calculate these two measures of in-migration are commonly collected in the national housing and population censuses applied every 10 years. During the census, for each individual in the population, the place of birth is recorded as well as place of residence 5 years prior to the census (for all individuals born by that time). This information is compared to the place of residence at the time of the census to generate the indicator values.

Usefulness

The governments in the MAR region typically lack the resources and level of organization to control and provide a rapid response to in-migration. Evidence of high levels of in-migration therefore serves as a red flag for possible environmental and social problems in the area in which it is occurring. Furthermore, a population's social structures and values are likely to be affected by external influences, such as an influx of migrant populations with different value systems. While it is difficult to attribute changes in resource use or environmental quality directly to in-migration and the influence of recently settled members, some relationship is probable.

When examined in tandem with other indicators of human health, education, and environmental quality, this indicator's scores can be interpreted with a greater degree of understanding and confidence.

Status

The graphs below demonstrate that, whereas the coastal populations of Honduras, Belize and Guatemala have been relatively stable, the MAR coastal areas of Mexico have been characterized by very high rates of both historical and recent in-migration. When tourism development began in Quintana Roo in the early 1970s, the state was relatively unpopulated. The labor needs of the booming tourism industry in Quintana Roo have therefore been met primarily by a workforce that has migrated into the state from other areas of Mexico.

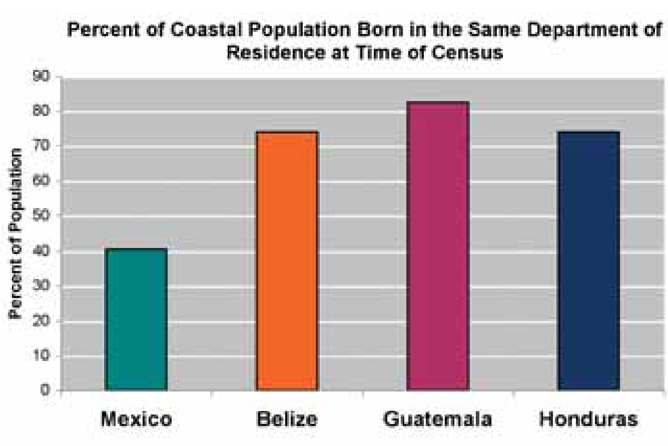
In-migration may be very localized, however, so it is useful to be able to pinpoint areas of higher in-migration at a more localized scale. Coastal municipal level in-migration data are provided in Appendix 3.

Data Needs

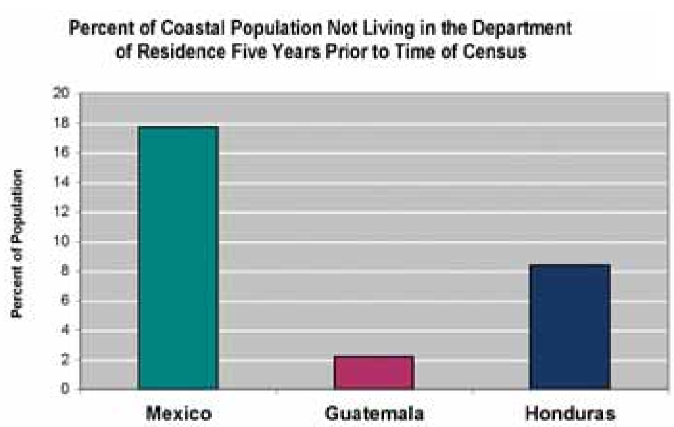
For a more complete understanding of migratory patterns in the region and associated impacts, additional information is needed regarding:

- Out-migration rates;
- The economic opportunities within coastal municipalities that may draw in-migration;
- The economic trends and opportunities in surrounding areas that may encourage out-migration;
- The perceptions of resource protection by long -standing residents versus newly migrated residents;
- Socio-cultural traditions (including language and cultural values and practices) and relationship to natural resource use.

Conservation and sustainable use of marine resources are becoming higher priorities in the MAR region. Numerous country-wide and local policies, laws, and regulations are in place to address issues from overexploitation of fishery resources, protection of critical habitat, and pollution and degradation of resources related to excessive use. The development and implementation of these policies are critical for conservation success. However, there is no consistent way to measure achievement of stated objectives.



Data Source[31]



Data Source[31]

Environmental Perceptions

What Is It?

The term environmental perceptions refers to the way people perceive, understand and value the environment. These perceptions and values can be considered within the framework of the individual, the community, a stakeholder or other demographic group, and over time. In the context of this Guide, the term refers specifically to perceptions of the MAR marine environment.

Why Do We Measure It?

Environmental managers rarely actually manage the environment since most ecological processes are outside their direct control. Instead, they more often manage human behavior, normally in an effort to avoid some negative environmental consequence. Good quality data on the perceptions of different stakeholder groups are important for effectively managing human behavior because they provide information on stakeholder knowledge regarding conservation issues and the potential for support, conflict or apathy in achieving conservation goals. Managers and conservationists also need to engage the public and increase their awareness of the status, threats and importance of protecting the marine environment.

Since the 1997 Tulum Declaration, local, regional and international conservation efforts have increased in the MAR region. Many of these efforts include some aspect of community or stakeholder outreach designed to strengthen the public support required to achieve long-lasting conservation success. Traditional natural resource harvesters in the MAR region have a long history of traditional knowledge and management of the environment, and that knowledge may make them more sensitive to issues related to marine conservation. However, modern trends toward increased urbanization can also bring new immigrants and leaders with development aspirations that do not necessarily coincide with the goals and perceptions of traditional groups regarding local environmental stewardship.

Environmental perceptions can be determined by using a variety of opinion survey techniques aimed at measuring the public's concerns, values, and understanding of environmental issues. In areas with adequate infrastructure, techniques can involve using randomized telephone, mail or Internet-based polls of the general population. However, due to the remoteness of much of the MAR region and the fact that poor people do not often have easy access to phones or the Internet, most areas require face-to-face survey interviews. Survey methods must be carefully designed to determine adequate sample size, and follow procedures for obtaining randomized or representative samples (depending on which is desired). Ideally, surveys should abide by general sampling protocols agreed to among a range of regional organizations involved in collecting such surveys[32].

Focus groups or other group consultation methods are also frequently used by development and conservation agencies to gauge stakeholder perceptions and preferences. Unlike surveys, these methods do not provide data that allow for rigorous statistical comparison of attitudes in large populations over different time periods. However, when conducted appropriately, these more qualitative approaches can provide very rich and detailed information regarding perceptions of different stakeholder groups and are especially valuable for obtaining a more detailed understanding of the rationale behind different opinions. These group consultation methods are therefore useful as stand-alone activities or as complements to surveys to obtain perception-related information.

Usefulness

It is important for managers, decision-makers and conservation organizations to understand the perceptions, values, and knowledge of various communities and stakeholder groups in order to tailor conservation and education messages appropriate to the groups' needs and interests. Without an informed and supportive public, lasting and environmentally beneficial policies are unlikely.

Perceptions of different use groups can differ greatly among stakeholders (e.g., fishermen versus tourist guides versus business people) and within the same group (e.g., trap fishers versus free divers). Even within a single stakeholder or demographic group, opposing viewpoints may confound generalized perceptions (e.g., mangrove forests may be perceived by some in the tourism industry as mosquito-breeding swamps in need of infilling – while others in the same industry may see them as valuable natural assets for shoreline protection and flood control, providing essential fish habitat that supports natural tourist attractions and seafood availability). Individuals with opposing viewpoints are often unaware of their fundamental differences in perceptions. Opinion surveys are useful tools to illuminate such differences and then help guide solutions that accommodate these different underlying perceptions.

Some have argued that strong environmental conservation ethics can manifest only after basic economic needs are fulfilled. However, an alternate viewpoint is that people with the least material wealth are most directly dependent on natural resources (e.g., utilizing the sea and forest for food and other resources). As noted above, many factors shape individuals' perceptions and opinions. Without solid evidence, broad generalizations regarding a correlation between socioeconomic status and opinions on specific conservation issues should be avoided. Surveys of environmental perceptions among different demographic groups can help identify potentially useful patterns in differing viewpoints both within and between groups.

Most important, by tracking key questions on environmental perceptions in the same way over time, we can monitor the progress of our education and awareness-raising efforts.

Status

An opinion poll of over 100 experts and practitioners from the Mesoamerican Reef (MAR) ecosystem region and abroad was conducted in September 2005 by the Healthy Reefs Initiative (see Section 10 Next Steps). The survey covered perceptions on the prevailing ecological condition of and threats to the Mesoamerican Reef ecosystem, its value, and current management efforts. Respondents included six different stakeholder groups.

Most respondents felt that unsustainable and unregulated coastal development/tourism was the greatest threat to the health of the MAR ecosystem, although agriculture/land pollution was also identified as a severe threat. Other recognized threats included global climate change and overfishing. Participants gave a poor ("some decline") rating for coral reefs, fisheries, water quality and governance/stewardship. Social well-being was considered fair ("stable"). Scientists and fishermen, in particular, noted a significant decline in coral reef ecosystem health, water quality and fisheries over the last decade, while tourism operators viewed the coral reef ecosystem health as stable. NGOs noted a decline in governance and stewardship, while government participants considered them stable.

Data Needs

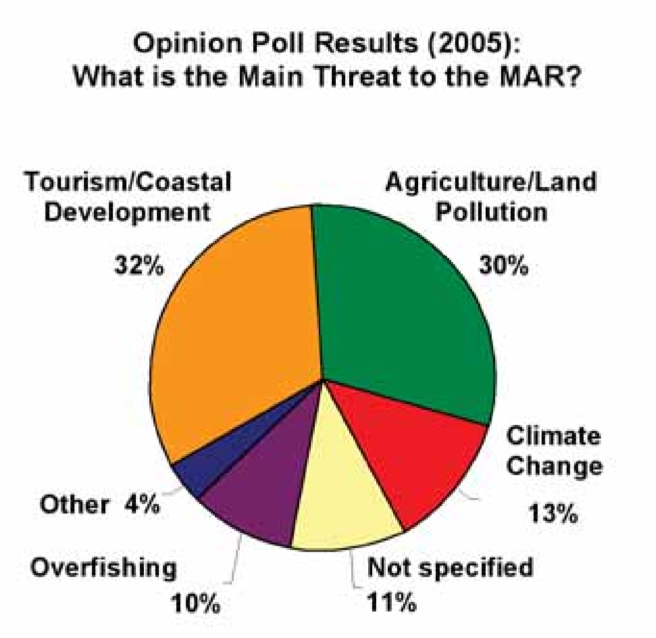
Many community-based opinion surveys have been conducted in the MAR, particularly in communities in or around protected areas. However, there is no known synthesis of these data or longer-term analysis of trends in environmental perceptions. A synthesis of these various surveys should be conducted, similar to the work of the Ocean Project, which synthesized different opinion surveys in the United States[33].

A comprehensive MAR-wide survey of public perceptions, opinions, values and concerns should be conducted as soon as possible. A core set of 4-5 questions should also be established for inclusion in a wide variety of opinion surveys conducted by partner organizations in the MAR.

Difficulties and future opportunities include:

- how to compare or combine perception-based measures of environmental quality with objective measures of environmental quality, and
- how to combine general survey results based on differing methodologies.

Environmental perception data should be considered in conjunction with other SW indicator data such as Poverty (SW4), Economic Contribution of Marine-related Activities (SW5), as well as ecological indicators such as Mangrove Areal Extent (S12), Coral Cover (S4) and Coral Mortality (F5).



Data Source: 6 in Sections 8-10: Final Section of References

Policy

Conservation Objective

Improve the protection and sustainable management of marine resources through the effective implementation of equitable, effective and transparent policies.

Threats

The lack of sustainable financing, deficient institutional capacity, a lack of comprehensive environmental policies and/or an inability to effectively implement existing policies, increasing corruption, and overall economic and political stability all threaten the effectiveness of environmental regulations.

Management Actions

- Work with all levels of government to improve environmental accounting in planning efforts and policy implementation.
- Improve MPA management effectiveness.
- Adopt and implement a minimum set of performance criteria in all MPA evaluations across the region.
- Achieve full financing for existing MPAs.
- Work with government and civil society to dismantle policies that facilitate corruption, and encourage policies that lead to a reduction in corruption and an increase in governmental effectiveness.

Policy indicators measure the development and effectiveness of policies most relevant to reef ecosystem health, such as the effectiveness of marine protected areas and the comprehensiveness of environmental legislation (including public participation mechanisms). Environmental policy indicators address how we can consistently measure the impact of the environmental policies, laws, and regulations in place in the MAR. Information on environmental policy and institutions can be developed into "response" indicators of how society responds and takes action to alleviate or prevent negative impacts on the ecosystem (e.g., management strategies or regulatory actions).

The indicators selected to track environmental policy are:

SW12 Environmental Sustainability Index

SW13 Marine Area within MPAs

SW14 MPA Effectiveness

SW15 World Bank Governance Indicators

Patricia Kramer

SW12

Environmental Sustainability Index (ESI)

What Is It?

The *Environmental Sustainability Index* (ESI) measures the capacity of nations or their sub-divisions to sustainably manage their natural environment over the next several decades.

This index, which was developed by the Yale Center for Environmental Law and Policy,[35] uses an aggregate dataset of 76 parameters that track natural resource endowments, past and present pollution levels, environmental management efforts, governance effectiveness, corruption, political and civil liberties and other measures of a country's capacity to improve its environmental performance. These are then aggregated into a single indicator of environmental sustainability capacity.

ESI scores can range from 0 to 100. In general, the higher the ESI value, the greater the tendency towards environmental stewardship. Lower ESI values tend to indicate poorer capacity for stewardship.

Benchmark

Increase ESI scores to at least 55 to 60 for all MAR countries. Work with Yale Center for Environmental Law and Policy group to develop ESI equivalents for small economies (Belize).

Target

ESI scores ranked in the top quartile (25%) for all MAR countries.

Red Flag

Stagnant or decreasing ESI scores for any country.

Why Do We Measure It?

Sustainable use of the environment and natural resources is the key to the future survival of global populations. Central to environmental sustainability is the capacity of policymakers and decision-makers to develop and implement informed regulations that protect the environment while meeting human development needs.

This index complements gross domestic product (GDP) and the human development index (HDI). The ESI can be compared to these two measures to understand the environmental sustainability required to maintain or improve economic or development conditions. This indicator thus promotes explicit consideration of how economic growth can be balanced with environmental sustainability. It also provides a quantitative guide for government agencies seeking to increase the capacity for environmental protection and stewardship in MAR countries.

How Do We Measure It?

The ESI incorporates 76 indicators into 21 components related to five aspects of environmental sustainability:

- Environmental systems,
- Environmental stresses,
- Human vulnerability to environmental stresses,
- Societal capacity to respond to environmental challenges, and
- Global stewardship.

These are then rolled up into a single comparable score from 0 to 100.

Usefulness

The ESI scores provide important information regarding the enabling environment necessary for sustainability at a national scale. ESI calculations are based on national averages, and values specific to MAR coastal areas are not available. Nevertheless, countrywide averages give an indication of the national stewardship "climate," which inevitably influences local environmental conditions and governance.

ESI scores should be cross-referenced with direct biological measures to verify whether stewardship capacities are translating into sustainable impacts on the ground.

Status

Finland is the country with the highest ESI score (75) and is thus ranked first among 146 countries. North Korea ranks last with a score of 29.2. The MAR countries have ESI scores of 44 - 47 and are thus ranked somewhere in the low-medium to low rankings. No score was calculated for Belize, due to concerns over direct comparisons of large-sized (e.g., Mexico) and small-sized (e.g., Belize) countries/economies [35].

Data Needs

An ESI scoring is needed for Belize to better assess sustainability in the MAR region. It would also be useful to have further analysis of the 21 specific dimensions that go into calculating ESI values for each country in the region and how they relate to reef ecosystem health.

Environmental Sustainability Index Score and Ranking per Country

Country	ESI Score	Ranking Compared to 145 Other Countries
Mexico	46.2	95
Belize	Not ranked	Not ranked
Guatemala	44	116
Honduras	47.4	87

Source: http://www.yale.edu/esi/ESI2005_policysummary.pdf

Toni Parras

SW13
SW14

Marine Area within MPAs

MPA Management Effectiveness

What Is It?

Marine area within MPAs (SW 13) refers to the percentage of a country's total territorial-seas area that lies within legally established marine protected areas (MPAs). Here, an MPA is defined as "any area of intertidal or subtidal terrain, together with its overlying water and associated flora and fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment."[38]

MPA management effectiveness (SW 14) is a systematic and structured measure of the degree to which management actions are achieving stated goals and objectives. This indicator is designed to serve as a general summary index that allows the tracking of MPA performance within a country or the region (combining individual MPA evaluations into a meta-analysis).

Why Do We Measure It?

Marine protected areas are a key component of marine conservation programs. They help protect marine biodiversity by conserving critical habitats, providing refugia and replenishment zones for heavily exploited fisheries resources, and fostering a higher level of enforcement and educational activities. Globally, the establishment of MPAs has lagged behind that of terrestrial protected areas, with only 0.6% of the world's marine area under protection[36] versus 12% of the land surface[37]. In the last decade, creation of marine protected areas has become a higher priority, as evidenced by the dramatic increase in the global number of MPAs — from approximately 1,300 in 1995[38] to 4,600 in 2005[36].

These two closely related indicators are used to track MPA success. The overall conservation goal is to develop and effectively manage an ecologically representative and functional network of marine and coastal protected areas in the MAR.

The first metric, marine area within MPAs, addresses the question of "How much is protected?" — regardless of the MPAs' purposes or levels of management. Marine scientists and international agencies have recommended that approximately 20% to 30% of a country's sea be included in MPA networks to achieve conservation and sustainable fisheries goals[39]. This indicator can be assessed at the country or regional level, as a measure of progress towards these recommended targets. There is some debate over whether all of this protected area should be fully protected or not.

The second metric, MPA management effectiveness, directly addresses the question of whether MPAs are effective in achieving their stated objectives. Each MPA has specific objectives and protective measures included in its designation. Some MPAs, for example, are designated no-take zones, while others are intended to serve as multiple-use or marine wilderness areas. Many newly designated MPAs are

Benchmark

At least 12% of the MAR marine area within MPAs.

All MPAs have on-site management (i.e., no "paper parks") with at least 70% of them routinely conducting effectiveness evaluations. Develop a regional, standardized method to evaluate MPA effectiveness.

Target

At least 20% of the MAR marine area within MPAs.

All MPAs are routinely evaluated using a regionally adopted protocol that incorporates biophysical, social and governance indicators. Average regional performance is ranked as good to excellent.

Red Flag

No progress towards meeting target percentage of the MAR marine area within MPAs.

Any reduction in percentage of MPAs being managed and evaluated.

Any decline in effectiveness ratings.

"paper parks," lacking any regulatory compliance, monitoring and enforcement.

At the site level, effectiveness evaluations serve to inform management, improve project planning, and promote accountability. At the pooled regional scale of this indicator, effectiveness summaries can serve as a tool for national managers and conservation planners to track progress across the MPA network as a whole.

How Do We Measure It?

Marine area within MPAs (SW13) is calculated as the area of territorial seas under protection divided by the total territorial-seas area, multiplied by 100 (for expression as a percentage). Protected area is determined by GIS calculation of the area within MPAs, (here, as determined by a WWF/MAR Fund Regional Marine and Coastal Protected Areas Database[40] and validated by the MPA Global database[36]). Total area of territorial seas for each country (i.e., the potential area that could be included within MPAs) is taken as defined by the Global Marine Boundaries Database (GMBD)[36]. (Also see Appendix 3 for more information.)

Quantifying MPA effectiveness (SW14) is a bit more complex. More than 25 different methods have been developed to evaluate MPA management effectiveness across the globe. In the MAR region, five methods have been applied, and new evaluation models continue to be developed (e.g., Belize National Protected Areas System Plan and Policy Project)[41].

These methodologies all differ significantly in terms of the comprehensiveness of their major assessment fields (e.g., biophysical, socioeconomic, governance fields) and the comprehensiveness of the indicators within each field. Of the five methods applied to date in the MAR, 29 potential indicators were common to these methodologies. However, few of these indicators were actually employed in the evaluations, making it difficult to compare the results at the level of specific indicators[42].

Usefulness

The percentage of marine area under protection (SW13) provides a quick, basic assessment of our progress in the fundamental step of MPA establishment. This indicator should eventually be refined to include a consideration of whether all key habitats, ecological processes and adequate connectivity are being preserved.

The effectiveness index (SW14) would be most useful and reliable if a standardized method and indicators were applied throughout the MAR. Changes in effectiveness could be tracked, and comparisons could be made. The influence of factors such as MPA size or management approach on effectiveness could be evaluated.

An alternative approach for conducting a basic synthesis of management-effectiveness evaluations performed using different methodologies considers each of the three main fields (biophysical, socio-economic, governance) independently, since some methodologies include only the governance field. The scores within each field can be averaged among all the MPAs within the group (country or region) to develop index values. A recent MSc thesis reviewed MPA management effectiveness methods applied in the MAR and attempted to synthesize the results from different methodologies into a more general index for each country[42]. The main conclusion of this effort was that there is a critical need for application of a standardized methodology in the region.

Status

The total area of territorial seas with the Mesoamerican Reef region is 64,154 km^2. Of this total, 8% is currently protected.

There are 32 MPAs in the region (not including coastal or terrestrial protected areas): six in full management phase, 15 in consolidation phase (i.e., under management, but still acquiring necessary equipment, staff and funds) and 11 in start-up phase (i.e., not yet managed, or with only initial management efforts)[40]. See Appendix 3 for a summary of Coastal and Marine Protected Areas in the MAR.

	Territorial sea (km^2)	Marine area protected (km^2)	Percent protected
Mexico	19,454	1,972	10%
Belize	18,848	2,542	13%
Guatemala	1,565	10	1%
Honduras	24,287	612	3%
MAR Total	64,154	5,136	8%

Data Source[36,40,42]

Almost all the managed MPAs in Belize have been evaluated at least once. Several MPAs have been evaluated more than once, but none has been evaluated more than once by the same method. The following table summarizes the contextual data for MPAs in Belize in 2000 and 2006. The most recently created MPAs (spawning aggregation sites) are still lacking active management. While the percent of MPAs undergoing management evaluations and the average score for governance have remained the same, the robustness (in terms of covering all three major fields and in terms of using more quantitative indicators) has increased.

MPA CONTEXTUAL DATA	Belize 2000	Belize 2006
% Sea in MPA	12.9%	13.5%
Number of MPAs	12	18
% MPAs with active management	50%	33%
% MPA performing ME evaluations	33%	33%
% MPAs evaluations covering 3 fields	0	86%
MPA AVERAGE EFFECTIVENESS RATING		
Biophysical	not included	71
Socioeconomic	not included	74
Governance	71	72

Data Source[36,40,42]

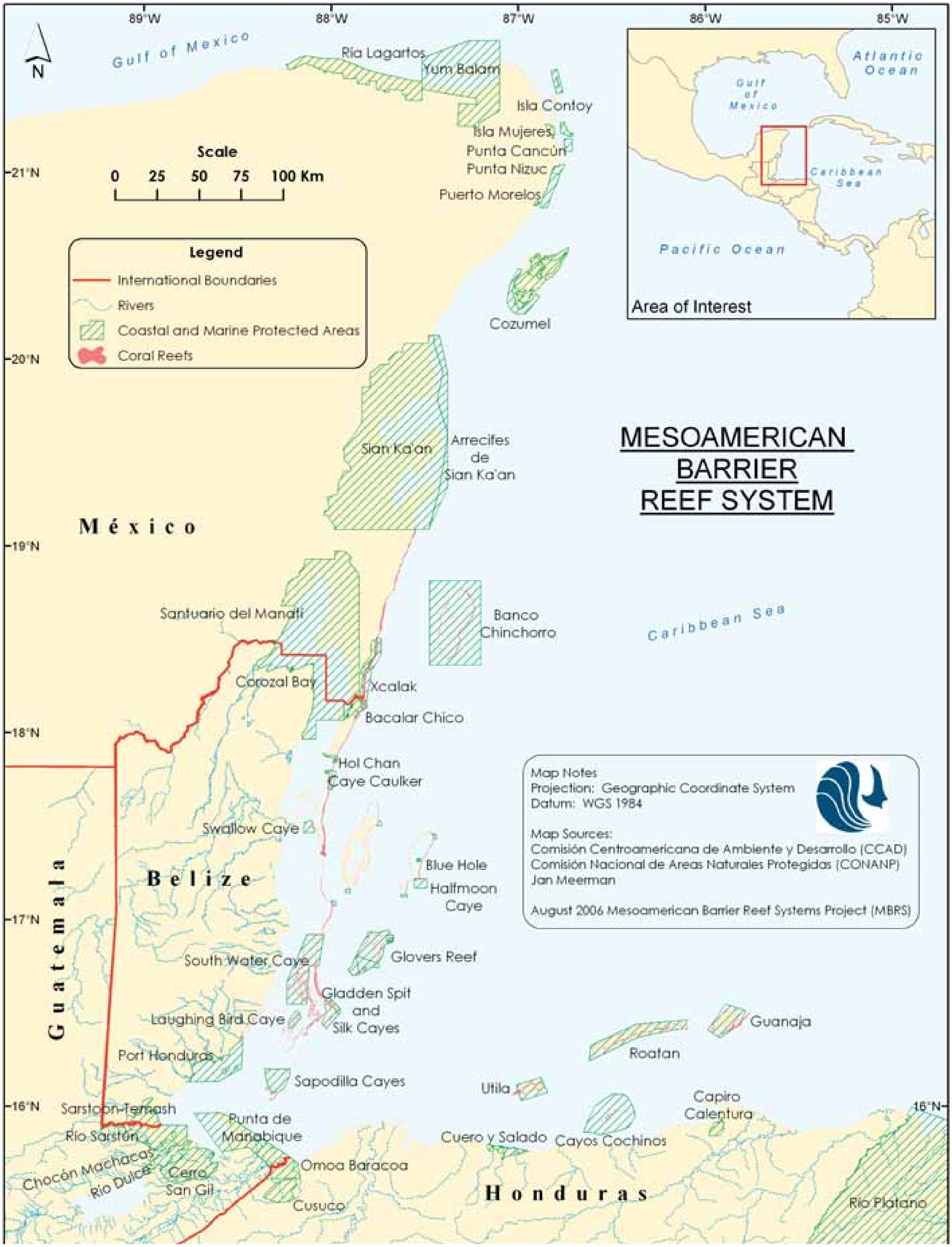
Data Needs

A more refined area indicator would consider the percentage of each habitat type within the MPA network. Regional data for such an indicator, however, are not yet readily available.

A paramount need is the adoption of a regionally consistent and robust measure of MPA effectiveness among all MPAs in the region. The MBRS project has recently coordinated the adoption of an accepted protocol[43] among many of the region's MPAs which should be more widely applied among all MPAs in the region. Finally, these data should be consolidated into a central regional database, facilitating a more robust quantitative analysis on the network scale.

Toni Parras

Ken Marks



POLICY

SW 13 14

SW15 World Bank Governance Indicators

What Is It?

The *World Bank Governance Indicators* set includes six indexes or themes that relate to good governance: (1) Control of Corruption, (2) Government Effectiveness, (3) Political Stability, (4) Rule of Law, (5) Regulatory Quality, and (6) Voice and Accountability.

Why Do We Measure It?

These indicators are used to track governance at the country level. The World Bank defines governance as “the traditions and institutions by which authority in a country is exercised for the common good.” Thus the indicators help to capture (i) the process by which those in authority are selected, monitored and replaced, (ii) the capacity of the government to effectively manage its resources and implement sound policies, and (iii) the respect of citizens and the state for the institutions that govern economic and social interactions between them [44,45].

The World Bank defines the six themes as follows:

- Control of Corruption measures the extent to which public power is exercised for private gain, including petty and grand forms of corruption, as well as “capture” of the state by elites and private interests.
- Government Effectiveness measures the quality of public services, the quality of the civil service and the degree of its independence from political pressures, the quality of policy formulation and implementation, and the credibility of the government’s commitment to such policies.
- Political Stability and Absence of Violence measures the perceptions of the likelihood that the government in power will be destabilized or overthrown by possibly unconstitutional and/or violent means, including domestic violence and terrorism.
- Rule of Law measures the extent to which agents have confidence in and abide by the rules of society, in particular the quality of contract enforcement, the police and the courts, as well as the likelihood of crime and violence.

Benchmark

For each country, increase the rankings of the six World Bank governance indexes by 5% over next five years.

Target

For each country, increase the rankings of the six indexes by 10% over next ten years.

Red Flag

A decrease in one of the World Bank governance indexes in any of the MAR countries.

- Regulatory Quality measures the ability of the government to formulate and implement sound policies and regulations that permit and promote private sector development.
- Voice and Accountability measures the extent to which a country’s citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.

How Do We Measure It?

The World Bank dataset includes several hundred parameters from 37 separate data sources. It covers 209 countries and territories for five one-year time periods: 1996, 1998, 2000, 2002, and 2004. The data, which are calculated and provided by the World Bank, are accessible at www.worldbank.org/wbi/governance/index.html.

Usefulness

The World Bank governance indicators are very useful in understanding the state of a country’s governance and accountability. The effectiveness or stability of a country’s governance is helpful in understanding a country’s potential for effectively managing its natural resources. Measuring the effectiveness of governance is difficult and data interpretation should include a review of all data limitations stated by the World Bank. In general, the higher the World Bank governance indicator value, the better the governance,

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suggesting that a country will likely be more effective at conserving natural resources. The dataset is particularly useful because it is a standardized and respected method calculated regularly by the World Bank and is easily accessible and comparable among different countries.

Status

The index scores for each country are given below for the year 2004. Values are given as a percentile rank, which indicates the percentage of countries worldwide that rate below the specified country. Higher values indicate better governance ratings. Of the four MAR countries, Belize had the highest values for all of the indexes except for Regulatory Quality, suggesting there is a fairly high level of overall effective governance. Mexico had the highest value for the Regulatory Quality[45].

Data Needs

Additional information or analyses of trends are needed to better understand the relationships between national-level governance indicators and specific national or local policies governing marine resource and environmental management and any subsequent changes in ecosystem health that may result from changes in the governance or stewardship contextual environment.

INDICATOR (2004)	MEXICO	BELIZE	GUATEMALA	HONDURAS
WB Control of Corruption	48.8	54.7	28.1	30.5
WB Government Effectiveness	56.7	61.1	18.8	27.9
WB Political Stability	44.7	66.0	22.8	26.7
WB Rule of Law	45.9	58.5	18.8	34.3
WB Regulatory Quality	68.0	62.1	49.3	39.4
WB Voice and Accountability	56.8	74.3	36.4	46.1

Data Source[45]

8 Synthesizing and Linking Indicators

The 58 indicators included in this guide were carefully selected from a much larger candidate list, using the following criteria:

- Relevance
- Feasibility
- Limitations
- Responsive to management interventions.

Our intent is that the indicator list be comprehensive, yet manageable in scope. Some of the indicators measure current conditions (e.g., ecosystem structure and function), while others measure activities or characteristics associated with drivers of change on the reef. Still others measure how these changes or characteristics affect people (social well-being).

We chose to present all the indicators within a single conceptual framework in order to:

- Highlight the complex connections among ecological and social systems, and
- Help reef stewards directly use monitoring data to guide management decisions.

We encourage the sharing and synthesis of information from many different sources. No single manager or program can be expected to collect and interpret data on every indicator.

Ultimately, we plan to provide a user-friendly and comprehensive database of indicators to managers, stakeholders and the public. This Web-based, searchable database will include a statement of caveats and limitations for each indicator. (For more information, see Section 10 – Next Steps and visit www.healthyreefs.org).

Everything in nature is connected and this is particularly true in marine ecosystems. All 58 indicators presented in this guide are connected to some extent, but some indicators are more closely linked than others.

Understanding associations among the various indicators is important because it helps guide the selection of appropriate suites of indicators that should be considered in tandem to interpret any given threat or management question. These issues are further discussed in Section 9 – From Indicators to Action. The linkages matrix (Figure 8.a) also helps illuminate the complex interactions and main influences on reef ecosystem health.

What is Linkage?

In general terms, a linkage is "the manner or style of being united," with more specific definitions used in the fields of genetics, linguistics, mechanical engineering, information technology and statistics.

In this guide, we use the term "linkages" to refer to associations or connections among indicators.

A linkage between indicators does not imply causation.

Many of the 58 Healthy Reef indicators may be related or associated with one another, but in some cases there is no direct correlation. Understanding the linkages among indicators requires understanding the contextual situation of each indicator and may even help reveal unforeseen relationships.

Linkages can help guide the selection of indicator suites needed to answer particular management questions or scenarios (as described in the following sections).

Some linkages involve causal or direct relationships, while others are more indirectly linked by another common variable or variables. The linkages figure (8.a) provides a first iteration of recording these linkages. Future iterations will include distinctive marks for more detailed categories of linkages (different symbols for different types of relationships) and will be refined with broader input.

Identifying what is driving a change in an indicator may require that multiple potential causes be linked and assessed. For instance, the number of native languages spoken in a community and the level of in-migration are closely related. In some communities, in-migrants in the MAR region move to a new area because of better resources or economic opportunities. The introduction of new migrants may cause a dilution of native languages. In other cases, the loss of native languages may be due to the availability of higher education that may encourage the national language to be spoken instead of native languages. Here, in-migration, access to more natural resources or economic opportunities, and higher education are associated with the prevalence of native languages, even though there may be no single causation.

Other types of linkages include direct and indirect causality. For example, the macroalgal index may be directly related to herbivory (specifically, the abundance of herbivorous fishes and Diadema sea urchins) and to abiotic factors (e.g., water quality and ocean color). At the same time, it is indirectly linked to fishing (e.g., volume of production, fish abundance), tourism and coastal development (e.g., the coastal development index and tourism development index) and land use and agriculture (e.g., agricultural input rates and sediment delivery rates).

The overall pattern of interconnectivity among the indicators (Figure 8.a) also highlights a number of cross-cutting indicators and attributes. For example, the World Bank governance indicators, MPA effectiveness, and environmental perceptions are all cross-cutting indicators because they affect policies and strategies influencing the drivers of change which, in turn, influence the ecological indicators. Other cross-cutting indicators, such as coral cover and coral:macroalgal index, are affected by changes in both functional and drivers-of-change indicators and, in turn, have repercussions on many social indicators.

The linkages highlight particularly effective areas for collaboration among groups engaged in different activities or fields of work. For example, workers in the field of human health might engage more closely with those involved in agriculture and tourism, given the strong linkages among these indicators.

Figure 8.a. Linkages Among Indicators

Black ovals denote a linkage between that indicator (rows) and the corresponding attribute (columns), giving a general pattern of linkages among indicators.

Linkages among Attributes (right) and Indicators (below)		Structure				Function				Drivers				Social			
		Biodiversity	Comm. Structure	Abiotic Factors	Habitat Extent	Reproduction	Coral Condition	Reef Accretion	Herbivory	Tourism	Agriculture	Fishing	Climate Change	Human Health	Economy	Culture	Policy
S1	Coral Diversity		●	●	●	●	●	●		●	●		●	●	●		●
S2	Fish Diversity		●		●	●				●		●	●	●	●		●
S3	Focal Species Abundance		●		●					●	●	●	●	●	●	●	●
S4	Coral Cover	●		●	●	●	●	●	●	●	●	●	●		●	●	●
S5	Coral:Algae Ratio	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●
S6	Fish Abundance	●			●	●			●	●		●			●	●	●
S7	Rugosity	●	●		●	●	●	●		●	●	●	●		●		
S8	Water Quality	●	●		●		●	●		●	●		●	●	●	●	●
S9	Ocean Color	●	●		●			●		●	●			●	●		●
S10	Sedimentation Rate	●	●		●	●	●			●	●				●		●
S11	Coral Reef Areal Extent	●	●	●		●	●	●	●	●			●		●	●	
S12	Mangrove Areal Extent	●	●			●		●	●	●	●	●			●	●	●
S13	Seagrass Areal Extent	●	●	●		●		●	●	●	●	●			●	●	●
F1	Coral Recruitment	●	●	●	●		●		●	●	●		●	●	●		●
F2	Fish Recruitment	●	●		●				●			●		●	●		●
F3	Coral Size Frequency		●	●			●		●								
F4	Fish Size Frequency		●		●				●			●			●		●
F5	Coral Mortality	●	●	●	●	●		●		●	●		●	●	●		
F6	Coral Disease	●	●	●		●				●	●		●	●	●		●
F7	Coral Bleaching	●	●	●	●								●				
F8	Coral Growth		●	●			●						●	●			●
F9	Bioeroders on Coral		●	●			●			●	●		●				●
F10	Reef Accretion		●	●					●	●	●		●	●	●		
F11	Herbivorous Fish Abundance	●	●		●	●						●			●		●
F12	*Diadema* Abundance	●	●			●						●	●		●		
F13	Fleshy Macroalgal Index		●	●	●	●				●	●	●					●
F14	Fish Bite Rates		●		●	●						●					●
F15	Green Turtle Abundance	●			●					●		●	●			●	●
D1	Coastal Development Index	●	●	●	●	●	●	●	●			●		●	●	●	●
D2	Tourism Index	●	●	●	●		●						●	●	●	●	●
D3	Tourism Sustainability	●	●		●		●								●	●	●
D4	Agricultural Input Rates	●	●	●	●	●	●	●		●		●	●	●	●		●
D5	Sediment Delivery Rates	●	●	●	●	●	●	●		●			●	●	●		●
D6	FORAM Index	●	●	●	●		●			●			●	●	●		●
D7	Contaminant Accumulation	●	●	●		●	●			●		●	●	●	●	●	●
D8	Certified Fisheries Products	●	●		●	●			●	●				●	●	●	●
D9	Volume of Production	●	●	●	●	●	●			●	●		●	●	●	●	●
D10	Conch Abundance	●		●	●				●	●	●				●	●	●
D11	Spiny Lobster Abundance	●		●	●					●	●				●	●	●
D12	Protected Fish Spawning Aggregations	●	●	●	●	●				●	●		●		●	●	●
D13	Photic Index	●	●	●	●	●	●	●		●	●			●	●		●
D14	Coral Bleaching Index	●	●	●	●	●	●	●	●	●	●			●	●		●
D15	Reef Resiliency to Bleaching	●	●	●	●	●	●	●		●	●			●	●		●
SW1	Contaminants in Breast Milk	●		●		●				●	●				●		●
SW2	Safe Water & Sanitation	●	●	●	●		●			●	●	●			●	●	●
SW3	Cholera & Other Diseases	●	●	●			●			●	●	●	●		●		●
SW4	Poverty	●	●	●	●	●			●	●	●	●	●	●		●	●
SW5	Economic Contribution of Marine Activities	●	●	●	●	●	●			●	●	●	●	●		●	●
SW6	Net Adjusted Savings Index	●			●					●	●	●		●		●	●
SW7	Human Development Index	●	●	●	●	●	●		●	●	●	●	●	●	●		●
SW8	Ethno-languages	●			●					●	●			●	●		●
SW9	Gender & Employment	●	●	●	●	●				●	●			●	●		●
SW10	In-migration	●	●	●	●	●	●		●	●	●			●	●		●
SW11	Environmental Perceptions	●	●	●	●				●	●	●	●		●			●
SW12	Environmental Sustainability Index	●	●	●	●					●	●	●		●	●		
SW13	Marine Area within MPAs	●	●	●	●	●	●	●	●	●	●	●	●		●		
SW14	MPA Effectiveness	●	●	●	●	●	●	●	●	●	●	●	●		●	●	
SW15	World Bank Governance Indicators	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	

9 From Indicators to Action

The challenges facing coral reef managers and conservation practitioners are enormous. This guide provides a common framework to interpret monitoring data — a tool to increase the effectiveness and impact of our collective conservation work. This section provides examples and suggestions on:

- Establishing a core set of priority indicators
- Using indicators to address management questions
- Examining sample management scenarios and decision support tools
- Increasing effectiveness through collaboration

Establishing a Core Set of Priority Indicators

Natural resource managers face the challenge of allocating limited financial resources to a variety of essential undertakings: collecting status data, implementing management actions, and evaluating program effectiveness. Coral reefs and their associated marine ecosystems are particularly complex, making this challenge even more difficult.

No one combination of indicators is right for all situations. In designing a monitoring program, reef managers need to choose indicator combinations that fit their particular situations and answer their specific management questions. For example, a an MPA in Xcalak, Mexico, may be more concerned with the direct impacts of growing coastal development than a more remote MPA on Isla Contoy, Mexico.

The measurement of only one or a few indicators cannot fully reflect the overall health of the ecosystem. For instance, even efforts to assess one of the main drivers of change, fishing, cannot rely on merely one of the fishing indicators. Instead, multiple indicators that address the volume of production, natural abundances of targeted species, management practices, and linked ecological and cultural indicators are needed to provide the full picture and guide management strategies.

No one combination of indicators is right forever. Changing conditions may require that new indicators be added to the monitoring program to respond to the introduction of a new activity or concern. Yet, a core set of indicators is needed for long-term monitoring by a variety of assessors.

We strongly recommend that all groups engaged in monitoring commit to the consistent long-term collection of a core set of highest priority ecological and social indicators.

While the full suite of "optimal" indicators monitored by any group (MPAs, NGOs, universities, government departments) may vary from one community or reef site to another, these core priority indicators are widely applicable and useful, particularly when shared and made widely available for broad regional comparisons.

Priority Ecological Indicators

Our highest priority ecological indicators — those denoted with a Priority 1 seal in the profiles — represent our best estimation of how to conduct a basic ecological assessment with the fewest possible indicators (Table 9.a). Such a "bare essentials" program may be appropriate for management programs with very limited budgets.

These indicators are sometimes classified as *status indicators* because they measure the current status of structural components and functional processes.

Priority Drivers and Social Indicators

The top ten highest priority indicators for drivers of change and social well-being are also presented in Table 9.a. These indicators were selected by the authors, with input by social experts, local managers, and regional consultations. It represents a first iteration and could be revisited at future regional workshops.

PRIORITY ONE 1 HEALTHY REEFS FOR HEALTHY PEOPLE

Our priority drivers and social indicators address the following:

- The main threats or drivers of change (tourism and coastal development, agriculture, fishing, global climate change)
- Incorporating community perception
- Management effectiveness

Table 9.a. HIGHEST PRIORITY INDICATORS	
Ecosystem Structure	Drivers of Change
S3 Focal Species Abundance	D1 Coastal Development Index
S4 Coral Cover	D2 Tourism Development Index
S6 Fish Abundance	D7 Contaminant Accumulation
S8 Water Quality	D10 Conch Abundance
S12 Mangrove Extent	D14 Coral Bleaching Index
Ecosystem Function	Social Well-being
F1 Coral Recruitment	SW2 Safe Water and Sanitation
F5 Coral Mortality	SW4 Poverty
F11 Herbivorous Fish	SW5 Economic Contribution of Marine...
F12 *Diadema* Abundance	SW11 Environmental Perceptions
F13 Fleshy Macroalgal Index	SW14 MPA Effectiveness

In the Mesoamerican Reef Ecoregion, there is a common understanding of the major threats to reef ecosystem health. A generally accepted threat model was developed by WWF in 2004[2]. It shows the "big picture" of how various natural resources are affected by the main threats (or drivers of change). (This particular model does not include global climate change, although GCC is listed as a major threat in WWF, TNC and MBRS planning documents.)

Our priority indicators focus on each of these main threats or drivers of change.

Many organizations are working in the region to address these threats through a variety of different conservation strategies, based on their respective organizational strengths and objectives. Thus, the general indicators presented in this guide cannot be expected to cover every potential strategy of every group working in the region, and the lack of any such specific indicator from this general list in no way diminishes its importance for measuring those specific strategies.

Our priority indicators also incorporate basic elements of social well-being like sanitation, poverty and the economic importance of marine ecosystems. We strongly encourage civil society groups to help enlist public support and participation in the process of collecting and compiling indicator data on local scales. Each community will have its own specific concerns and visions for benchmarks, targets and red flag values for these indicators.

Finally, our priority indicators also measure the effectiveness of broad conservation strategies (such as public environmental awareness and perceptions, and MPA effectiveness) that are incorporated in the efforts of most organizations and can be evaluated at a regional comprehensive level.

Of course, each organization, activity or project will have specific indicators designed to measure the performance of those actions. We encourage readers to visit the online resources produced by Foundations of Success (www.fosonline.org) for a number of valuable tools and papers on this topic.

Using Indicators to Address Management Questions

Effective monitoring programs require realistic expectations about what types of management questions can and cannot be answered by indicator data. Examples of some common questions that managers *can* address with the indicators presented in this guide are shown in Table 9.b.

Table 9.b. Important Management Questions That Can Be Answered with Monitoring Data

Ecosystem Structure (S)	
Biodiversity	Have we been able to increase focal species abundance on any scales? Which species (or functional groups) are facing the most rapid declines?
Community Structure	Has the decline in coral species resulted in loss of reef habitat for fish? Which groups within the reef community (fish, corals, etc.) are faring better or worse over time?
Abiotic	Is water quality declining or improving in my area? Do we have correlations between abiotic variables and community structure? If so, which correlations are strongest?
Habitat Extent	Can we identify hotspots of habitat loss (and then address them)? Are losses occurring on local or regional scales?
Ecosystem Function (F)	
Reproduction & Recruitment	Is there a decline in reproductive success of key species or groups?
Coral Condition	Is there an outbreak of coral disease or bleaching in any given time or area(s)? Have any such outbreaks resulted in higher than average mortality?
Reef Accretion & Bioerosion	Is the decline in coral condition reducing reef structure? Is the rate of bioerosion increasing over time or in areas with poorer water quality?
Herbivory	Is there higher herbivory inside 'no-take zones,' and is this correlated with higher coral cover and lower macroalgal cover?
Drivers of Change (D)	
Tourism & Coastal Development	How much habitat is being altered or loss due to coastal development? Which segments of the tourism industry are adopting sustainable tourism and coastal development practices?
Land Use & Agriculture	How prevalent are contaminants in reef ecosystems? Have agroindustries reduced their use of pesticides and fertilizers after adopting better management practices?
Fishing	How is the production of seafood changing over time? Are declining populations of commercial species correlated with any measurable declines in reef structure or function?
Global Climate Change	Are the frequency, intensity and resulting mortality of bleaching events increasing over time? Can we identify reef areas that are less prone to bleaching or are more resilient to bleaching events?
Social Well-being (SW)	
Human Health	Are chemical contaminants accumulating in humans in amounts that exceed standards for the protection of human health? Is improper sanitation increasing and threatening human and environmental health?
Economy	Have changes in ecosystem health led to economic loss or loss of ecosystem services? Are there measurable benefits (poverty reduction) associated with having healthy reefs nearby?
Culture	How much do people value reef ecosystems? Have those values changed over the last 10 years as ecosystem health changed? Are women being afforded equal opportunities for employment?
Policy	Is the effectiveness of our MPA management efforts increasing over time in the MAR? Which national governments are improving their environmental stewardship and which are not?

Other typical questions cannot be fully answered with monitoring data, despite the breadth of these indicators (Table 9.c).

The improved understanding gained through monitoring *can* help inform our understanding of these more difficult questions. Some of these more complex questions can also be addressed by using the indicator data in conjunction with other research data, models or published theoretical and quantitative information.

Table 9.c. Typical Management and Conservation Questions that Cannot Be Fully Answered with Monitoring Data

What are the main causes of reef degradation on 'my favorite reef' and overall in the MAR?
To what degree is human activity affecting the spatial and temporal trends in coral mortality and coral recruitment?
Where are the main sources of contamination in my reef area?
How will the addition of any one additional proposed resort, port, road or other coastal development project affect the structural and functional indicators? (Which straw will break the camel's back?)
What percentage of recent measured declines in coral cover is the result of "local factors" versus larger scale factors associated with global climate change, hurricane activity, etc.?

Examining Sample Management Scenarios and Decision Support Tools

In this section, we present examples of typical management scenarios and their implications for indicator selection. The examples encompass the four main drivers of change in the MAR:

- Tourism,
- Agriculture,
- Fishing, and
- Global Climate Change.

Decision trees can be used to guide systematic indicator selection and program assessment[2]. To illustrate the process, we present four sample decision trees (Figures 9.a – 9.d) that illustrate scenarios commonly encountered by MAR reef managers and corresponding indicators suited to each scenario.

Each decision tree begins with a general conservation goal and an overarching question. For example, a program concerned with tourism effects (Figure 9.a) might aim to "Maintain ecosystem integrity while supporting a sustainable tourism industry," while asking, "Is tourism affecting the reef ecosystem?"

Each decision tree includes three types of monitoring:

- Status monitoring includes typical ecological monitoring (e.g., coral and fish diversity, habitat extent).
- Threat or activity monitoring measures the extent of threat-based activities or industries.
- Evaluation of management strategies incorporates performance evaluation of broad conservation strategies employed by many organizations in the region.

To use the decision tree, begin at the top by answering the overarching yes/no question, then follow the arrows for guidance.

For example, for tourism-related effects (Figure 9.a), the overarching question might be "Is tourism affecting the reef ecosystem? If not (or if we don't know), we'll want keep an eye on the situation through routine status monitoring. If tourism is affecting the reef ecosystem we'll want to assess the degree of impact.

If the effects are mild (i.e., no "red flags," and indicator benchmarks/targets are being met), we continue regular *status monitoring*. If, however, indicator values fall within the "red flag" zone or fall short of benchmark/target values, we'll want to look into potential causes. If we don't know the potential causes, then *activity monitoring* is the next step.

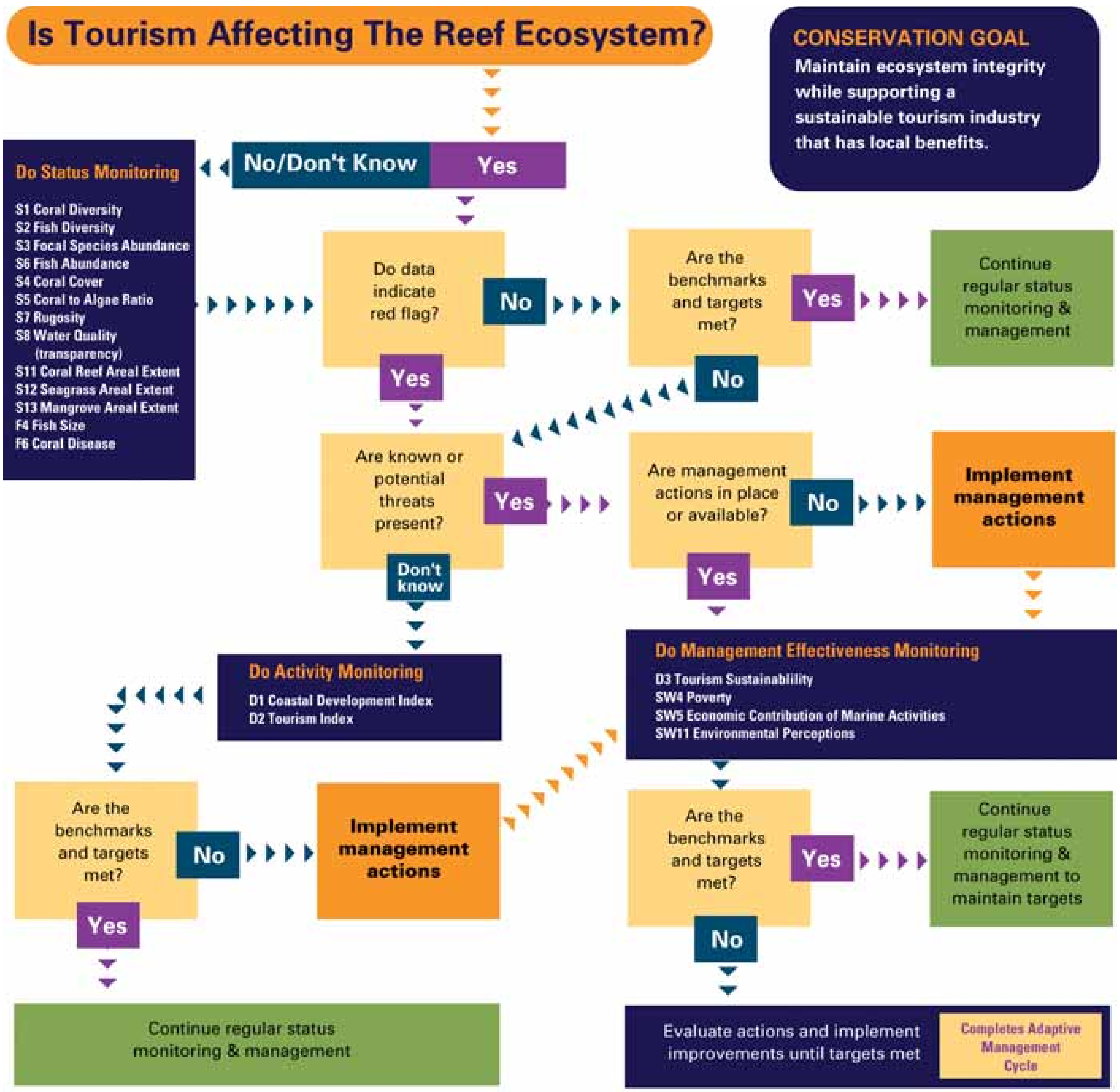
Scenario 1. Tourism and Coastal Development

This decision tree is a sample scenario that can guide the selection and interpretation of indicators in situations where tourism and coastal development are of concern. The most significant issues with tourism-driven development involve loss of coastal habitat (including mangroves), the need to maintain ecosystem integrity to support the industry, and social changes (both positive and negative) associated with development.

This sample decision tree focuses on these three areas to monitor:

- Status of critical coastal habitats and key ecological parameters that are important to the tourism industry, (e.g., coral cover and diversity, fish abundance)
- Activities likely to affect status indicators (e.g., coastal development and tourism activities)
- Effectiveness of interventions (e.g., business participation in eco-sustainability schemes)

Figure 9.a



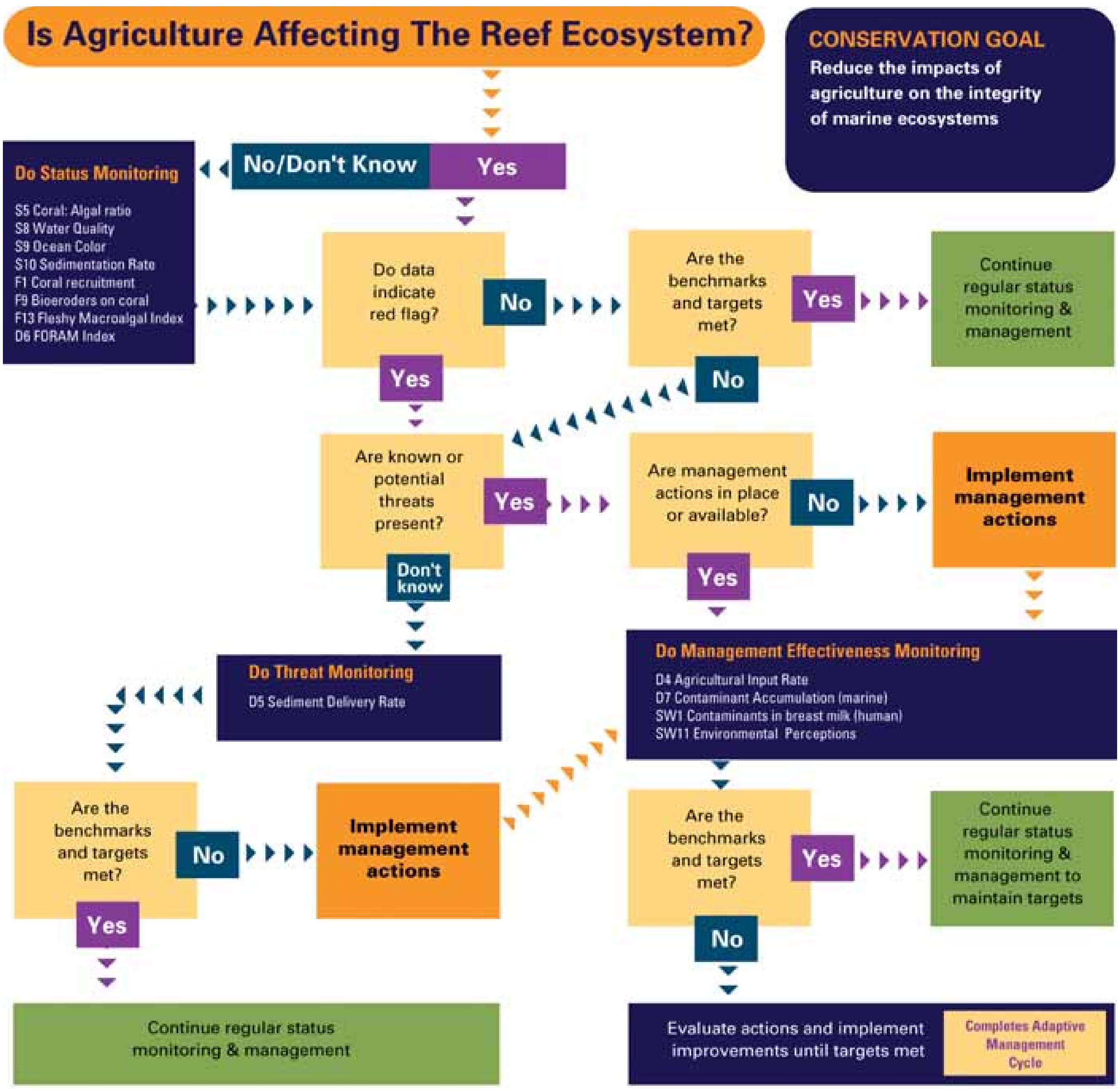
Scenario 2. Agriculture

This decision tree is a sample scenario that can guide the selection and interpretation of indicators in situations where managers are concerned about inland land use, particularly agriculture. The most significant issue with agriculture is the runoff and contamination from agro-chemicals (including nutrients) and sediments.

This sample decision tree therefore focuses on these three areas to monitor:

- Status of key ecological parameters impacted by agriculture (sedimentation rate, ocean color)
- Estimated level of main threats (e.g., sediment delivery rate)
- Effectiveness of interventions (e.g., agricultural input rates, contaminant accumulation in marine life)

Figure 9.b



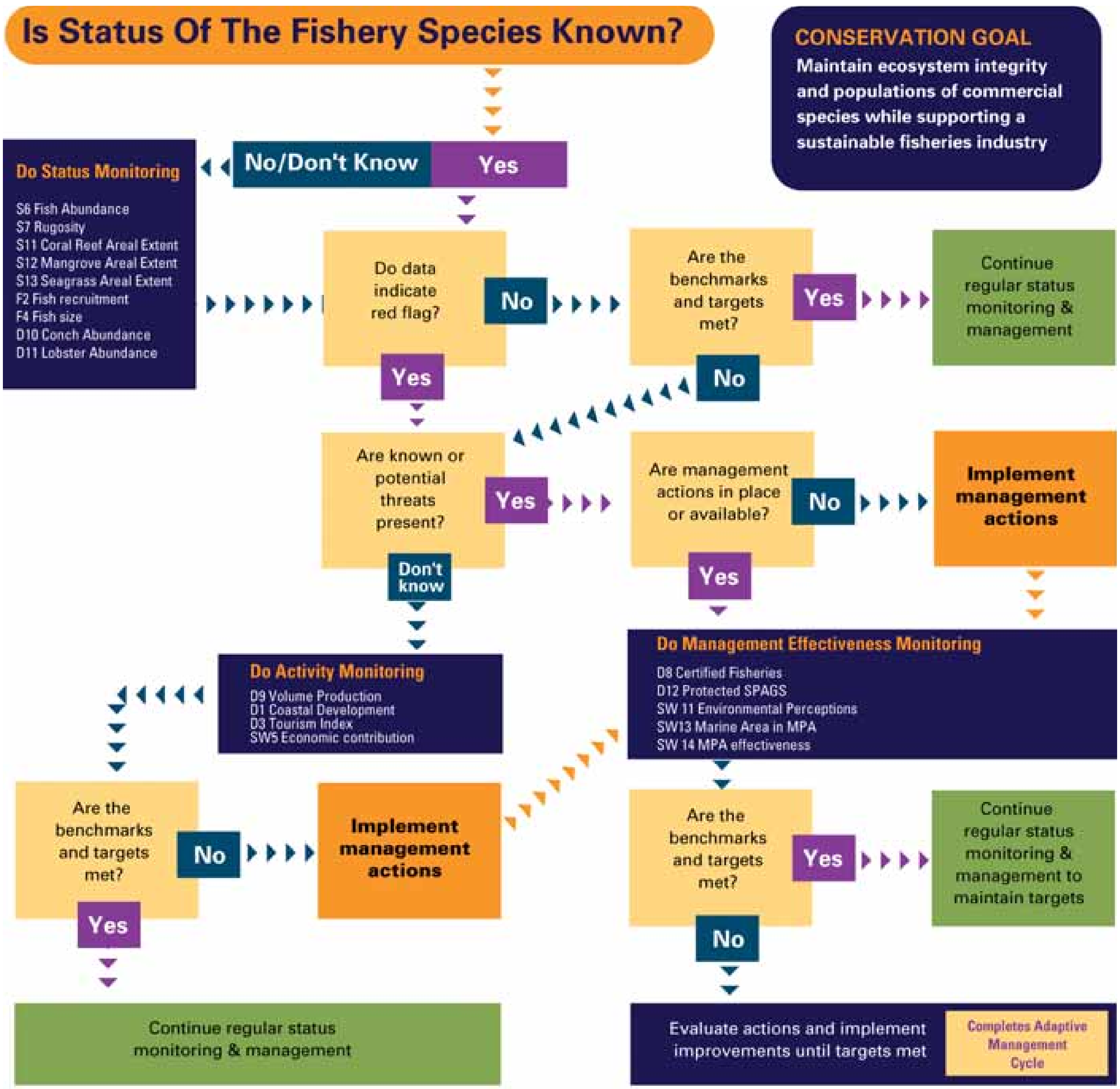
Scenario 3. Fishing

This decision tree is a sample scenario that can guide the selection and interpretation of indicators in situations where managers are concerned with overfishing. The most significant issue with fishing is the propensity to harvest at a level beyond which the natural population can replenish itself. Fishing pressure can be mitigated by regulatory controls on harvest volume, animal size, closed seasons and fishing gear.

This sample decision tree therefore focuses on these three areas to monitor:

- Status of commercial species and critical habitats (e.g., fish abundance, extent of mangroves)
- Level of fishing activity (e.g., volume of production)
- Effectiveness of interventions (e.g., certified fisheries, MPA effectiveness)

Figure 9.c



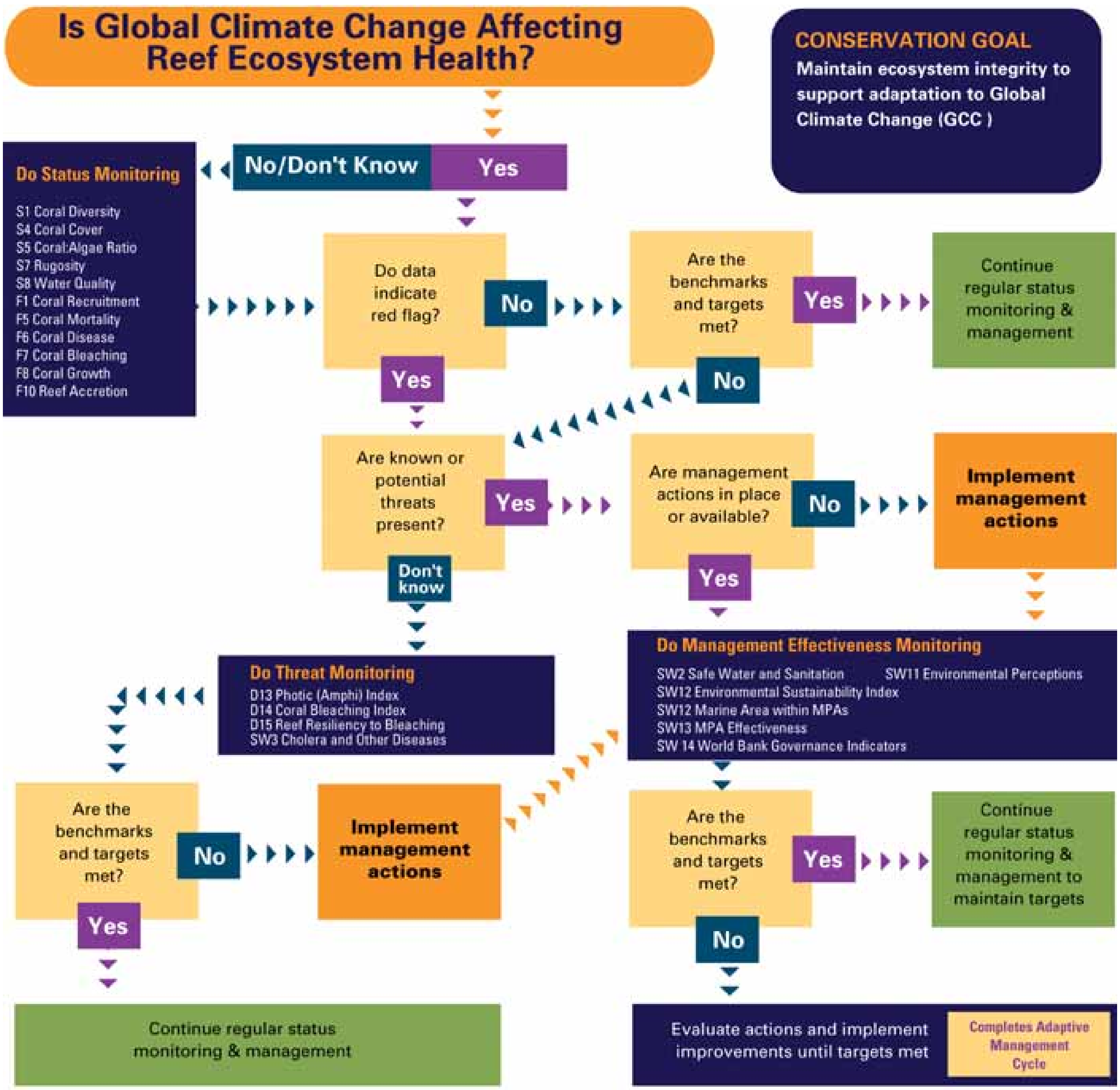
Scenario 4. Global Climate Change

This decision tree is a sample scenario that can guide the selection and interpretation of indicators where managers are concerned with the threat of global climate change. The most significant concern is the increased frequency and intensity of coral bleaching events and the ability of coral reefs to persist through these events. For local marine managers, the effects of global climate change often cannot be addressed directly at the local scale. One strategy is to incorporate some coral reef areas that exhibit more resilience or resistance into existing MPAs. Another strategy is to temporarily limit human activities or disturbances on reefs that are experiencing bleaching.

This sample decision tree therefore focuses on these three areas to monitor:

- Status of key ecological parameters impacted by GCC (e.g., coral bleaching and mortality)
- Level of main threats (e.g., coral bleaching index, cholera or other diseases)
- Effectiveness of interventions (e.g., marine area within MPAs, environmental sustainability index)

Figure 9.d



Increasing Effectiveness through Collaboration

Environmental monitoring has increased substantially throughout the MAR in the last decade, as has the number of conservation and management programs. International, national and local organizations and governments are all involved. This enormous effort is beginning to produce measurable success in conserving the region's spectacular marine resources. One example is the Spawning Aggregations Working Group in Belize, a wide coalition of organizations that successfully negotiated an agreement to protect eleven spawning aggregation sites in Belize in 2003.

Still, there is a growing consensus that conservation and management efforts in the MAR can be much more effective through increased collaboration. A recent study of "Who's doing what in the MAR?"[4] examined regional organizations and donors to assess gaps, overlaps and areas of potential collaboration. One example activity matrix is presented below for regional organizations working on fisheries issues (Table 9.d). **Many key partners share common objectives and have expressed a willingness to work together in a more structured fashion, but full strategic collaboration has yet to be achieved.**

Examples of goals common to most organizations focused on marine conservation in the MAR:

- Maintain or enhance the health of coral reef ecosystems
- Reduce the negative impacts of human activities by reducing pollution from inland runoff and agricultural practices, eliminating destructive fishing and reducing overfishing, implementing sustainable tourism and coastal development practices, minimizing impacts of global climate change.
- Improve effectiveness of management actions and marine protected areas
- Raise awareness of the value of healthy reef ecosystems and the need for conservation (this aspect actually appears to be absent or of lower priority in recent years)

A related goal of sustainable development organizations and emerging as a goal in some conservation organizations is:

- Improve people's quality of life by reducing poverty, ensuring access to safe water and sanitation, and recognizing cultural values of reef ecosystems and other natural resources.

With threats expanding rapidly, the reasons for working together are clear. **Strategic collaboration and resource-sharing will increase efficiency, optimize opportunities, and generate greater conservation impact across the region.**

Table 9.d. Overfishing and Illegal Extraction (modified from Gorrez, 2005)[4].

Threat/Stressor	Strategies/Actions	Regional Stakeholders	Anticipated Outcomes/ Impacts	Impact Measures	Comments
Overfishing Extraction of marine fisheries resources beyond the capacity of the biological system to maintain natural and economically productive levels. In the region this has resulted in the severe depletion of resource populations and localized extinctions in some cases.	Promotion of Sustainable Fisheries Management: Maintain or restore viability of targets species populations such as Nassau grouper, conch, lobster, rainbow parrotfish and sharks 1. MPA management and strengthening 2. Harmonized closed season for queen conch, lobster and marine turtles 3. Limited commercial use of marine turtles 4. Regulation of fishing gear – gillnets 5. Alternative livelihoods development and provision – specifically to alleviate pressure on SPAGs 6. Fisher co-management capacity building and community-based ecological monitoring Research and Monitoring 1. Spawning aggregation site-based research 2. Impact of MPAs on Nassau grouper, sharks and rays 3. Nassau grouper restoration project	ICRAN-MCRA MBRS Project/ CCAD Oak Foundation Summit Foundation TNC WCS World Bank/ GEF WWF	1. Development, implementation and acceptance of best practices for fisheries all along the supply chain. 2. Well-developed capacity for ecological and socioeconomic monitoring. 3. Reduced fishing pressure through alternative livelihoods provision. 4. Effective conservation and management for priority SPAGs in the region. 5. Decreased incidence of overfishing of target species.	• SPAGs species abundance, breeding population structure, behavior • Target species abundance • Number of fishers successfully transitioned into alternative livelihood • Improved economic status of fishers through alternative livelihoods	1. Majority of investments are to address overfishing. 2. Spawning aggregations are a primary focus of addressing overfishing issues. 3. Strong potential for collaboration in lobbying for regulatory frameworks, developing best practices for fisheries and MPA-based efforts. Gaps 1. Direct threat-abatement through volume limitations, size catch limitations and enforcement of these laws. 2. Monitoring of regional policy harmonization strategies. 3. MPA infractions related to illegal fishing to determine success of threat abatement/enforcement strategies. 4. Improved impact measures for alternative livelihoods. 5. Interpreting indicator data in conjunction with one another.

10 Next Steps

Filling the Gaps

Our ability to conserve ecological and social well-being depends in part on our understanding and use of critical indicator data. This guide provides a comprehensive overview of the key attributes of reef health, but much work remains to fill data gaps, standardize information, and share it all in a publicly available and user-friendly clearinghouse.

The Healthy Reefs for Healthy People Initiative focuses primarily on enabling the use of existing information. In the course of that undertaking, we have encountered a number of important data gaps. Here we highlight the major gaps (by theme) that need to be filled through additional data-collection (Table 10.a).

The Healthy Reefs Initiative has teamed up with several research institutions to begin filling some of these gaps. We seek the input and assistance of research institutions, government agencies, donors and others interested in collaborating in this expanding effort.
We also need to improve our interpretation of the key indicators of reef health and social well-being. One important task is identifying the most significant indicators of overall health through a quantitative meta-analysis of regional data. Reference (i.e., benchmark, target and red flag) values will also be refined as further collaborators provide more data.

We encourage all researchers and data managers to register their datasets on the Healthy Reefs website and provide us with input for the design and operating procedures for the planned Healthy Reefs online database.

Reporting on the Health of the Reef

The Healthy Reefs Initiative is assisting with the State of the Reef reporting process, which will officially convey eco-health information to the general public and decision-makers. In July 2006, the heads of state of the four MAR countries signed a Declaration of Renewed Commitment to the Tulum Declaration and called for the development of triennial State of the Reef reports[5]. The Healthy Reefs Initiative was an early proponent of a periodic State of the Reef report for the MAR.

We will also publish a series of science-based reef report cards for the general public. These brief, straightforward reports will explain recent results for a small set of core reef-health indexes that cover issues such as coral health, fisheries and water quality, plus human communities, economies and governance.

Table 10.a. Major Data Gaps at a Glance (see individual indicator profiles for details).

Ecosystem Structure	Ecosystem Function	Drivers of Change	Social Well-being
Regionally representative data on reef community structure and diversity Regional analysis of areal extent of major habitats (historical and current) Regionally comparable status of focal (threatened) species	Status of regional coral recruitment patterns Coral growth rates, trends and impacts of disturbances Bioerosion on coral over at regional scales Herbivory rates inside and outside no-take reserves	Updated land cover by crop type Updated agricultural input rates by watershed and by crop GIS layers of coastal-development habitat alteration Database of tourism businesses and practices for each sector Ecological impacts of fishing (by studying no-take zones)	Environmental risks to human health Cultural perceptions on the value of reefs Economic dependence on reef resources In-migration statistics for region Regionally comparable MPA management effectiveness studies

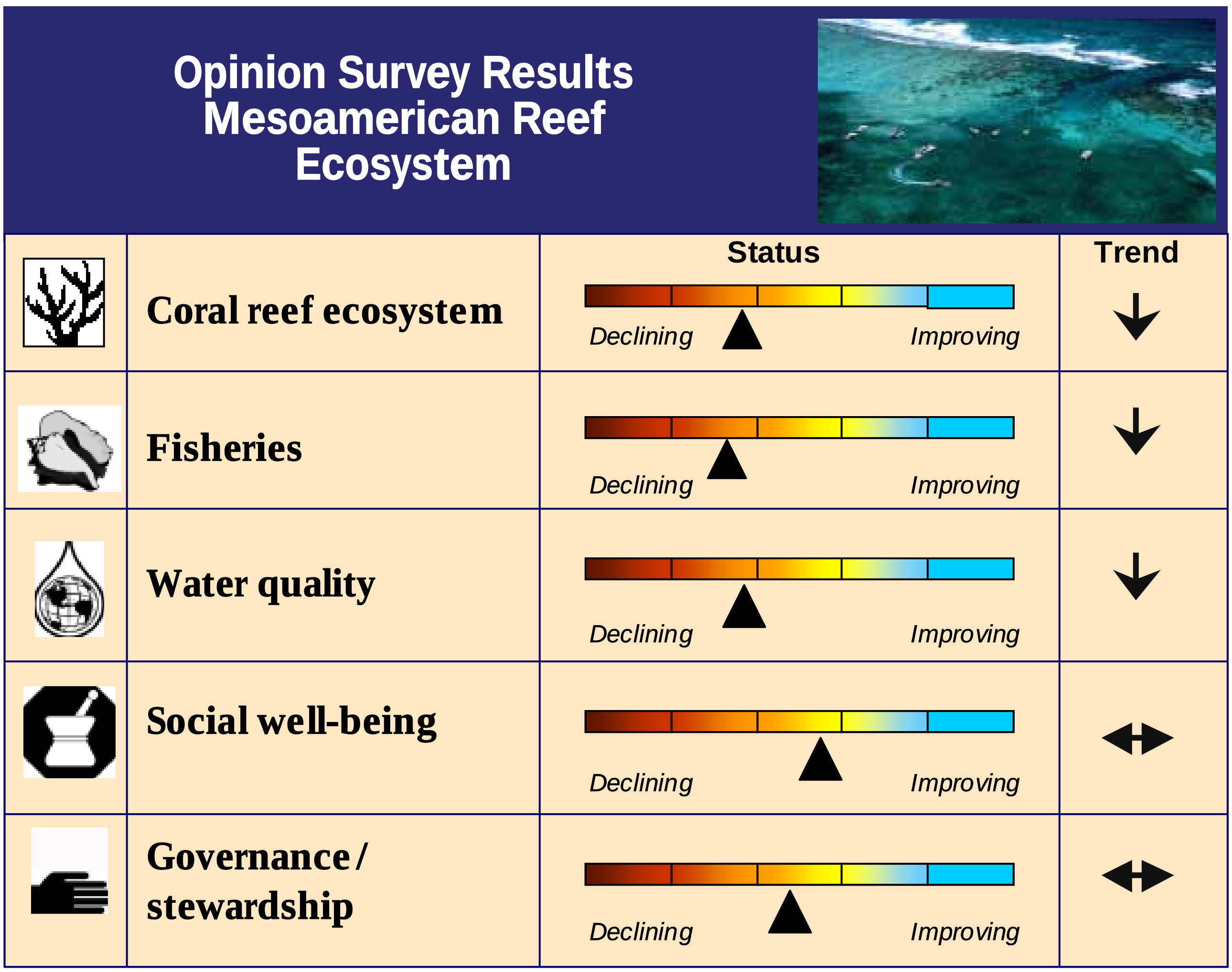
These report cards (national and regional) will serve to:

- Bring the state of the environment, including human dimensions, up front in the minds of politicians and the general populace
- Enlist public support for environmental programs and advocacy issues
- Galvanize political action in support of sustainable ecosystem management

Reporting on Environmental Perceptions

We also believe it is critically important to monitor, understand, and convey public opinions and perceptions about the environment. The Stakeholder Opinion Survey[6], taken in October 2005, was our first such survey (Figure 10.a). These results clearly illustrate the concern stakeholders have for the health of the MAR. We intend to regularly update the survey, expand its breadth, increase the number of people and groups surveyed and compare results against the data-driven "report cards."

Figure 10.a. Results of 2005 Opinion Survey on the Health of the Mesoamerican Reef



The purpose of the opinion survey was to capture perceptions on the prevailing conditions of the Mesoamerican Reef Ecosystem. A small group (*n*=102) of people (primarily managers, conservationists, scientists, and stakeholders) participated in the Healthy Reefs Opinion Survey (fall 2005). The above graphic illustrates the collective responses to the following question:

How would you grade the status over the last 10 years of the Coral reef ecosystems, Fisheries, Water quality, Social well-being, and Governance/stewardship in the Mesoamerican Reef Ecosystem?

More information on the survey results is available on our website at www.healthyreefs.org.

Transforming the Status Quo

This guide provides readers with a holistic understanding of reef ecosystem health and an enhanced interpretation of their own monitoring data. By using a common currency of standard metrics, many organizations in the region will contribute to and benefit from a wider pool of accessible and meaningful data for a more comprehensive and compelling evaluation of the MAR's ecological and social well-being.

Achieving this lofty goal will require the cooperation and collaboration of all partners. The following table illustrates some of the transformations required to affect (or change) our "in the box" way of thinking and our traditional approach to resource management and conservation.

Table 10.b Sea Change of Transformations (What the Initiative Aims to Transform)

Status Quo	➔	Evolving Into…
Local Spatial Scale	➔	Ecoregional Spatial Scale
Short-term perspective	➔	Long-term perspective
Eco-centric (ecology)	➔	Eco-social integration
Single-metric analysis	➔	Multi-metric analysis
Negative perspective	➔	Positive perspective
Exclusionary	➔	Inclusive of stakeholders
Disparate standards for monitoring & data analysis	➔	Standardized data analysis
Many separate studies and databases	➔	Common reporting platform with open access database
Disparate local or organizational visions	➔	Common vision & definition of reef health


Lisa Carnes

Getting Involved

The Healthy Reefs for Healthy People Initiative is taking off, and we invite everyone concerned with the future of the Mesoamerican Reef to join forces with us. It is only through the combined effort of a critical mass of committed institutions and individuals that we can achieve our shared goal of having healthy reefs for healthy people for generations to come.

The Healthy Reefs Initiative seeks to mobilize all stakeholders and to work in a holistic manner such that social and ecological health dimensions merge into one collective enlightened consciousness. The challenge ahead is to bring people and data together in a cohesive platform, collaborate meaningfully at an unprecedented level of eco-health analysis, and produce useful products that will inspire people to think and act.

There are a number of ways you can get involved:

- **Join our virtual network**
- **Participate in regional workshops**
- **Join the data exchange**
- **Become a Healthy Reefs mentor**
- **Link up websites**
- **Spread the word**

Join our Virtual Network. Register on www.healthyreefs.org and encourage your colleagues to join as well. There are different levels of participation:

Members: We will create a "digital directory" of supporters. This will be useful for sharing information, locating consultants, and identifying new collaborations, particularly places or fields of expertise. You can elect to be added to an electronic discussion group, to receive the quarterly e-bulletin, and to gain access to our digital library.

Partners: Organizational partners contribute staff time, in-kind support, data and ideas. They help develop and guide our strategy and plan of action. Partners represent a major component of the 'practitioners' for whom this guide was developed and they host many of the individual mentors who will help catalyze and implement ideas.

Supporters: We recognize the invaluable contributions of time, expertise, data and goodwill from all of our partners. However, we also recognize the financial scale of our aspirations. Here we invite and recognize financial supporters of this Initiative.

Participate in regional workshops: We envision hosting annual Healthy Reefs for Healthy People symposia as a part of the Initiative. These symposia will provide an ongoing platform for dissemination of integrated ecological and social information, and discussion of emerging issues. The symposia will also serve as the launching event for the annual Mesoamerican Reef report cards.

Join the data exchange: Without regionally comprehensive data there is no new story to tell. We are developing a database and welcome your suggestions and concerns. Stay abreast of developments through our website and share your data when the time comes. A special data blog will be established on the website to openly discuss and resolve data-related issues.

Become a Healthy Reefs mentor: We need a respected cadre of mentors who will help the emerging generations of practitioners. A team of mentors can help hone our message to fellow practitioners and to the general public. To become a mentor, simply indicate your interest on the Virtual Network enrollment form and include your area of expertise.

Link up websites: Link your project's website to the Healthy Reefs website and ask colleagues to do the same. Then, remember to let us know about your link and help us achieve our goal of 100 links for 2007. Participation includes online discussions (blogs), surveys and contributions to the newsletter — all accessible through the website.

Spread the word: Spreading the word about social transformation requires networking and eloquent speaking. Enlist and inform colleagues and others outside the traditional environmental circles. Those working in health care, poverty alleviation, governance, advocacy, journalism, and private businesses are important targets outside our inner circle. Spread the word and the work highlighted in this guide. Use the guide, encourage others to use it, and provide us with feedback. A dedicated guide blog will be established on the website to share and discuss issues related to the guide — including the reference values and priority indicators.

We welcome feedback and ideas on the vision, the approach, and the nature of the transformation underway.

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Glossary

Abiotic Refers to nonliving objects, substances or processes. Factors that are non-biological but play an important role in an organism's environment (e.g. substrate, temperature, currents, pH).

Accretion Slow addition to the seabed (or reef substrate) by deposition and consolidation of sediment or other intercellular material. The growing together or adherence of parts that are normally separate.

Acroporids (Taxonomy). A Family name of branching corals in the Order Scleractinia, Class Anthozoa, Phylum Cnidaria.

Algae Aquatic, eukaryotic, photosynthetic organisms (Kingdom Protista), ranging in size from single-celled organisms to giant kelp. They are distinguished from plants because they lack true roots, stems, leaves and flowers. They include three phyla that are often classified by the following functional groups:

"Macro" algae includes all fleshy (non calcified) alga (Phaeophyta, Rhodophyta, Chlorophyta) that project higher than 1 cm above the substrate;

"Calcareous" algae are macroalgae that contain calcium carbonate (Rhodophyta, Chlorophyta);

"Crustose" algae are hard (calcified) coralline algae (Rhodophyta) that encrust reef surfaces;

"Turf" algae are all those fine or filamentous algae that do not grow more than 1 cm high.

Anthropogenic Caused (or induced) by humans.

Apex predator A predator which is not itself preyed upon as a species. These animals are often at the end of food chains, where they have a crucial role in maintaining and determining the health of ecosystems.

Attribute An attribute is any condition or state that affects reef health and integrity and can be directly or indirectly measured by specific indicators. In this paper, we describe two main categories of attributes - structural and functional.

Baseline data A quantitative level or value from which other data and observations of a comparable nature are referenced. It is sometimes considered as the 'natural' condition of an ecosystem, community or species without human intervention/impacts.

Belt transect Area surveyed not only under transect line but within a certain distance either side of the line (a one meter wide belt for example).

Benchmark A benchmark is the minimally acceptable limit for the next five years.

Benthic Refers to organisms that live on or in sea or lake bottoms (called benthos).

Bioeroders Organisms that cause bioerosion.

Bioerosion Erosion of calcium carbonate (corals, reef cement and structure) by organisms through chemical dissolution or activities such as boring, scraping, etching, etc.

Biodiversity The number and variety of organisms found within a specified ecosystem or geographic region. The variety or richness of ecosystems, habitats, communities, and species.

Biomass The quantity of living matter (living organisms, species, etc) expressed as unit of weight per unit area or unit volume.

Biota The combined flora and fauna of a region or spatial scale of interest. The number of organisms that occupy an ecosystem.

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Biotic	Of, or having to do with life or living organisms. Produced or caused by living organisms.
Browsers	Herbivores that nibble, crop or graze on new growth.
Calcareous	Composed of, containing, or characteristic of, calcium carbonate or calcium; hard.
Calcification	The process by which corals, calcareous algae, and other organisms extract calcium from seawater and convert it to calcium carbonate.
Calcium carbonate	A colorless or white crystalline compound, $CaCO_3$, occurring naturally as chalk or limestone; secreted by corals and other marine organisms; the main substance of reefs and seashells.
Carbonate budget	In terms of coral reefs, can be considered as the result of interaction between the opposing processes of calcification (production of $CaCO_3$) and biological degradation (bioerosion) or chemical dissolution of $CaCO_3$.
Carbonate saturation state	Within the water column, calcium (Ca^2+) content varies little, hence the calcium carbonate saturation state (CSS) is controlled by concentration of carbonate (CO_3^{2-}) ions, pH, water pressure, temperature and salinity: CSS = (Ca^2+) × (CO_3^{2-}) ÷ K'sp, whereas K'sp is the equilibrium solubility product for the mineral phase of calcite or aragonite, respectively. Since the concentration of carbonate ions cannot be measured directly, it is calculated using the dissociation constants of carbonic acid (H_2CO_3), and measurable parameters such as total inorganic carbon dioxide (Σ CO_2) dissolved in sea water, alkalinity, pH, and partial pressure of carbon dioxide exerted by sea water (pCO_2).
Carnivory	The act of organisms feeding upon animals.
Catch per unit effort	The number of fish caught by an amount of effort. Catch per unit of effort is often used as a measurement of relative abundance for a particular fish; the total catch divided by the total amount of effort (time, gear) used to harvest the catch.
Chlorophyll	Any of a group of green pigments found in chloroplasts of plants, algae & cyanobacteria (photosynthetic organisms).
CO_2 Carbon dioxide	A colorless, odorless, incombustible gas formed during respiration, combustion and organic decomposition. A main global warming gas.
Colored dissolved organic matter (CDOM)	Dissolved organic molecules (such as tannins, pigments, etc.) within a water body that impart a green or yellow to brownish coloration to the water.
Community	A naturally occurring assemblage of organisms that live in the same environment and are mutually sustaining and interdependent; A group of populations that interact in time and space.
Community structure	The abundance and distribution of species in a given community.
Competition	The simultaneous demand (and competitive interactions) by two or more organisms for limited environmental resources, such as nutrients, living space or light.
Connectivity	A spatial concept involving the exchange of items like nutrients, pollutants, organisms or genes. (e.g., larval dispersal). It is measured by using models, tracking larvae, tagging studies, etc.
Coral bleaching	When the symbiotic algae, zooxanthellae, which live within the corals' tissue are reduced or lost due to environmental stressors it causes the coral to look white or mottled or pale.
Coral mortality	Coral death, vs. partial mortality (live tissue loss) which may or may not result in coral death.
Corallites	A coral cup; the skeleton of an individual polyp.

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Cryptic	Pertaining to concealment, usually in reference to color pattern or behavior (e.g., hiding in reef crevices)
Diadema antillarum	Long-Spined Urchin. A Caribbean-wide epidemic in the early '80's wiped out over 90 percent of the population but they are now recovering in some areas.
Denuders	Organisms that strip substrate of covering, make it bare.
Detritus	Accumulated organic material or debris.
Drivers of Change	Any human-made or natural occurrence or activity that directly or indirectly causes degradation of reef health and integrity. Drivers of change disrupt the natural structure and functioning of reefs and associated ecosystems.
Ecoregion	An ecoregion is defined (WWF) as a large area of land or water that contains a geographically distinct assemblage of natural communities that(a) share a large majority of their species and ecological dynamics; (b) share similar environmental conditions, and; (c) interact ecologically in ways that are critical for their long-term persistence.
Ecosystem Health	The capacity of an ecosystem to maintain the full range of natural populations and ecological processes at both local and regional levels over time scales appropriate for ecosystems. Usually involves a human component or value.
Endangered Species	A species in danger of extinction and whose survival is unlikely if causal factors continue operating. Included are species whose numbers have been drastically reduced to a critical level or whole habitats have been so drastically impaired that they are deemed to be in immediate danger of extinction. (see IUCN Red List).
Extinct	Species no longer exists, anywhere.
Ecologically Extinct	Species occurs at such low abundance that it no longer fulfills its natural ecological functional role.
Locally Extinct	Species no longer exists in a specific region.
Fecundity	The productiveness or potential productiveness of an organism, measured in the number of viable offspring it may produce; the number of eggs an animal produces each reproductive cycle; the potential reproductive capacity of an organism or population
Fluvial	Of, relating to, or inhabiting, a river or a stream. Produced by the action of a river or a stream.
Focal Species	A key species whose status is threatened (as per IUCN Red List) or indicative of the condition of many other flora and fauna that rely on similar habitats.
Food web	All the interactions of predator and prey, included along with the exchange of nutrients into and out of the ecosystem. These interactions connect the various members of an ecosystem, and describe how energy is converted and passes from one organism to another.
Function	Functional attributes include the key ecological processes of reef health and basically describe how structural components interact. They are the processes required to sustain biodiversity.
Functional group	Organisms that perform similar functional roles within an ecosystem (e.g., herbivores controlling algae, filter feeders removing particulate matter from the water column).
GIS	Geographical Information System: A system for creating and managing spatial data and associated attributes. A tool that allows users to create interactive queries (user created searches), analyze the spatial information, and edit data.

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Global climate change The Framework Convention on Climate (FCCC) defines it as “a change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere, and that is in addition to natural climate variability over comparable time periods.” The Intergovernmental Panel on Climate Change (IPCC) defines climate change more broadly as “any change in climate over time whether due to natural variability or as a result of human activity”. Our usage in this Guide is partly in line with the IPCC, (considering ocean conditions as a part of the broader climatology) but focusing on the anthropogenic component of change, as in the FCC definition. The impact and consequences for eco-health are the same regardless of what percentage of the variability is anthropogenic.

Grazing pressure The amount of grazing (consumption of plants and algae) within a community or ecosystem. It can be a function of the abundance of specific grazers and suitable foraging grounds.

Guild A group of species that use the same resources in a similar way; an ecological association based on similar roles in a community rather than evolutionary descent, as for example, filter feeders or browsers.

Habitat The area or environment where an organism or community normally lives or occurs. Habitat types are distinguished from one another by their distinct biotic and abiotic composition and structure that forms living space.

Health The World Health Organization defines it as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity”. More specifically Health can be considered “level of functional and/or metabolic efficiency of an organism at both the micro(cellular) and macro(social) level. In the medical field, health is commonly defined as an organism’s ability to efficiently respond to challenges (stressors) and effectively restore and sustain a “state of balance,” known as homeostasis.

Herbivore An animal that feeds on plants or algae.

Indicator A direct or proxy measurement of an ecological process, environmental condition or stressor, or organism for which it is indicative.

In situ In the natural or original position.

Keystone species A species that has a disproportionately (relative to its abundance) large impact on other species, the ecological community or key ecological processes.

Littoral The region or zone between the limits of high and low tide. Of, or pertaining to, a shore, especially a seashore.

MPA Marine Protected Area. Any area of intertidal or subtidal terrain, together with its overlying waters and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment (IUCN) A broad, inclusive term which includes both mulit-purpose sites with some restrictions as well as the more restrictive “no take“ marine reserves.

Meta-analysis The process or technique of synthesizing research results by using various statistical methods to retrieve, select, and combine results from previous separate but related studies.

Microhabitat The physical environment that surrounds influences and is utilized by an organism, within a limited spatial area of interest (e.g., a single coral head, or a crevice within a coral head).

Multivariate analysis An analysis of more than one statistical variable at a time.

Natality The ratio of total live births to total population in a specified community or area over a specified time.

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No-take zone An area where no fishing, hunting or extraction is allowed.

Nutrification A process of nutrient enrichment in which the increased availability of nutrients (e.g.,nitrate, phosphate) stimulates the growth of plants (e.g., benthic algae, phytoplankton). Extreme cases lead to eutrophic conditions in which the oxygen content is depleted (often leading to fish kills, etc) and carbon sequestered.

Ocean acidification The decrease in the ocean's pH and the resulting increase in acidity as the oceans absorb carbon dioxide released into the atmosphere by human activities.

Ocean color A term that refers to the spectral reflectance leaving a water body, as measured with a variety of satellites or airborne sensors that are used to help access primary production, run-off and sedimentation.

Overfishing Harvesting at a rate greater than the population can sustain. A level of fishing effort or fishing mortality such that a reduction of this level would, in the medium term, lead to an increase in the total catch;

Pelagic Of, relating to, or living in open oceans or seas rather than waters adjacent to land or inland waters.

Phytoplankton Microscopic green plant component of the plankton which is responsible for most of the photosynthetic activity in the ocean.

Predation The act of capturing prey (animal) as a means of active feeding.

Productivity The rate at which radiant energy is used by producers to form organic substances as food for consumers

Proxy A measured variable used to infer the value of a variable of interest (but for which direct measurement is not feasible).

Polyp A coelenterate, such as a hydra or coral, having a cylindrical body and an oral opening usually surrounded by tentacles.

Quadrat Any of a group of small, usually rectangular plots arranged for close study of the distribution of plants or animals in an area.

Recruitment The influx of new members into a population by reproduction or immigration.

Red Flag A red flag is a warning signal that indicates a level of concern for the indicator.

Remote sensing The use of infrared, radar or other satellite imagery to assess something from a far distance (e.g. landscape/seascape patterns).

Resilience Refers to an organisms ability to withstand high levels of environmental stress (temperature,sediment, etc) without mortality.

Riparian Of, on, or relating to the banks of a natural course of water.

Runoff Water that has been on land and moves seaward as a result of rain, flooding, irrigation or flushing. Runoff is frequently high in nutrients and suspended sediments, possibly including chemical contaminants.

Rugosity The topographic complexity of the reef, the physical relief.

Glossary

Sclerochronology	The study of physical and chemical variations in the accretionary hard tissues of organisms, and the temporal context in which they formed. Sclerochonology focuses primarily upon growth patterns reflecting annual, monthly, to even sub-daily increments of time. Familiar examples include annual bandings in reef coral skeletons or daily growth increments in mollusk shells and fish otoliths. Sclerochronology is analogous to dendrochronology, the study of annual rings in trees, and equally seeks to deduce organismal life history traits as well as to reconstruct records of environmental and climatic change through space and time
Scrapers	Herbivores that can actually dig into the substrate or corals, such as parrot fish or urchins.
Secchi disk	Visibility disk used to measure the transparency of the water column.
Sessile	Permanently attached or fixed; not free-moving.
Spawning aggregation	Aggregation is loosely defined as at least three times the normal population or grouping of the species; spawning can be determined by physical or behavioral changes or actual spawning.
Stable isotope	An isotope of a chemical element which is not spontaneously radioactive. Elements can exist in both stable and unstable (radioactive) forms. Most elements of biological interest (including C, H, O, N and S) have two or more stable isotopes, with the lightest of these present in much greater abundance than the others. Among stable isotopes the most useful as biological tracers are the heavy isotopes of carbon and nitrogen. These two elements are found in earth, the atmosphere, and all organisms.
Structure	Structural attributes are the key physical components of an ecosystem and their organization, including abiotic (e.g., sun, water) and biotic (abundance and distribution of organisms) attributes. Abiotic and biotic parameters contribute to biodiversity by providing different arrays of organisms and habitats.
Target	A target is the optimally feasible condition or goal to aim for in the next 15-20 years in order to achieve long-term ecological integrity.
Trace elements	A chemical element required in minute quantities by an organism to maintain proper physical functioning.
Transect	A line used to survey the distribution of organisms or substrate across a given area. Sample plots or points are established along the transect for collecting data
Trophic integrity	A balanced, nutritional environment (in tact food web) where complex functional biological processes are maintained as matter and energy are passed up to successive levels of the food web.
Trophic level	The specific position or hierarchy in a food web (e.g., primary producer, herbivore, first level carnivore).
Water quality	Refers to abiotic conditions or qualities such as pH, salinity, turbidity, and nutrient levels.
Zooxanthellae	Single-celled, photosynthetic dinoflagellates that live symbiotically in coral polyp tissue. They provide corals with food, color, and assist with calcification.

For additional terms see http://coris.noaa.gov/glossary/and http://en.wikipedia.org

Maps of Regional Indicator Status from AGRRA database (2005 version)

List of Maps

1. Coral cover
2. Total fish biomass
3. Commercial fish biomass
4. Rugosity
5. Coral recruitment
6. Coral size
7. Recent coral mortality
8. Coral disease
9. Coral bleaching
10. Parrotfish biomass
11. Surgeonfish biomass

Legend Key

- Each legend provides the indicator's units (e.g., % or g/100m^2).
- Data are separated by two reef types — reef crests and fore reefs.
- Each map point is colored to represent a scale from Poor to Good conditions as follows:
  - Good
  - Fair
  - Poor

Map Data Sources

Multiple indicators of coral reef condition were examined using data from the Atlantic and Gulf Rapid Reef Assessment (AGRRA) ACCESS database, one of the largest databases in the region with data from over 800 sites in the Caribbean (www.agrra.org). Data used to generate the following maps were obtained from different AGRRA surveys (table below) and obtained from the AGRRA 2004 database. Exceptions include data for fish diversity (from Reef Environmental Education Foundation (www.reef.org), *Diadema* sea urchin abundance (The Nature Conservancy's *Diadema* database -www.tnc.org), and Honduras coral cover data (The World Wildlife Fund- www.wwf.org).

Akumal & Xcalak, Quintana Roo, México	March 1999
Central-southern coast, Quintana Roo, México	June-October 1999
Chinchorro Banks, Quintana Roo, México	July 2000
Northern and south-central barrier reef, Belize	May 1999
Lighthouse Atoll, Belize	July-September 1999
Turneffe Atoll, Glovers Reef & barrier reef, Belize	July 2000

Interpretation of Data

Map data presented were collected using similar methods; however, several caveats need to be recognized when interpreting AGRRA data[1,2]. First, reefs are inherently different based on natural geomorphology, species composition and proximity to human impacts, thus natural variation is expected. Second, AGRRA data was collected at different spatial and temporal scales thus the timing (year data collected such as pre or post 1998 bleaching) and spatial extent (e.g., # of sites, spatial area) varies among the various AGRRA surveys. In addition, data comparisons are best done when comparing among similar reef types (e.g., reef crests and reef crests). Caveats notwithstanding, the AGRRA method provides a snapshot assessment of reef condition that is facilitating multi-scale spatial and temporal comparisons of key species and functional groups and guilds in the wider Caribbean[3].

The 'condition scale' shown in each legend was derived by comparing the Mesoamerican Reef data to historical data averages as well as to the Caribbean averages from the AGRRA database. While the numbers represent actual data points, the colors are provided as a qualitative assessment of reef condition.

The data shown represents conditions from 1999 – 2000. Recently, a large scale AGRRA survey of the entire MAR was conducted between 2005-2006 and this new data, in combination with data from the Mesoamerican Barrier Reef Project (MBRS), will provide a more comprehensive and updated assessment. Using GIS to map coral reef condition data can be a useful visual tool for managers.

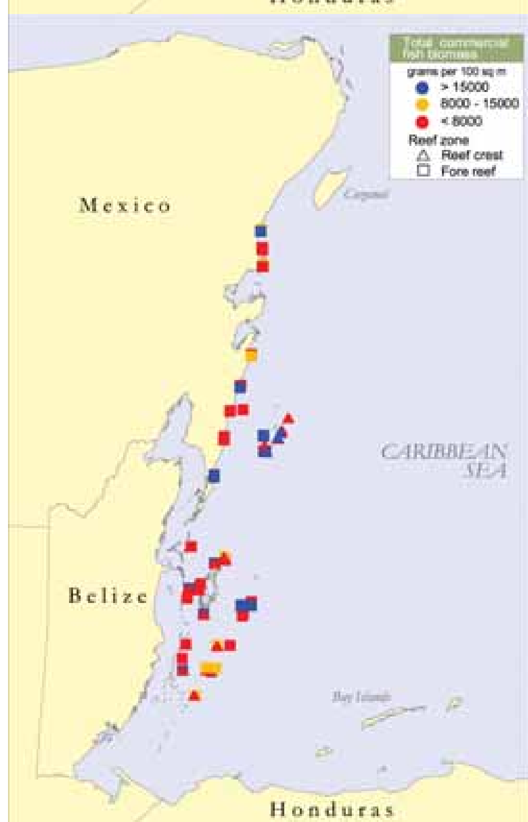
Maps of Regional Indicator Status from AGRRA database (2005 version)

References

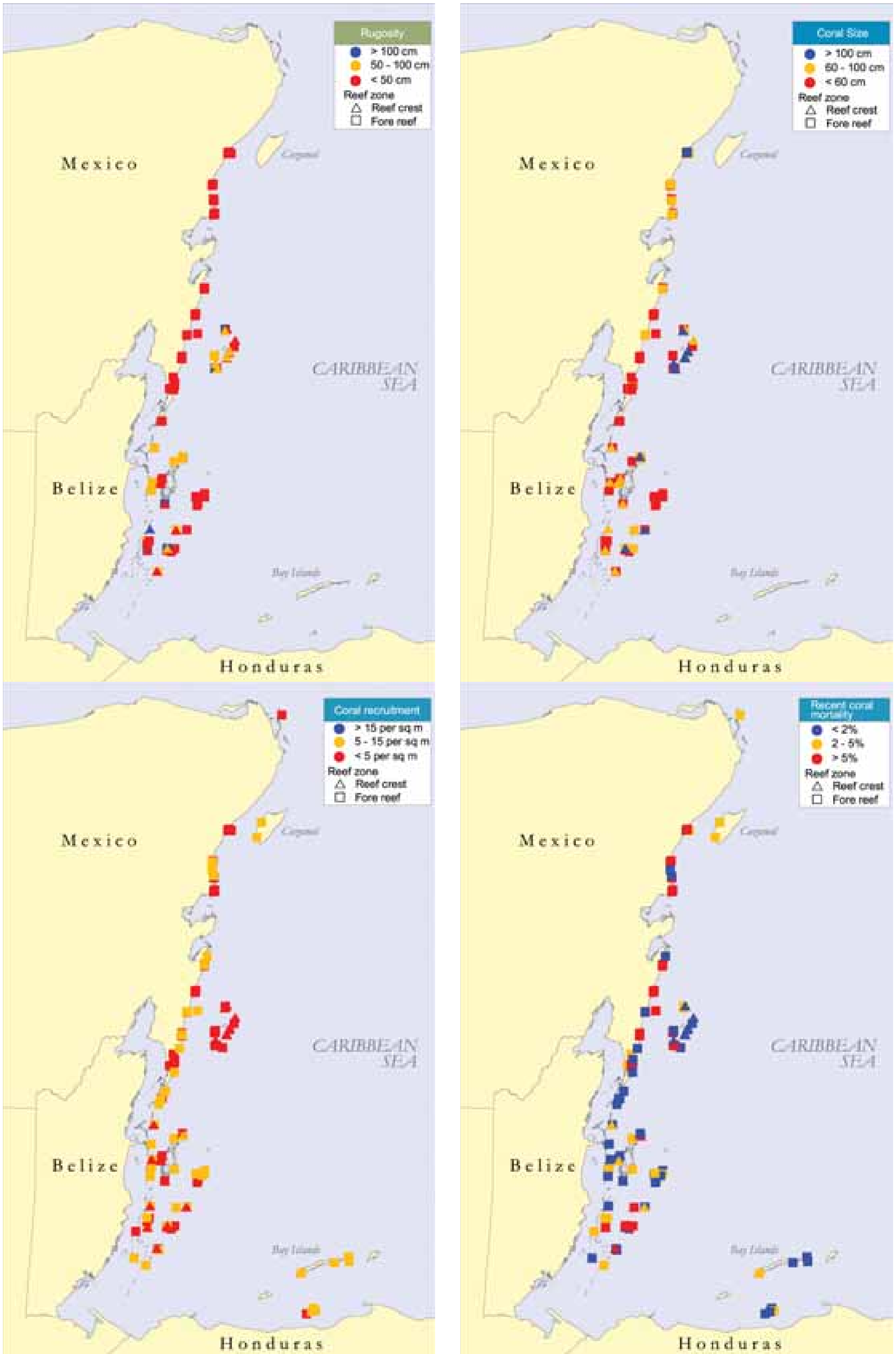
1) Lang, J.C. and K.W. Marks. 2006. Release of the AGRRA (Atlantic and Gulf Rapid Reef Assessment) Database and Summary Products for 1997-2004 V1.2. (http:www.agrra.org/Release_2006-10/AGRRA_README-2006-10.doc).

2) Marks, K.W. and J.C. Lang. 2006. AGRRA summary products, version (10/2006), available online at http:www.agrra.org/Release_2006-10/.

3) Kramer, P.A. 2003 Synthesis of coral reef health indicators for the Western Atlantic: Results of the AGRRA Program (1997-2000). Pp. 1-55 in JC Lang (ed), Status of coral reefs in the Western Atlantic: Results of Initial surveys, Atlantic and Gulf Rapid Reef Assessment (AGRRA) Program Atoll Res Bull 496.

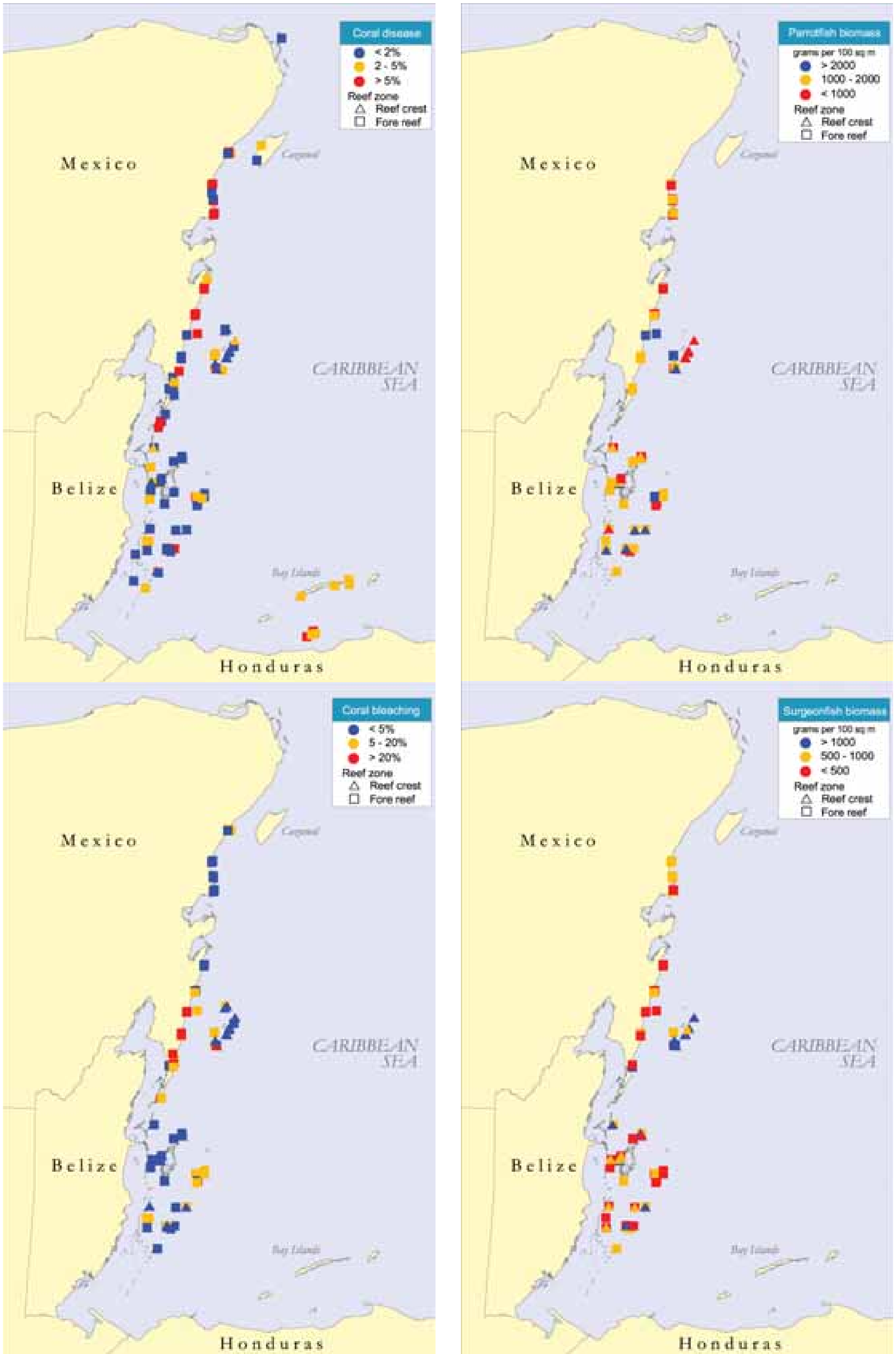


Maps of Regional Indicator Status from AGRRA database (2005 version)



Appendix 2.

Maps of Regional Indicator Status from AGRRA database (2005 version)



APPENDIX 3.

IUCN Red List of Threatened Marine Species in the MAR†

Scientific Name	Common Name	Red List
Monachus tropicalis	Caribbean Monk Seal	Extinct
Epinephelus itajara	Goliath Grouper	Critically Endangered
Pristis perotteti	Largetooth Sawfish	Critically Endangered
Dermochelys coriacea	Leatherback	Critically Endangered
Eretmochelys imbricata	Hawksbill Turtle	Critically Endangered
Epinephelus nigritus	Warsaw Grouper	Critically Endangered
Caretta caretta	Loggerhead	Endangered
Pristis pectinata	Smalltooth Sawfish	Endangered
Chelonia mydas	Green Turtle	Endangered
Lepidochelys olivacea	Olive Ridley	Endangered
Pagrus pagrus	Red Porgy	Endangered
Epinephelus striatus	Nassau Grouper	Endangered
Rhincodon typus	Whale Shark	Vulnerable
Trichechus manatus ssp. manatus	Antillean Manatee	Vulnerable
Scarus guacamaia	Rainbow Parrotfish	Vulnerable
Epinephelus niveatus	Snowy Grouper	Vulnerable
Balistes vetula	Queen Triggerfish	Vulnerable
Dermatolepis inermis	Marbled Grouper	Vulnerable
Lachnolaimus maximus	Hogfish	Vulnerable
Lutjanus cyanopterus	Cubera Snapper	Vulnerable
Trichechus manatus	American Manatee	Vulnerable
Lutjanus analis	Mutton Snapper	Vulnerable
Hippocampus erectus	Lined Seahorse	Vulnerable
Sanopus astrifer	Whitespotted Toadfish	Vulnerable
Sanopus greenfieldorum	Whitelined Toadfish	Vulnerable
Sanopus reticulatus	Reticulated Toadfish	Vulnerable
Sanopus splendidus	Splendid Toadfish	Vulnerable
Crocodylus acutus	American Crocolile	Vulnerable
Orcinus orca	Killer Whale	Lower Risk
Stenella attenuata	Bridled Dolphin	Lower Risk
Stenella coeruleoalba	Euphrosyne Dolphin	Lower Risk
Stenella longirostris	Long-Beaked Dolphin	Lower Risk
Carcharhinus leucas	Bull Shark	Lower Risk
Carcharhinus limbatus	Blacktip Shark	Lower Risk
Carcharhinus longimanus	Oceanic Whitetip Shark	Lower Risk
Carcharhinus plumbeus	Sandbar Shark	Lower Risk
Galeocerdo cuvier	Tiger Shark	Lower Risk
Isurus oxyrinchus	Shortfin Mako	Lower Risk
Mustelus canis	Dusky Smoothhound	Lower Risk
Negaprion brevirostris	Lemon Shark	Lower Risk
Prionace glauca	Blue Shark	Lower Risk
Sphyrna lewini	Scalloped Hammerhead	Lower Risk
Sphyrna zygaena	Smooth Hammerhead	Lower Risk
Aetobatus narinari	Spotted Eagle Ray	Data Deficient
Feresa attenuata	Pygmy Killer Whale	Data Deficient
Hippocampus reidi	Longsnout Seahorse	Data Deficient
Lagenodelphis hosei	Fraser's Dolphin	Data Deficient
Manta birostris	Manta Ray	Data Deficient
Mesoplodon densirostris	Blainville's Beaked Whale	Data Deficient
Sotalia fluviatilis	Estuarine Dolphin	Data Deficient
Sphyrna mokarran	Great Hammerhead	Data Deficient
Squalus mitsukurii	Green-Eye Spurdog	Data Deficient
Stenella clymene	Atlantic Spinner Dolphin	Data Deficient
Stenella frontalis	Atlantic Spotted Dolphin	Data Deficient
Steno bredanensis	Rough-Toothed Dolphin	Data Deficient
Thunnus thynnus	Northern Bluefin Tuna	Data Deficient
Tursiops truncatus	Bottle-Nosed Dolphin	Data Deficient
Xiphias gladius	Swordfish	Data Deficient

† Based on a search (www.iucnredlist.org) of marine species in the Atlantic-western central and country searches for additional species known to occur in the region. The list was edited with expert reviews to remove species that are known not to occur in recorded in the MAR. However, this is a working list and we encourage further input and revision through our website, www.healthyreefs.org.

The following was taken from the Institute For Environmental Modeling At University Of Tennessee, Knoxville (www.tiem.utk.edu/~gross/bioed/bealsmodules/shannonDI.html):

> The Shannon diversity index (*H*) is commonly used to characterize species diversity in a community. Shannon's index accounts for both abundance and evenness of the species present. The proportion of species *i* relative to the total number of species (p_i) is calculated, and then multiplied by the natural logarithm of this proportion ($\ln p_i$). The resulting product is summed across species, and multiplied by -1:
>
> $$H = -\sum_{i=1}^{S} p_i \ln p_i$$
>
> Shannon's equitability (E_H) can be calculated by dividing H by H_{max} (here $H_{max} = \ln S$). Equitability assumes a value between 0 and 1 with 1 being complete evenness.
>
> $$E_H = H/H_{max} = H/\ln S$$

Variables

H	Shannon's diversity index
S	total number of species in the community (richness)
p_i	proportion of S made up of the *i*th species
E_H	equitability (evenness)

S2 FISH DIVERSITY

Two measures that approximate diversity and abundance are REEF's Density Index and Sighting Frequency. The following text is from REEF's website on interpreting REEF data (www.reef.org/data/interpret.htm).

> The REEF Density Index (DEN) is a measure of how many individuals of a species are observed based on a scale ranging from 1 to 4. Abundance category weights are Single = 1; Few = 2; Many = 3; and Abundant = 4. This weighted density average (Den) is calculated as follows:
>
> $$DEN = \frac{(S * 1) + (F * 2) + (M * 3) + (A * 4)}{(\text{\# of surveys in which species was observed})}$$
>
> The DEN indicates which abundance category the species was most often recorded in when it was recorded. For example, Den=2.2 would be reflective of a species that was most often recorded in category 2 (Few) but because the density index is greater than 2, there were some abundances recorded for this species in the other, larger abundance categories (either category 3 or 4). The DEN index should be used as an abundance guide because area is not rigorously controlled in the RDT method. It should also be kept in mind that the DEN parameter is reflective of sighting distributions in the four different abundance categories (S, F, M, and A) and different distributions of sightings in each abundance category could potentially give similar values of DEN. In other words, it does not account for non-sightings.

Sighting Frequency (%SF) is collected using the roving diver method by REEF.

Sighting Frequency is a measure of how often a fish species was observed. It indicates the percentage of times out of all surveys that the species was recorded. The %SF is calculated as follows:

$$\%SF = 100 * \frac{S + F + M + A \text{ (for each species)}}{\text{(\# of surveys)}}$$

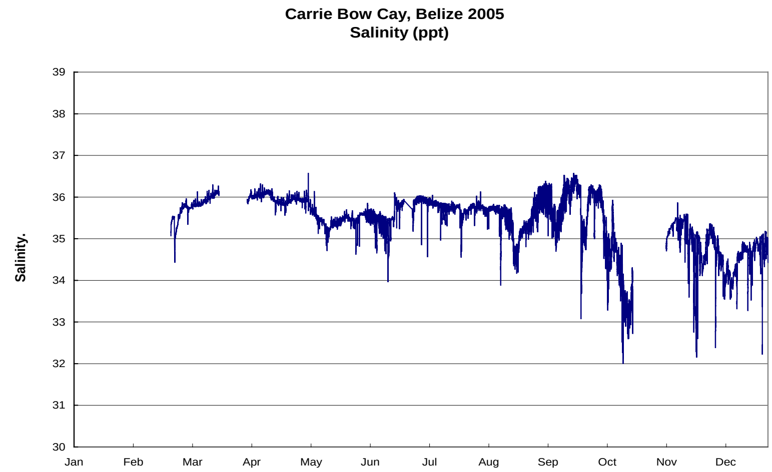
By simultaneously examining the sighting frequency (%SF) and DEN, data summaries can be interpreted for fish species. The DEN and %SF scores can be multiplied to provide a measure of species abundance, which includes zero observations.

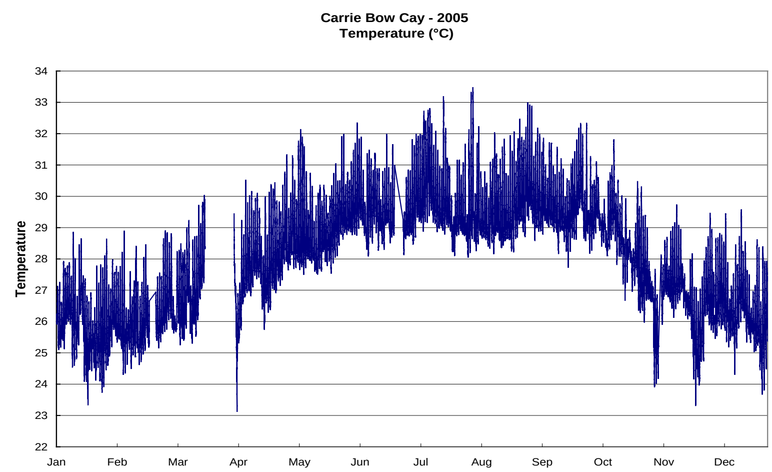
S2, S6, F4 and F11 FISH ABUNDANCE AND DIVERSITY MEASURES

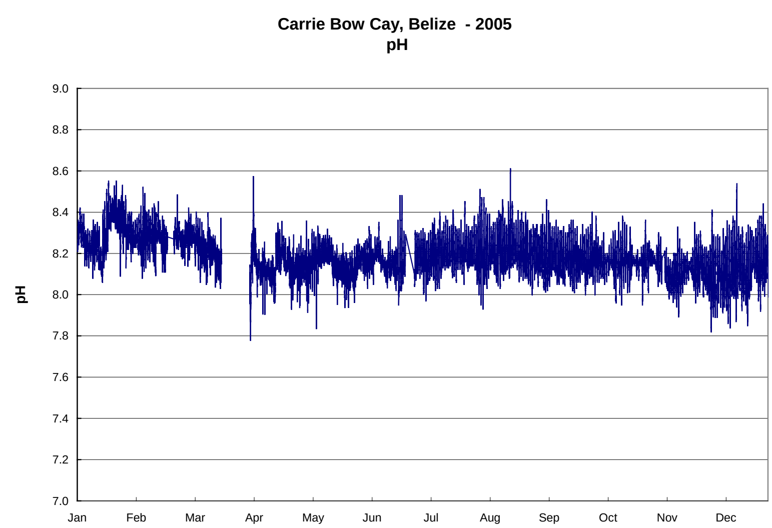
Key fish families and species in the western Atlantic are: (based on www.AGRRA.org and www.fishbase.org)

- Pomacanthidae (angelfish): High recreational value; targeted for aquarium collection (e.g., *Pomacanthus paru, P. arcuatus, Holocanthus tricolor*).
- Acanthuridae (surgeonfish): Key herbivores (e.g., *Acanthurus bahianus, A. chirurgus, A. coeruleus*).
- Chaetodontidae (butterflyfish): Key herbivores (e.g., *Chaetodon capistratus*).
- Balistidae (triggerfish): Commercially significant. Key predators of *Diadema* [e.g., *Balistes vetula* (queen triggerfish), *B. capriscus* (gray triggerfish), *Melichthys niger* (black durgon), *Aluterus scriptus* (scrawled filefish), *Cantherhines pullus* (orangespotted filefish), *C. macrocerus* (whitespotted filefish)]
- Lutjanidae (snapper): Commercially significant. Key carnivores (e.g., *Lutjanus griseus, L. apodus, L. mahogoni, Ocyurus chrysurus*).
- Haemulidae (grunt): Commercially significant (e.g., *Haemulon flavolineatum, H. chrysargyreum, H. sciurus, H. plumierii).*
- Scaridae (parrotfish): Key herbivores (e.g., *Sparisoma viride, S. aurofrenatum, Scarus taeniopterus, S. vetula*).
- Serranidae (groupers): Commercially significant. Key carnivores. *Epinephelus spp*. and *Mycteroperca spp.* (e.g., *Epinephelus guttatus, E. striatus, Mycteroperca bonaci, M. tigris*).
- *Lachnolaimus maximus* (hogfish): Commercially significant.
- *Bodianus rufus* (Spanish hogfish): Commercially significant.
- *Sphyraena barracuda* (barracuda): Commercially significant.
- *Carangoides ruber* [formerly *Caranx ruber* (bar jack)]: Commercially significant.
- *Microspathodon chrysurus* (yellowtail damselfish): Key herbivore.

Water Quality Example Data







Data Source: Caribbean Coral Reef Ecosystems Program (CCRE), Smithsonian Institution. http://cbc.riocean.com/

D3 TOURISM SUSTAINABILITY INDEX

No eco-certification programs have been established for the cruise industry. However, the following guidelines help measure the extent to which the cruise industry is working to mitigate ship-based as well as shore-based impacts. The following priorities of a formal partnership between Ocean Conservation and Tourism Alliance and the cruise industry are:

- Using best practices for wastewater management
- Establishing destination partnerships: working with local governments and communities to maintain high-quality travel experiences by protecting the natural and cultural assets of cruise destinations
- Promoting environmental education: raising guest and crew awareness of and support for critical conservation issues
- Promoting vendor environmental education: lessening the environmental impacts of suppliers

D6 FORAM INDEX

Calculation: (see reference 13 under Drivers of Change)

*Calculate the proportion (P) of specimens for each functional group by summing the specimens of each genus of that group (N) and dividing by the total number of specimens counted (T).

$P_s = N_s/ T$, where subscript "s" represents symbiont-bearing foraminifers
$P_o = N_o/T$, where subscript "o" represents opportunistic foraminifers
$P_h = N_h/T$, where subscript "h" represents other small, heterotrophic foraminifers

*Weight proportions to calculate the FORAM Index (FI):

$$FI = (10 \times P_s) + (P_o) + (2 \times P_h)$$

D9 TOTAL VOLUME OF PRODUCTION PER SPECIES

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004
Caribbean Spiny Lobster										
Belize	608	448	534	468	552	503	394	525	541	555
Honduras	1,257	1,450	1,176	1,237	1,541	823	612	772	1,021	950
Mexico	896	756	844	613	645	747	782	1,070	818	980
Strombid Conch										
Belize	1,026	1,105	1,926	1,891	1,051	1,745	1,980	1,380	1,770	2,101
Honduras	675	609	868	601	721	713	1,005	386	1,002	89
Mexico	4,963	2,566	5,218	3,293	7,243	8,295	8,730	6,293	5,841	4,840
Guatemala: Western Central Atlantic Marine Production in Guatemala										
Marine fishes	270	270	195	213	196	203	200	200	200	200
Penaeus shrimps	120	120	90	115	96	163	150	150	150	150

Data Source[30]

Appendix 3.

Municipal Level Indicators of Social Well-being in the MAR

POLITICAL BOUNDARIES			SW2 SAFE WATER AND SANITATION (percent of population)		SW9 GENDER AND EMPLOYMENT: (labor force participation rate percent of population)			SW7 HUMAN DEVELOPMENT INDEX (localized)		SW10 IN-MIGRATION (percentage of population)		SW8 ETHNO-LANGUAGE (Percent of population speaking)
Data Source (under SW References)			21,22,46,47		30			26,27		31		20,21,22,23
Country	District / Department / State	District / municipality	Water	Sanitation	Total	Male	Female	Score	Year	Population not living in municipality 5 years before census	Population born in department / district of census	
BELIZE	BELIZE	Belize	67.5	92.7	65.5	76.7	55.2	--	--	--	73.1	65.0
BELIZE	COROZAL	Corozal	91.7	97.7	56.5	80.6	32.3	--	--	--	82.5	12.1
BELIZE	STANN CREEK	Stann Creek	88.4	93.0	61.2	75.1	46.3	--	--	--	62.9	62.3
BELIZE	TOLEDO	Toledo	87.4	77.0	54.5	81.2	29.0	--	--	--	77.1	73.5
GUAT	IZABAL	Livingston	76.6	67.2	35.0	55.8	14.0	0.595	2002	2.9	85.3	49.1
GUAT	IZABAL	Puerto Barrios	90.2	91.9	37.6	54.7	21.0	0.704	2002	2.3	81.0	4.4
HONDURAS	ATLANTIDA	Arizona	88.6	79.5	34.0	57.2	10.6	0.617	2002	9.2	67.8	3.3
HONDURAS	ATLANTIDA	El Porvenir	83.9	67.6	34.5	52.6	14.6	0.709	2002	15.6	73.9	2.5
HONDURAS	ATLANTIDA	Esparta	91.9	83.1	38.9	61.7	14.5	0.636	2002	7.1	72.1	1.2
HONDURAS	ATLANTIDA	Jutiapa	78.6	61.7	36.3	61.5	10.1	0.633	2002	10.4	67.8	4.6
HONDURAS	ATLANTIDA	La Ceiba	87.9	76.2	36.7	52.5	22.4	0.782	2002	9.4	71.0	8.7
HONDURAS	ATLANTIDA	La Masica	85.4	76.2	32.8	57.0	8.9	0.652	2002	8.2	69.8	0.5
HONDURAS	ATLANTIDA	San Francisco	91.3	83.0	35.2	54.8	15.5	0.657	2002	10.2	73.7	1.8
HONDURAS	ATLANTIDA	Tela	85.2	77.0	34.3	54.4	14.7	0.681	2002	6.2	75.6	8.7
HONDURAS	COLON	Balfate	66.0	55.4	37.6	64.7	8.2	0.605	2002	8.0	64.7	7.6
HONDURAS	COLON	Iriona	72.0	42.1	43.2	63.8	21.9	0.694	2002	8.0	78.7	36.8
HONDURAS	COLON	Limon	79.8	51.3	33.6	54.7	11.7	0.657	2002	11.9	71.0	21.2
HONDURAS	COLON	Santa Fe	76.6	60.7	48.4	69.5	45.1	0.665	2002	4.5	74.8	51.3
HONDURAS	COLON	Santa Rosa de Aguan	63.1	47.1	33.0	54.5	11.3	0.659	2002	6.9	82.5	39.5
HONDURAS	COLON	Trujillo	88.0	69.9	34.3	54.5	12.7	0.667	2002	12.4	71.2	6.3
HONDURAS	CORTES	Omoa	89.8	85.2	34.3	54.4	14.0	0.660	2002	5.4	81.9	1.2
HONDURAS	CORTES	Puerto Cortes	91.0	86.6	38.9	55.5	23.0	0.726	2002	6.4	77.7	3.7
HONDURAS	GRACIAS A DIOS	Brus Laguna	65.3	26.5	15.6	22.7	8.7	0.749	2002	1.6	97.0	91.3
HONDURAS	GRACIAS A DIOS	Puerto Lempira	60.0	28.9	45.1	58.5	32.6	0.681	2002	2.1	96.3	82.9
HONDURAS	ISLAS DE LA BAHIA	Guanaja	94.4	89.8	41.4	59.5	22.9	0.794	2002	12.1	67.3	19.3
HONDURAS	ISLAS DE LA BAHIA	Jose Santos Guardiola	82.3	80.3	28.7	45.2	13.6	0.833	2002	9.0	68.0	49.6
HONDURAS	ISLAS DE LA BAHIA	Roatan	92.3	82.3	40.6	57.2	25.2	0.811	2002	16.4	50.0	26.0
HONDURAS	ISLAS DE LA BAHIA	Utila	78.5	89.1	44.8	59.7	28.9	0.770	2002	23.0	50.1	11.9
MEXICO	QUINTANA ROO	Benito Juarez	94.8	94.7	61.7	82.2	40.1	0.829	2000	23.8	28.3	11.9
MEXICO	QUINTANA ROO	Cozumel	85.1	95.5	61.7	81.9	39.8	0.800	2000	15.4	41.6	12.7
MEXICO	QUINTANA ROO	FelipeCarrillo Puerto	86.0	31.4	44.5	71.6	16.8	0.702	2000	2.0	80.9	72.9
MEXICO	QUINTANA ROO	Isla Mujeres	88.7	92.3	61.9	82.5	38.2	0.777	2000	14.3	41.7	13.4
MEXICO	QUINTANA ROO	Othon P. Blanco	92.7	72.8	51.0	72.5	29.7	0.798	2000	6.8	55.2	11.4
MEXICO	QUINTANA ROO	Solidaridad	58.9	81.5	65.4	86.6	39.1	0.762	2000	32.3	33.8	21.7

Sources: Honduras: UNDP Indice de Desarrollo Humano 2003; Mexico: Indicadores municipales de desarrollo humano en México, http://saul.nueve.com.mx/disco/index.html.

APPENDIX 3.

Coastal and Marine Protected Areas in the MAR† (for SW13 and SW14)

No.	PA Name	Country	Proposed	Declared	Start Up	Consolidation	Full Operation	Size Ha	Coastal	Marine	Private / National	Managment Category
1	Río Dulce	Guatemala		X	X			13,000	Coastal		National	National Park
2	Bahía Santo Tomás	Guatemala		X	X			1,000		Marine	National	Permanent not taken zone
3	Chocón Machacas	Guatemala		X		X		6,265	Coastal		National	Biotopo
4	Bocas del Polochic	Guatemala		X		X		20,760	Coastal		National	Wild Life Refuge
5	Cerro San Gil	Guatemala		X			X	47,433	Coastal		National	Forest Reserve
6	Río Sarstun	Guatemala		X	X			35,202	Coastal		National	Wildlife Reserve
7	Punta de Manabique	Guatemala		X		X		132,900	Coastal		National	Wildlife refuge
	Guatemala Totals			7	3	3	1	256,560	6	1		
8	Raggedy Cay	Honduras	X		X			2,589	Coastal		National/public	Marine landscape
9	Raggedy Cay Southwest Kay	Honduras	X		X			2,528		Marine	National	Marine Natural Monument
10	Cayos Cochinos	Honduras		X			X	48,925		Marine	National	Marine Natural Monument
11	Bosque de Pino de Guanaja	Honduras		X	X			2,680	Coastal		National	Forest Reserve
12	Bosque Oeste de Roatán	Honduras	X		X			1,500	Coastal		National	Marine protected Area
13	Isla del Cisne	Honduras		X	X			793		Marine	National	National Park
14	Turtle Harbour - Rock Harbour	Honduras		X		X		855		Marine	National	National Park
15	Michael Rock (Guanaja)	Honduras	X			X		2,647		Marine	National	National Park
16	Reserva Marina Sandy Bay West End	Honduras		X		X		2,846		Marine	National	(including resource management)
17	South West Cay / Half Moon Cay	Honduras	X		X			2,589		Marine	National	Marine Protected Landscape
18	Santa Elena	Honduras	X		X			9,580	Coastal		Public/private	Wildlife refuge
19	Isla de Barbareta	Honduras	X		X			10,107	Coastal		National	Biological Reserve
20	Barras del Rio Motagua/Omoa Baracoa	Honduras	X		X			8,843	Coastal		National	Wildlife Refuge
21	Cuero y Salado	Honduras		X		X		13,255	Coastal		National	Wildlife Refuge
22	Refugio de Vida Silvestre Port Royal	Honduras	X		X			834	Coastal		National	National Park
23	Punta Izopo	Honduras		X		X		18,820	Coastal		National	
24	Capiro y Calentura / Laguna de Guaymoreto	Honduras		X		X		4,856	Coastal		National	National Park
25	Río Platano	Honduras		X		X		833,675	Coastal		National	Biosphere Reserve
26	Punta Sal (Janeth Kawas)	Honduras		X		X		37,996	Coastal		National	Parque nacional
	Honduras Totals		9	10	10	8	1	1,005,918	12	7		
27	Half Moon Caye	Belize		X		x		3,954		Marine	National	Natural Monument
28	Blue Hole	Belize		X		X		414		Marine	National	Natural Monument
29	Hol Chan	Belize		X			X	1,545		Marine	National	Marine Reserve
30	Glovers Reef Marine Reserve	Belize		X		X		35,067		Marine	National	Marine Reserve
31	Laughing Bird Caye	Belize		X		X		4,095		Marine	National	National park
32	Sarstoon Temash	Belize		X		x		16,938	Coastal		National	National park
33	Bacalar Chico	Belize		X		X		11,418		Marine	National	Marine Reserve & National Park
34	Shipstern	Belize		X		X		8,228	Coastal		Private	National park
35	Gladden spit	Belize		X		X		10,513		Marine	National	Marine Reserve
36	South Water Caye Reserve	Belize		X		X		47,703		Marine	National	Marine Reserve
37	Sapodilla Cays	Belize		X		X		15,619		Marine	National	Marine Reserve
38	Swallow Caye	Belize		X	X			3,631		Marine	National	Wildlife Sanctuary
39	Port Honduras	Belize		X		X		40,469		Marine	National	Marine Reserve
40	Corozal Bay	Belize		X	X			73,050		Marine	National	Willife Sanctuary
41	Caye Caulker	Belize		X		X		3,974		Marine	National	Marine & Forest Reserve
42	Payne's Creek	Belize		X		X		14,739	Coastal		National	National Park
43	Golden Stream Corridor Reserve*	Belize		X		X		6,086	Coastal		Private	Ya'axche Conservation Trust
44	Gales Point Manatee	Belize		X	X			3,682	Coastal		National	Wildlife Sanctuary
45	Gra-gra Lagoon	Belize		X	X			534	Coastal		National	National park
46	Caye Glory	Belize		X	X			547		Marine	National	Marine Reserve
47	Caye Bokel	Belize		X	X			558		Marine	National	Marine Reserve
48	Dog Flea Caye	Belize		X	X			576		Marine	National	Marine Reserve
49	Sandbore	Belize		X	X			521		Marine	National	Marine Reserve
50	South Point	Belize		X	X			533		Marine	National	Marine Reserve
51	Burdon Canal	Belize		X	X			2,127	Coastal		National	Natural Reserve
	Belize Totals			25	10	14	1	306,521	7	18		
52	Banco Chinchorro	México		X		X		144,360		Marine	Federal gov.	Biosphere Reserve
53	Sian Kaán / Uaymil/Arrecifes de Sian Ka'an	México		X			X	651,000	Coastal		Federal gov.	Biosphere Reserve
54	Isla Contoy/Playa de Isla Contoy	México		X			X	5,128		Marine	Federal gov.	Biosphere Reserve
55	Yum Balam	México		X		X		154,052	Coastal		Federal gov.	Wildlife protection zone
56	Costa Occidental Isla Mujeres Punta Cancun/ Punta Nizuc	México		X			X	8,673		Marine	Federal gov.	National Park
57	Arrecife de Puerto Morelos	México		X		X		9,067		Marine	Federal gov.	National Park
58	Arrecifes de Cozumel	México		X			X	11,988		Marine	Federal gov.	National Park
59	U-Yumil C'EH	México		X	X			638	Coastal		Private	Wildlife Reserve
60	Santuario del Manatí	México		X	X			281,320	Coastal		State gov.	Ecological conservation zone
61	Arrecifes de Xcalak	México		X			X	17,949		Marine	State gov.	National Park
62	Xcacel - Xcacelito	México		X	X			362	Coastal		State gov.	Narional Park
63	Laguna Manati y Chacmochuch	México		X	X			203	Coastal		State gov.	Ecological conservation zone
	Mexico Totals			12	4	3	5	1,284,740	6	6		
	MAR Totals		9	54	27	28	8	2,853,739	31	32		

Source: MAR Fund/WWF October 2005.

†*Coastal* defined as beside coast or not more than 1 mile from coast (included by connectivity role).