PART II

THE TESTIMONY OF ECONOMIC VALUATION IN OCEAN MANAGEMENT

9 Collaborative, adaptive management of the Mesoamerican Reef

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1 INTRODUCTION: MANAGING CORAL REEFS FOR A HEALTHIER FUTURE

The Mesoamerican Reef region (MAR) is a global leader in the conservation and management of coral reef ecosystems. The ecoregion has included 35 percent of its territorial sea within marine protected areas (MPAs), although only 3 percent is within fully protected 'no-take' zones. Given the long-standing focus on coral reefs, not surprisingly the percentage of coral reef habitat that is fully protected is higher (13 percent), with an impressive 68 percent of the region's coral reefs lying inside the MPAs (HRI 2016). Many MPAs are managed through innovative collaborations between government, communities and conservation organizations – with growing private sector support and recognition of the economic value of MPAs. The existing fully protected areas are successfully safeguarding some of the endangered and critically endangered, large groupers within the MAR. The region faces growing stressors of increasing population, sewage, land-based pollution, coastal development, overfishing and climate change. However, there are resilient reefs often in unexpected places and protected reefs with some underlying ecological issues that may be preventing recovery of health.

The Healthy Reefs Initiative (HRI) began in 2004 and has forged a unique and strong alliance of over 65 partner organizations, each working in their own way to safeguard this fascinating reef system, while also joining forces through the initiative to evaluate the health of the reef and measure our collective progress in managing it. Through the production of routine Report Cards on the health of the reef, followed by detailed evaluations of management actions in the Eco-Audits, HRI provides valuable tools for catalyzing public awareness and swifter, more comprehensive reef management actions on a large scale.

The data collected in the collaborative Report Cards, measure the ecological results of management actions that are themselves evaluated through the Eco-Audit process. Together, this collaborative process of reef monitoring, reporting, recommending, evaluating and refining management actions represents the adaptive management cycle in action (Figure 9.1). Over the past decade HRI and its partners have expanded and evolved their collective effort to protect this amazing coral reef system for a healthier, more prosperous future.

The Mesoamerican Reef and related ecosystems provide livelihoods for more than 1 million people, with fishing and tourism activities as the main sources of income, particularly in the coastal communities. There has been considerable non-governmental organization (NGO), multilateral and national support for marine conservation over the

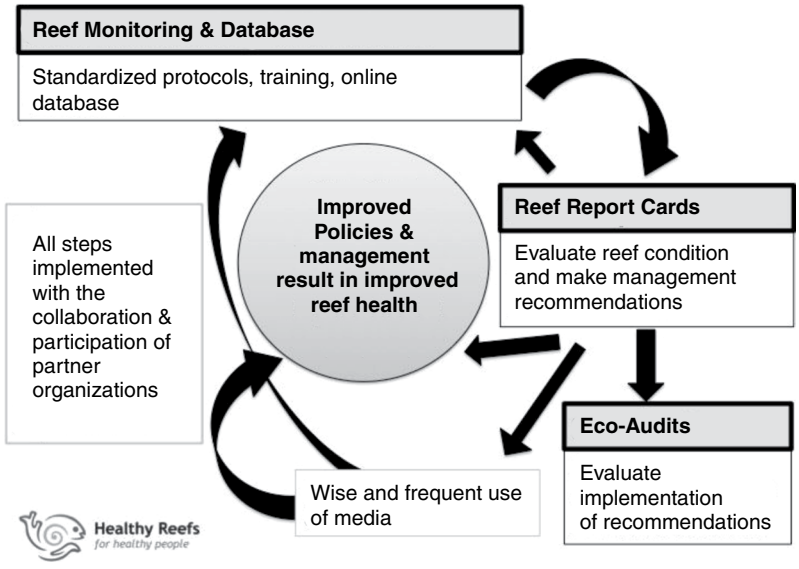

Figure 9.1 Healthy Reefs Initiative adaptive management cycle

past 15 years, albeit most of these interventions have been sporadic and not necessarily coordinated among the four countries concerned, that is, Mexico, Belize, Guatemala and Honduras. Coral reefs provide shoreline protection from storms and hurricanes, medicines, food and recreational activities, with a recent estimated global value of US$172 billion per year (EurekAlert-AAAS 2009). In 2008, the World Resources Institute (WRI) estimated that Belize's coral reef and coastal mangroves provided about US$395–559 million per year in direct benefits and ecosystem services (Cooper et al. 2008).

Despite the well-recognized importance of coral reefs, additional socio-political management challenges persist. These threats are rooted in, among others,

> a lack of legislative and administrative frameworks, low levels of compliance with existing legislation, difficulties in enforcement, lack of funding for implementation of Government mandates, lacunas in regional and local planning, and boundary conflicts between neighboring States. Not only do these factors threaten the Mesoamerican Reef ecosystem functions and services, food security at the sub-regional level, and climate change adaptability, but they also represent significant lapses in the coastal States obligations under international law and commitments through international and regional instruments. (Cortes 2011, pp. 91–2)

In an unprecedented international initiative of conservation and sustainable development, the Presidents or Prime Minister of each Mesoamerican country (Ernesto Zedillo, Mexico; Manuel Esquivel, Belize; Alvaro Arzú Irigoyen, Guatemala; and Carlos Roberto Reina, Honduras) signed the Tulum Declaration on 5 June 1997. The objective was to acknowledge the shared resource and commit to its long-term protection. A further goal of this agreement was to strengthen the cooperation and coordination between the four countries, with help from the Central American Commission on Development and Environment (CCAD), the World Bank, and other international and local organizations

taking part in the conservation of the MAR. The Tulum Declaration set the framework for developing regional institutional regulations, policies and agreements for the sustainable use and conservation of this shared invaluable resource. It provided a solid first step towards establishing a regional multi-lateral approach to support and advance conservation, management and sustainable use of the Mesoamerican Reef.

Over the past ten years, the HRI has developed a collaborative, common vision and definition of reef health, including quantitatively defined indicators which are monitored and jointly reported with partners. It has grown to include more than 65 partners in the Mesoamerican region. The HRI organizes annual partner meetings to collectively review the reef health data, develop management recommendations presented in the Report Cards, and to evaluate the implementation of management recommendations through the verified Eco-Audit process. This regional effort continues to strengthen and solidify collaborations within the region. The scientifically credible and respected Report Cards on reef health are one of the only such routine science to action examples of a standardized consistently produced report that is widely disseminated including national and international media, and tightly linked to ongoing management actions throughout the MAR. The Healthy Reefs Initiative and its partners have been collecting and sharing standardized coral reef monitoring data for eight years, producing four Report Cards on ecosystem health and three Eco-Audits of management actions. The Eco-Audit is a systematic multinational evaluation involving four countries, over 50 organizations and more than 350 analytical documents, and is thought to be the only multi-national environmental audit of its kind globally. Over the years this dual evaluation process has contributed to measurable actions that have improved the health and management of the MAR, including the establishment of new MPAs and fully protected zones, the protection of key herbivores (parrotfish), and the strengthening of sewage effluent standards, to name just a few.

This collaborative process and the user-friendly tools, provide decision-makers with the most comprehensive yet easily understandable scientific data available. The reports guide decision-makers in resource management policies, aimed at protecting both the reef and the livelihoods of communities depending on healthy reefs. The reports also enable the evaluation of management actions on a regional scale and put the concept of 'adaptive reef management' into practice. This chapter describes the collaborative, adaptive management process in more detail, giving results of the most recent Report Card and Eco-Audit, and providing examples of how the process has promoted improved management and environmental decision-making. Improving management will not only benefit the region's reefs but also the health of the millions of people living along the coast. Over the next 50 years, reefs will face greater stress from increasing population, growing seafood demand and climate change. Collectively producing routine ecosystem and management evaluations on a large scale provides a proven means for catalyzing swifter and more comprehensive reef management actions and a broader public understanding of and appreciation for the value of this reef system.

2 STUDY AREA

The spectacular Mesoamerican Reef extends over 1000 kilometers from the northern tip of the Yucatan Peninsula, Mexico, south to the Bay Islands off the north coast of

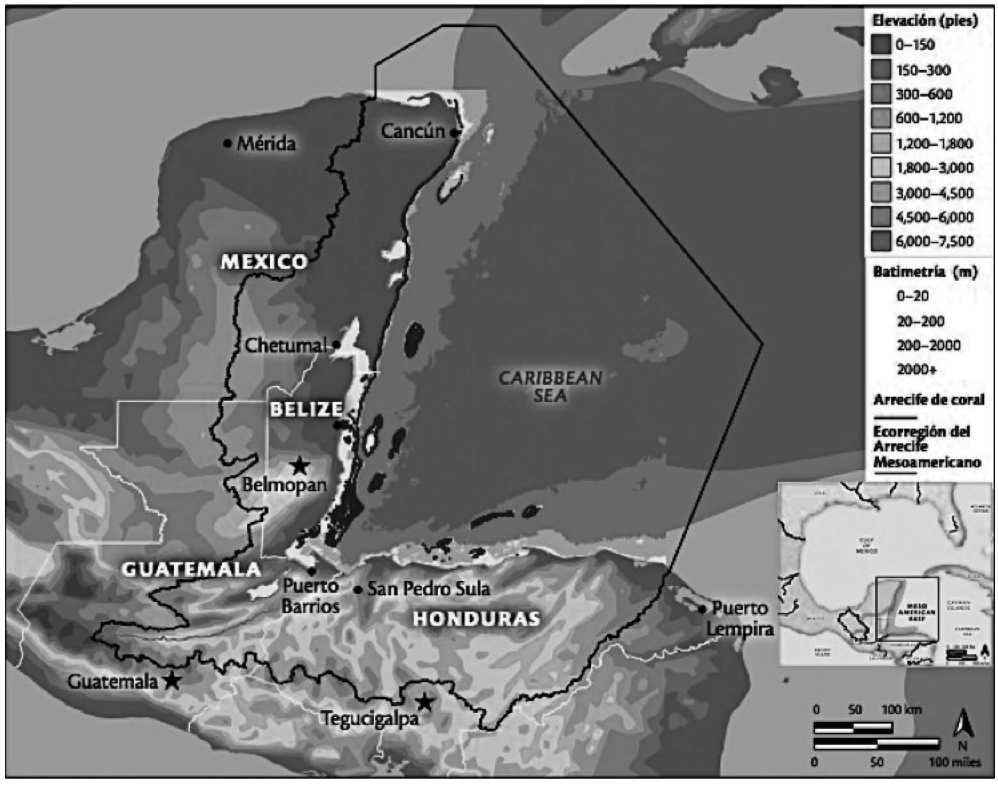

Figure 9.2 Mesoamerican Reef region

Honduras, including Guatemala's Caribbean coast and all of Belize (Figure 9.2). It includes the Western Hemisphere's longest barrier reef, in Belize, and extends offshore to depths of over 5000 meters. It also includes a wide variety of coral reef types including: long barrier reefs, nearshore fringing reefs, offshore atolls and numerous patch reefs. 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 seven endangered and seven critically endangered marine species.

The MAR is considered one of the world's biodiversity hotspots and has a strong history of marine conservation, including the establishment of several MPAs by the mid-1980s growing to 45 by 2015. These MPAs now cover 35 percent of the territorial seas within the MAR ecoregion, but only 3 percent of this territorial sea is within fully-protected (strict 'no-take' zones) although the number increases to 13 percent of coral reefs area within fully-protected zones and 68 percent of coral reefs within MPAs (HRI 2016).

The Mesoamerican Reef ecoregion also encompasses the Caribbean watersheds of the four countries, recognizing the need to integrate watershed management, pollution control efforts far inland into the marine conservation and planning efforts. The people of the region are rich in ethnic and cultural diversity, including Miskito, Pech, Garifuna, Caribbean Creole, Mestizos, K'ekchi, Mopan and Yucatec Maya. Many cultural tradi-

tions are closely tied to marine and coastal resources; thus the protection of these marine resources through sound management practices is necessary for maintaining these rich cultural traditions. Over-exploitation of marine resources is not the only threat to cultural traditions, as mass tourism and exposure to foreign cultures and market demands all encourage a more detached, globalized culture, especially among younger generations. Nevertheless, many coastal communities have managed to maintain a strong local cultural identity and preservation of traditional languages and practices, with locally managed MPAs contributing to this success. Here, more than most places, the health of the human population, communities and economies, depends largely on our ability to maintain healthy reefs.

The list of threats to reef health has grown in scope and intensity over the past decade. The four main threats (over-fishing, coastal development and sewage, inland land clearing and agriculture, and climate change) have been recognized since the early 2000s and continue to escalate in scope and intensity, despite some specific management successes. The relatively 'new' threats (within the past decade) include: (1) potential for offshore oil development in Belize and Honduras and (2) the invasive lionfish, which is now virtually everywhere in the MAR, although several control efforts are underway. Climate change is already impacting the reef through ocean warming or coral bleaching, ocean acidification and stronger hurricanes. There seems to be little hope of achieving a global treaty that will successfully achieve the maximum 1.5°C temperature increase needed to protect coral reefs. Given that the MAR countries are not major contributors to greenhouse gas emissions, their role in averting the worst impacts of climate change is through the successful implementation of the science-based adaptive management strategies described in this chapter.

3 COLLABORATIVE AND ADAPTIVE MANAGEMENT OF RESOURCES

Since its launch in 2004, the HRI has engaged organizations, agencies and academic institutions in a collaborative process of recommending priority management actions. It continues to maintain active partnerships with over 65 organizations and agencies. The HRI's mission is to 'track the health of the Mesoamerican Reef, the human choices that shape it, and our progress in ensuring its long-term integrity'. The establishing and maintaining of functional and cost-effective regional networks involved in coral reef monitoring and conservation can be a challenge. The HRI continues to assist and promote the collective successes of its partners within the four countries and catalyzes implementation of the most successful management actions throughout the region.

The HRI has focused on reef health evaluation as part of its core mission. Our partners report that, at the MPA site level, other management priorities, such as enforcement, often take precedence to monitoring, and the scientific support and training provided by HRI is a welcome and needed form of support. The HRI has provided regional partners with ten coral reef monitoring courses, serving over 120 field researchers over the past decade. Supporting partners through capacity building provides the opportunity for field personnel to synergize with other activities and carry out data collection. The goal is to integrate monitoring within routine management activities that would ensure that reef health monitoring activities are internalized and sustainable over the long term. This is

a particular challenge given that all of the HRI's funding to date has been raised from international private foundations, mostly in annual grants.

Annual partner meetings have also been a key element in building consensus, sharing information and crafting the science-based message. Keeping partners informed of recent management and science developments is important. These meetings are also used to vet the regional criteria, indicators and draft results for the Eco-Audit, and to prioritize national and regional recommendations for the four countries. Partners also have an opportunity to share data, and information related to progress with site management and to validate the results of monitoring work and assessment of management progress within their respective area of expertise and geographic scope based on data and supporting documentation. Another function that the HRI has served has been in providing a regional picture of the status of the resource that puts other site-based and national evaluations in context. This is supported with access to reef health data through an online database. Partners also capitalize on these regional meetings for related working group gatherings. The HRI serves as a needed conduit for information and facilitates the sharing of information among partners, also keeping them engaged in this regional network.

3.1 Report Cards Evaluating Reef Health

The HRI is one of the first attempts globally to develop measurable ranking criteria for indicators of coral reef health (McField and Kramer 2006, 2007). The Reef Health Index (RHI) evaluates the ecological condition of the reef according to four key indicators vital to the structure and functioning of healthy coral reef ecosystems – the change or decline in the status of one of these indicators can have a cascading or domino effect on the entire ecosystem (Kramer and Kramer 2000). Over the past ten years, HRI and partners have collaborated to facilitate data-sharing and promote adaptive management by producing four Report Cards on ecosystem health and three Eco-Audits of management effectiveness.

HRI and partners systematically measured the health of 248 reef sites across 1000 kilometers of reef within the four countries for the 2015 Report Card, which provides detailed maps of coral reef condition on a variety of spatial scales – from regional to local. Regional scale data provide insight on larger-scale reef health patterns that can help identify transboundary issues, while subregional and local data help detect finer-scale patterns of reef condition. The country-focused maps also provide individual indicator scores at the site level. These new data maps provide guidance for partners on where to focus conservation actions at the most appropriate, effective management scale.

Figure 9.3 shows the Reef Health Index at 248 sites surveyed with each site color-coded according to its RHI score. Each country graph also shows the percentage of sites in each health condition, as well as the number of sites per country within the circle, and a general graph for the entire MAR. The MAR has been divided into 18 subregions, where the graph on the right shows its RHI result as well as the result for each indicator, clearly showing what the scores for each indicator for that subregion.

The most recent overall Reef Health Index (RHI) score was 'fair' (2.8), on a scale of 'critical' (1) to 'very good' (5), as seen in Figure 9.4. At the regional scale, coral cover has improved, increasing from 10 percent to 16 percent, yet fleshy macroalgae have also increased dramatically. Herbivorous fish have recently increased and are much needed to reduce macroalgae. More herbivores and higher grazing intensity may create more

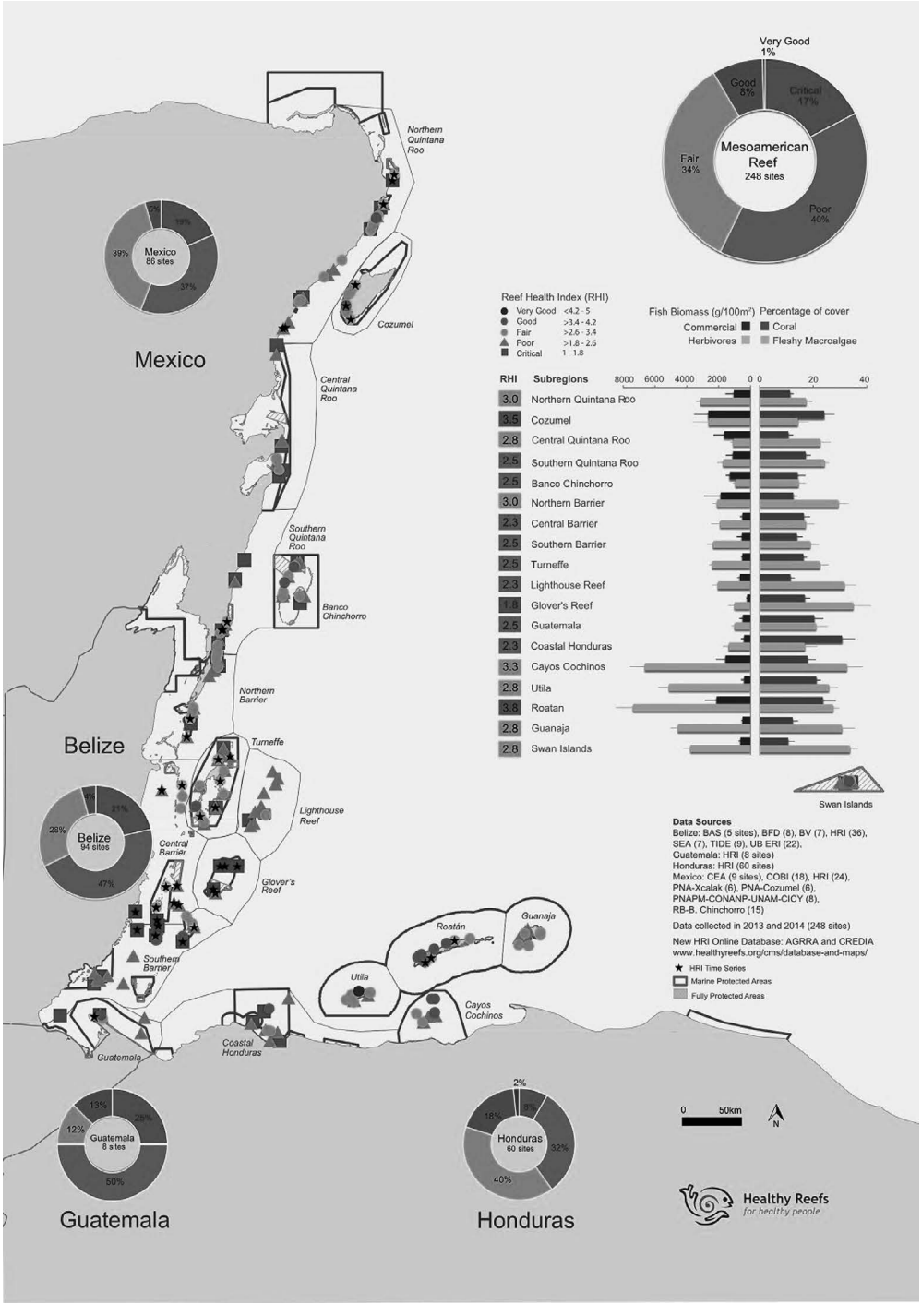

Figure 9.3 Reef Health Index in the Mesoamerican Reef

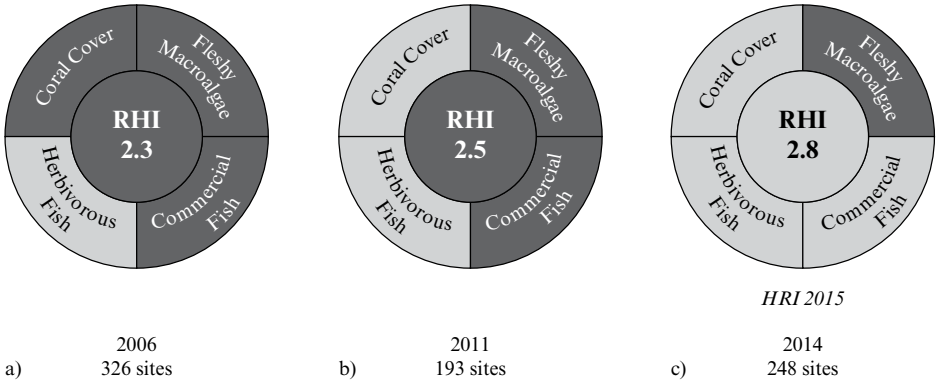

Figure 9.4 Reef Health Indices 2006–1014

favorable conditions for corals to grow. Commercial fish biomass is higher than 2006, although large groupers were rare, found mainly in fully protected zones of MPAs (Kramer et al. 2015).

Reef Health Index

The development of a single index, the RHI, facilitates the mapping and reporting on reef health for a 'big picture' snapshot of the MAR. Indicators are parameters or metrics of an ecosystem that relay relevant information on the condition of the ecosystem. They help translate the complex concept of ecosystem health into tangible, rigorously defined quantities by which changes in condition can be assessed over time. The mean value of each indicator is compared to the following thresholds and given a grade from one ('critical') to five ('very good'). The grades are averaged to obtain the RHI score for each site. Thus a site with a given RHI score (for example, 'fair') may have different combinations of indicator(s) ranking in different conditions to result in that averaged score.

The RHI is based on these four indicators using the ranges listed in Table 9.1, which are then combined and equally weighted:

- Coral cover is the amount of reef surface covered by live stony corals, contributing to its 3D framework.
- Fleshy macroalgal cover is the proportion of reef covered by fleshy algae.

Table 9.1 Reef Health Index indicator ranking and ranges

Reef Health Index indicators	Very Good (5)	Good (4)	Fair (3)	Poor (2)	Critical (1)
Coral cover (%)	≥40.0	20.0–39.9	10.0–19.9	5.0–9.9	<5.0
Fleshy macroalgal cover (%)	0–0.9	1.0–5.0	5.1–12.0	12.1–25.0	>25.0
Key herbivorous fish (g/100m2) (only parrotfish and surgeonfish)	≥3480	2880–3479	1920–2879	960–1919	<960
Key commercial fish (g/100m2) (only snappers and groupers)	≥1680	1260–1679	840–1259	420–839	<420

- Herbivorous fish is a measure of the biomass of important grazers on plants that could overgrow the reef.
- Commercial fish is a measure of the biomass of fish species commercially important to people.

The Mesoamerican Reef is in fair condition, with encouraging improvements of indicator scores at regional and local scales (see Figure 9.5). Some of the main findings of the report, compared with data from 2006, include:

- Coral cover is increasing, although slowly. Reducing local threats can give corals time to recover.
- Fleshy macroalgal dominance is widespread. Improving water quality will benefit reefs.
- Herbivory is key to controlling macroalgae. Protecting herbivores will reduce seaweed.
- Snappers and groupers have increased locally. Creating more fully protected areas will allow them to grow larger and produce more fish for the future.

Accessible data are a core component of HRI

The HRI practices full sharing of all data and information, most of which are gathered collectively with our partners, and used to inform management decisions. These data are available in an online database accessible on our website (www.healthyreefs.org). The database system uses DevInfo, a web application for organizing, storing and visualizing data. The software's visualization tools allow the user to generate graphs or maps to visualize ecological indicators at different spatial or taxonomic levels. These graphs and maps are easily customizable and can be shared through social networks. The data can be exported in several formats (csv, xls), which can be loaded to other compatible statistical analysis programs.

Although we only use four indicators to calculate our RHI, the data-gathering protocol we use, the Atlantic and Gulf Rapid Reef Assessment (AGRRA), gathers over 15 different indicators, and can be used to analyze a reef site for various factors and conditions. HRI shares its data with the AGRRA database, which has over 800 sites across the Caribbean region, and allows comparison over various spatial and temporal ranges (www.agrra.org). HRI is also on the Caribbean Steering Committee of the Global Coral Reef Monitoring Network (GCRMN) which aims to increase data sharing and standardization of monitoring across the Caribbean.

Application in management: creating and enforcing marine-protected areas

The use of HRI's tools has allowed local partners to identify reef sites with outstanding results for certain indicators. For example, two reef areas in Honduras have been declared MPAs due to the discovery of unprecedented high coral cover. Based on a standard of between 16 percent and 18 percent live coral cover (LCC) for the MAR, sites that show above 50 percent LCC are worthy of further investigation.

Cordelia Banks, Roatan: in 2006, a site on the southern coast of Roatan, in the Honduran Bay Islands, showed 70 percent LCC, based on our survey. Cordelia Banks, as the site is known, had already been identified by an International Development Bank

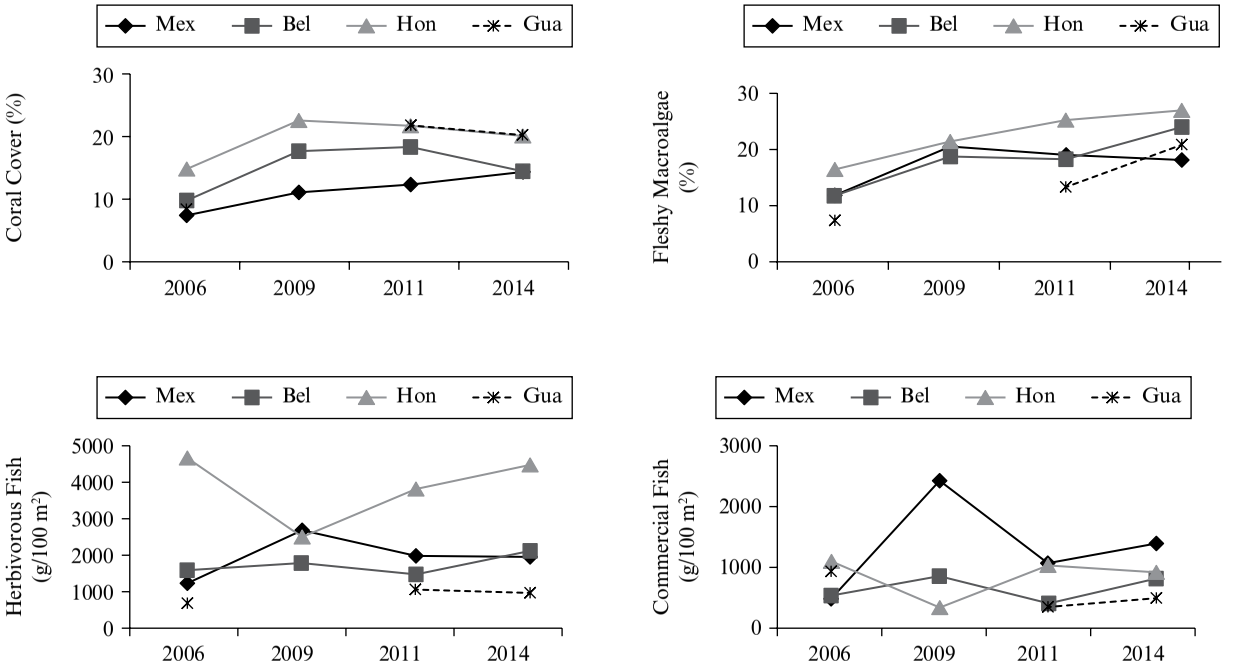

Figure 9.5 Trends of four indicators of the MAR Reef Health Index

(IDB) funded natural resource management program as one of the sites of interest and subject to further protection. In order to justify this enhanced protection as an MPA, further sites were investigated, and three banks were reported with healthy stands of *Acropora cervicornis* (staghorn coral). The coral cover information served as a basis to create the needed documents for the Honduran government to change the category of the site, from a Multiple-Use Zone to a Site of Wildlife Importance, where stricter management zones can be defined. This MPA was declared in April 2012 and now covers 1700 hectares. The management plan, which defines different use-zones, was created based on the coral cover information gathered by HRI with its partners using the AGRRA reef monitoring methodology.

Capiro Banks, Tela: during a 2011 reef monitoring training workshop sponsored by HRI and its local partners, a series of coral banks were first discovered by these researchers. Capiro Banks covers an area of approximately 800 hectares and boasts 69 percent live coral cover in one of the sites. The site was known to fishermen, who have been using it as fishing grounds for many decades, and always stated that the best catch (snappers and groupers) could be had in this site. As the incredibly high coral cover was discovered, HRI and the Coral Reef Alliance (CORAL) partnered up to gather more detailed information on several areas of the banks. The data gathered showed that several banks were covered in *Undaria tenuifolia* (lettuce leaf coral), with remarkably low cover of fleshy macroalgae as well as high numbers of *Diadema sp.* urchins (long-spined urchins). The urchins were keeping the macro-algae at bay, while the lettuce leaf coral was growing and covering all the clean substrate areas left behind by the urchins. While gathering all this underwater data, large colonies of *A. palmata* (elkhorn coral) were found populating the nearshore reefs of Punta Sal. These led to further investigation and over 800 colonies of elkhorn coral were counted and mapped within the entire Bay of Tela. All this biological information was compiled into a technical report, presented to the Honduran government, and served as the foundation for MPA declaration. Together with help from all the local partners, an MPA covering 111 000 hectares was declared as a Site of Wildlife Importance in February of 2014.

Application in management: zoning within MPAs

Site-based data on coral cover and fish biomass have also been used to create zones within MPAs managed by our partners within the MAR. For example, the reef health data collected around Cordelia Banks allowed zoning the MPA by:

- creating areas where no fishing is allowed, in sites that showed the greatest number of juvenile fish;
- creating areas where only scientists and managers are allowed to enter and where no tourism activities are allowed, in sites where live coral cover is the highest, in order to minimize impact from recreation activities;
- creating artisanal fishing areas, in sites where larger, more mature fish were commonly found; and
- creating boat traffic channels, in areas with low coral cover and greater depth which allow for safe boat traffic.

The area on Roatan, formerly known as the Sandy Bay-West End Marine Reserve, is now part of a larger MPA, the Bay Islands National Marine Park. This area, before its inclusion in

the larger marine park, was patrolled and managed by a local grassroots non-governmental organization called Friends of the Roatan Marine Park. This NGO was created by the local dive shops and concerned citizens, who could clearly see the reduction of fish numbers in the area where no adequate patrolling was being carried out. Prior to beginning patrols fish biomass was low, especially for large-fish, along this entire area. Once patrols were under way, and poachers were being removed or arrested, fish biomass began to increase

3.2 Eco-Audits Evaluating and Catalyzing Management Actions

The MAR provides a diverse array of goods and services to the people of Belize, Guatemala, Honduras and Mexico. Unfortunately, the intensity and range of threats to the region's coral reefs have increased rapidly, much faster than efforts to effectively manage them. This has been documented by the HRIs 2008, 2010, 2012 and 2015 Report Cards for the Mesoamerican Reef. The stress stems, at least in part, from inadequate management of local pressures. We need to take more management actions to improve reef health, and implement them faster.

The Eco-Audit is a systematic multinational evaluation of the implementation of recommended reef management actions by governments, NGOs and the private sector. It communicates and celebrates reef management success stories, while also drawing attention to critical gaps and future opportunities. It is intended to catalyze faster, more effective management responses to coral reef degradation and to increase the accountability of governments, the private sector and NGOs. It also seeks to establish a baseline understanding of the current status of reef management efforts.

The Eco-Audit also provides a mechanism for partners in each country to communicate, convene, and collaborate in addressing critical issues. Ultimately, this effort seeks to improve the health of the Mesoamerican Reef, thereby contributing to the national economies of the MAR countries and restoring the natural wealth of these globally important coastal ecosystems.

The recommendations that are evaluated in the Eco-Audit are discussed throughout the year with all our partners, and finalized during our yearly regional partners meeting, where they are prioritized and ranked. The Eco-Audit ranks the performance and progress made in implementing 28 reef management indicators organized into these seven major themes, including: marine protected areas, ecosystem-based fisheries management, coastal zone management, sanitation and sewage treatment, research, education and awareness, sustainability in the private sector and global issues. The ranking system uses clearly defined and transparent five-point ranking criteria for each indicator. Rankings are verified by means of verification (MOVs) documentation. Over 350 MOVs to support each theme were presented in the 2016 Eco-Audit.

The analysis of each theme and indicator is objective, science based and validated. The HRI and its regional partners are committed to maintaining audit standards that are unbiased, fact based, transparent and replicable. The financial and management auditing firm of PricewaterhouseCoopers Costa Rica (PwC) has reviewed the conceptual methodology (in 2011) and verified the presence and quality of the supporting documentation for each score in the 2011 2014 and 2016 Eco-Audits. The eco-audit has been a collaborative effort, drawing on input from partners, stakeholders and key experts throughout its implementation.

Table 9.2 Marine protected areas (MPAs) and no-take zones (NTZs) in the Mesoamerican Reef*

	Reef area Km^2	TS Km^2	MPA area Km^2	NTZs area Km^2	% of TS inside MPAs	% of TS inside NTZs	Reef area inside MPAs	% of reefs inside MPAs	Reef area inside NTZs Km^2	% of reefs inside NTZs
Mexico	491	18640	7986	755	43	4.1	398	81	74	15
Belize	649	18768	4013	532	21	2.8	315	49	81	13
Guatemala	62	1560	936	10	60	0.6	62	100	0	0
Honduras	160	23987	9819	524	41	2.2	151	95	16	10
MAR	1362	62954	22754	1821	36	3	926	68	171	13

Notes:
TS = territorial seas, extend 12 nautical miles from the outermost inhabited land.
* NTZs are also known locally as fisheries replenishment zones.

Source: Adapted from the 2016 Eco-Audit (www.healthyreefs.org).

Key findings in the eco-audit

The Eco-Audit presents readily available solutions accessible for immediate implementation. It reminds us that we do not really manage coral reefs – we manage human behaviors and our impacts on the reef. Protected areas are crucial but alone are not enough to reverse the decline of coral reefs. The overall 2016 score for the Mesoamerican region was 62 percent, which is an improvement in the implementation of recommended management actions compared to 54 percent in 2011 and 57 percent in 2014. The highest scoring management theme was Research, Education and Awareness (88 percent); the lowest scoring was Sanitation and Sewage Treatment (47 percent). Improvements were measured in every theme except sewage and sanitation.

Three of the 28 indicators have been fully implemented including: indicator (1a) Percentage of each country's maritime are inside MPAs, with the MAR protecting almost twice the targeted 20 percent of its territorial sea was achieved in 2014 with the amount of coral reef area inside MPAs increasing to 68 percent (Table 9.2); (5a) Standardized monitoring and reporting was fully implemented, due to regular regional assessments and the openly available online database, and (5c) Understandable information on reef condition, threats and values, available to the general public and stakeholders.

While we celebrate the achievement of attaining 36 percent of territorial seas within MPAs, we also recognize that if we continue at this current pace of fully implementing the recommended management actions, it will take about 50 years to fully implement the remaining 27 management actions needed to sustain a healthy reef. Over the next 50 years the reef will face greater stress from increasing population, growing seafood demand and climate change. The eco-audit shines a transparent and equitable light on these four countries and helps encourage the fuller faster implementation of the recommended management actions. Positive media attention and praise for success help inspire, while the desire to avoid negative press helps move management actions to completion. Establishing a friendly competition among these four neighboring countries to achieve better reef

management scores is also an advantage of the approach. The country-based results for 2016 remain unchanged from the previous two assessments, with Belize (68 percent) demonstrating the fullest implementation followed closely by Mexico (64 percent), Honduras (60 percent) and Guatemala (54 percent). Interestingly Honduras had almost twice as many conservation action improvements (9) as the other countries (Mexico and Guatemala with 5 and Belize with 4). In 2016, all four countries improved in two regional indicators for a standardized open monitoring database (5a) and creating understandable information on reef health (5c) (HRI, 2016).

4 DISCUSSION: KEY ELEMENTS AND CHALLENGES FOR SUCCESSFUL LARGE-SCALE REEF MANAGEMENT

Conservation and sustainable use of the Mesoamerican Reef requires well-informed and routine collaboration among government departments and politicians, civil society, research institutions and the private sector users and beneficiaries across four countries and sustained for the long term. The collaborative vision and evaluative platform provided by the independent HRI enables but does not fully ensure successful management. In this section we further explore some of the enabling conditions that are needed to support success, including long-term financing, broad stakeholder and community involvement, and generating broader support for monitoring through highly visible and simplified application of reef health data linked to recognition of the economic value of the resource.

4.1 Financial Sustainability of Basic Long-term Monitoring

Sustaining long-term monitoring efforts has been a challenge for many initiatives and there are probably more global examples of failures than successes, except in cases where the government has committed long-term funding (such as on the Great Barrier Reef in Australia). The Mesoamerican Barrier Reef System (MBRS) project helped initiate regional marine conservation through a five-year initial phase of an intended 15-year program that lasted from November 2001 to June 2007. 'GEF provided US$11.0 million grant financing for this project with co-financing by participating countries of US$3.2 million, and US$0.5 million in-kind contribution from beneficiaries' (Alderman et al. 2007, p. 6). The MBRS Project was executed by the Central American Commission on Environment and Development (CCAD) on behalf of the four participating countries and implemented by the World Bank on behalf of the Global Environmental Facility (GEF). '$US 4.4 million (GEF financing US$ 2.67 million) was allocated for the design of a Synoptic Monitoring program. The component also funded a large amount of equipment for monitoring, including boats and engines at various monitoring sites' (Alderman et al. 2007, p. 17).

The HRI complemented this project with approximately US$2 million in private funding from 2005 to 2015, and also leveraged in-kind contributions over the same period. The government-endorsed MBRS project helped pave the road for the more encompassing partnership of efforts within HRI, which allows partners to keep monitoring costs down-sized, localized and at optimal efficiency. The HRI Report Cards represent

a mixture of partner-collected data and HRI core team data (accounting for just over half the total 248 sites included in the 2015 Report Card). The HRI has sponsored ten reef-monitoring training workshops over the past decade, training over 120 field biologists in species identification and monitoring methodology. Regular monitoring training and quality assurance testing is a critical component of the HRI's collaborative monitoring program. While the cost of marine park management in general, and coral reef monitoring in particular, is relatively high compared with terrestrial areas, the economic benefits are also much higher per hectare (EurekAlert-AAAS 2009).

The Mesoamerican region has a variety of management agencies and co-management organizations that have learned to integrate monitoring efforts in creative and cost-effective ways. This includes the use of community researchers and volunteer/educational experience programs that have multiple benefits in addition to acquiring data useful to management and policy decisions. Several local NGOs have engaged community stakeholders in monitoring, enforcement and educational activities. This community engagement brings multiple benefits since managers can maintain a human resource list of trained individuals ready to support its data collection activities only when needed, while also helping community residents to diversify their regular livelihoods (many are fishers or tour guides).

4.2 Community Involvement Examples: the Toledo Institute for Development and Environment, Roatan Marine Park and Centro Ecológico Akumal

Within the region, an effectively sound strategy to help reduce the cost of monitoring and provide wider benefits that are by-products of broader community involvement in monitoring has been employed by several partner organizations, including Centro Ecológico Akumal (Ecological Akumal Center, CEA) in Quintana Roo Mexico, Roatan Marine Park in Honduras and the Toledo Institute for Development and Environment (TIDE) in Belize.

The CEA has been successful in creating a community-based program in marine management. The CEA has the objective of integrating the conservation of natural resources, sustainable development and the welfare of local and regional communities. To accomplish this task, it has developed a wide range of programs (sea turtles, scientific research and environmental management, coastal ecosystems, coastal management, water quality, environmental education and communication) which, acting in synergy, allow the CEA to generate technical and scientific information on the condition of natural resources of the region (including coral reefs, seagrass, mangroves and wetlands), implement strategies and coastal management best practices (such as the Management Plan for Akumal Bay and Fish Refuge Zone at Akumal), as well as integrate the local and regional community through mechanisms of environmental awareness and social participation (certification courses for tourist guides, lectures and workshops on environmental education, training in ecosystem monitoring, and so on).

Working with national and international volunteers actively participating in its programs, allows CEA to expand its scope, socialize the information generated, meet the costs of long-term monitoring of coastal and marine resources and provide benefits to local communities. Likewise, working together with enhanced social diversity around Akumal (tour operators, fishermen, owners, members of government, private sector and

education sector at all levels), enriches the scope of the CEA to the society and strengthens their participation in it, to promote more responsible socio-economic development, organized and committed to the environment.

The CEA's Coastal Ecosystems Program coordinates the monitoring and assessment of coral reefs, seagrass beds and wetlands in and around Akumal. This program works through a volunteer-based program, which funds the operations and allows the development of human resources with technical skills to continue the monitoring. Since 2006, they have implemented two to four 'phases' of reef monitoring, each lasting three months, including training and operation monitoring. Since 2013, volunteers have been trained and monitored seagrass bed as well, most recently with the technical assistance of specialists from the National Autonomous University of Mexico (UNAM). Information obtained from continuous monitoring has helped define management strategies and management of Akumal resources such as the Management Plan for Akumal Bay and the recent creation of the Zone of Fish Refuge at Akumal, both serving the problem of heavy use and degradation of reefs and seagrass beds in the region. Likewise, the CEA seeks to socialize the information in forums of awareness to generate environmental responsibility among the users of Akumal at a regional and international level, seeking to ensure the sustainability of both natural resources and the economy and quality of life for local residents.

In many MPAs in Belize, management actions to promote long-term sustainability of resources, includes measures to exclude extraction from some core replenishment areas, which can be met with resistance from the fishing community. In order to combat this perception of reduced resource use, organizations such as the Toledo Institute for Development and Environment (TIDE) have successfully employed a strategy that involves community members from buffer communities in their monitoring and enforcement work. Fishers from these communities depend on the extraction of conch, lobster, finfish species and, most recently, sea cucumber as a source of local protein and for family revenue, as well as for export.

Their temporary employment has multiple benefits and community residents have demonstrated that with sufficient training they can be proficient field technicians performing well in the AGRAA training course that includes both written and field-based skills assessments. This program not only provides needed human capacity support for the local NGO but it also helps community residents to pursue careers in a field that can utilize their technical knowledge. It has the added benefit of building credibility for the results coming from the data when communicated back to the communities in which the researchers live.

In Belize, a concerted effort is being made by several NGOs and government agencies to assist with identifying and initiating alternative livelihood programs to help mitigate the impacts of expanding no-take zones as fishers transition away from an entirely open access fishery.

In Roatan and Tela, Honduras, the HRI has also worked towards involving the local community, particularly dive guides, in coral reef monitoring. Divers trained by the HRI to conduct monitoring may move around within the Bay Islands, but remain a part of the broader conservation community. These people have continued to assist with monitoring, and an added conservation value by becoming key players in getting tourism/business support for local and central government efforts to increase MPA declarations. They are

now a part of an available human resource pool that is eager to participate in monitoring elsewhere, such as Guatemala, Trujillo, Guanaja and Cayos Cochinos.

The value of involving local communities and stakeholders cannot be overstated, particularly given the potential spin-offs, such as the creation of knowledgeable advocates for marine conservation, which makes the investment in training worthwhile. The employment also adds to the existing level of direct employment opportunities provided through the MPAs. Employment from marine and coral resources represents as much as 30 percent of the economically active population (EAP) for countries such as Belize and the state of Quintana Roo, Mexico (HRI 2014). The HRI was able to cost-effectively collect accurate data through collaboration with partners, particularly those managing MPAs and through their engagement of local community researchers.

4.3 Highly Visible, Understandable Results Linked to Recognized Economic Value

Biodiversity and ecosystem services are essential for poverty eradication, which is one of the foundations of the Strategic Plan for Biodiversity of the Convention on Biological Diversity (CBD) (Lucas et al. 2013). In Turner and Daily's discussion of ecosystem services framework and natural capital conservation they submitted that, in order to make well-informed decisions about trade-offs between different management states, all costs and benefits should be taken into account, including ecological, sociocultural and economic values and perceptions. To facilitate planning, design and decision-making, large amounts of data on ecosystem services (and their values) are needed which can come from both meta-analysis and new empirical data. In both cases, databases are essential and should be readily accessible through the Internet to enable easy storage and retrieval of the data (Turner and Daily 2008).

Given this fundamental objective, managers and government agencies have also recognized the need to value the ecosystem services provided by coral reef and related habitats by valuing the ecosystem services that include direct extraction values, such as fisheries, as well as non-extractive uses, such as tourism and shoreline protection. Despite this compelling need, there have been few actual examples of incorporation of economic valuation into policy and decision-making in the Caribbean. (Nunes and Gowdy 2015).

The WRI's 2008 evaluation of Belize's reef and mangrove ecosystems, did not assess 'the Total Economic Value' but instead focused on the three main goods and services provided by these resources in the Caribbean (and the Mesoamerican region): tourism, fisheries, and shoreline protection, finding a total annual value of approximately US$395 million to $559 million per year. Coral reef and mangrove-associated tourism contributed an estimated US$150 million to $196 million per year to the national economy in 2007 (12 to 15 percent of GDP) (Cooper et al. 2008). The WRI's report also noted that:

> Fishing is an important cultural tradition, as well as a safety net and livelihood for many coastal Belizeans. Annual economic benefits from reef and mangrove-dependent fisheries was estimated at between US$14–16 million. Reefs and mangroves also protect coastal properties from erosion and wave-induced damage, providing an estimated US$231 to US$347 million in avoided damages per year. By comparison, Belize's GDP in 2007 was US$1.3 billion. These estimates capture only three of the many services provided by coral reefs and mangroves, and should not be considered the 'total' value of these resources. These numbers should be regarded as a lower bound estimates. Valuing of important ecosystems is one of the key steps in providing

> policy-maker, resource users and beneficiaries with the information needed to make critical management and policy decisions. (Cooper et al. 2008, p. 2)

This economic value has been used in Belize to help develop the Coastal Zone Management Plan and to provide context and justification for reef damages in a precedent-setting Supreme Court case for the Westerhaven ship-grounding incident in 2010. A recent review by Waite et al. (2015) found that only 17 out of 100 economic valuations had been definitively utilized for policy or decision-making (including Belize).

A new approach to using economic valuation information for the specific purpose of addressing the difficulties in improving wastewater treatment in the Caribbean is now under way. Across the region, 80 percent of domestic wastewater entering the Caribbean Sea remains untreated, 51.5 percent of households lack sewer connections and only 17 percent of households are connected to acceptable collection and treatment systems. The Caribbean Regional Fund for Wastewater Management (GEF CReW) project was established to help address the challenges of the lack of resources and infrastructure to properly treat wastewater, which has led to water pollution negatively affecting coastal and freshwater ecosystems and human health.

By comparing the economic benefits of ecosystem services provided by healthy coral reefs and associated ecosystems with the economic costs of not properly treating sewage (related to human health impacts and loss of ecosystem services owing to declining ecosystem health), the high cost of improving sewage treatment can be clearly justified. When waters that are used for marine recreation, tourism and that support the livelihoods of communities, such as fisheries, are impacted with under-treated or untreated sewage, the social costs of dealing with water-borne illnesses are astounding. Operational costs for running treatment facilities are high, and most communities are hard pressed to cover these costs when added on to potable water treatment and distribution costs. However, when compared through economic studies, the cost of treatment versus the full social and environmental costs of not having treatment, the most cost-effective option is the proper treatment of wastewater. Pilot studies within this project suggest that the forecasted benefits from investment in improved wastewater management exceed the costs, as indicated by a higher score for the future scenario(s) as compared with the current wastewater management situation (Gray et al. 2015). An earlier, 2003, study by Shuval estimated that polluted coastal waters generate 120 million excess cases of gastroenteritis and 50 million excess cases of antibiotic responsive diarrhea (ARD) annually, resulting in a global cost of $12 billion per year in public health expenses (Shuval 2003).

The HRI considers the implementation of economic valuation of coral reefs and the improvement in sewage treatment to meet land-based sources of marine pollution (LBSMP) protocols as two of 28 key management actions evaluated in their eco-audits. The evaluation of progress is one of the key steps in providing policy-maker, resource users and beneficiaries with the information needed to make critical management and policy decisions. Once the public and policy-makers fully understand the value of their reef system, the current status as evaluated through biennial Report Cards and the successful implementation of recommended management actions (evaluated through Eco-Audits), sound stewardship of this invaluable natural resource can be achieved.

5 SUMMARY

Publishing regular, easy to understand reports on the health of the reef, allows managers, policy-makers, stakeholders and the interested public to stay informed and become more supportive of needed reef management actions. It is critically important to use plain language, vivid imagery and compelling stories to bring scientific information out of the closed sphere of the scientist and into the mainstream world of practitioners, policy-makers and a wider audience that can support policy and resource managers. Effective use of the media is critical to achieving this broad social reach. In addition, the time, effort and financial resources needed to build and coordinate a network of over 65 organizations, using a standardized data collection methodology, agreed upon indicators and a data-sharing platform are significant (HRI budgets are approximately $430 000 per year), but essential to large-scale, science-based adaptive management.

One of the most important components of the HRI is having the collaboration of different sectors (government, private, academia and NGOs) that fosters integrated discussions and the collaborative production of Report Cards and Eco-Audits. The ownership and responsibility for the results is thus viewed as a common output of the collective effort, although some aspects of the eco-audits have specific organizational or national roles and responsibilities. The national-scale reporting framework of the eco-audits also promotes friendly competition among neighboring countries to achieve improved results and further raise the bar of marine stewardship in this vibrant region.

The Mesoamerican Reef has invaluable natural resources that contribute to the economy of its countries through touristic activities, commercial and artisanal fisheries, storm protection, provision of other food and medicines, and more. The cultural value of the reef is well known but difficult to value. Although this value is recognized, balancing national development goals with sustainable uses that maintain livelihoods, reduce poverty, secure food supply and mitigate the effects of climate change, remains a growing challenge. Regular monitoring of both the health of the ecosystem and the extent of human management actions are required and must be extensively reported in a variety of ways for different audiences. The HRI has benefited from ten years of scientific support from the Smithsonian Institution and national universities in the four countries, from the main civil society organizations concerned with marine conservation and from the government departments charged with management. Armed with the support of robust science, managers and community-based NGOs can speak with a stronger more unified voice about the need to strengthen management actions aimed at ensuring the long-term integrity of the Mesoamerican Reef system and the millions of livelihoods dependent upon it.

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