Indicators for management of coral reefs and their applications to marine protected areas

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Abstract

Informed planning and decision-making in the management of natural resources requires an ability to integrate complex interactions in ecosystems and communicate these effectively to stakeholders. This involves coping with three fundamental dilemmas. The first comes from the irregular pulse of nature. The second is the recognition that there are no strictly objective criteria for judging the "well-being" of an ecosystem. The third is posed by the quest for indicators with some integrative properties that may be used to analyze an ecosystem and impart the information to the relevant resource users. This paper presents some examples of indicators used to: 1) assess the status of a coral reef and, in particular, the state of its fisheries resources; 2) identify reefs that are most threatened by human activities; and 3) evaluate the likelihood of success of management interventions. These indicators are not exhaustive, but illustrate the range of options available for the management of coral reef ecosystems.

Introduction

Man has barely come to grips with understanding how ecosystems function and is now struggling to manage its finite resources in a sustainable manner. Science and research play a major role in providing the information required to plan and decide on management actions. This involves making some sense out of the complexities of interactions in the ecosystem and communicating the knowledge and its implications efficiently to multiple stakeholders (Hovgard et al. 2001).

There are three fundamental dilemmas that have to be dealt with in understanding these complexities. The first comes from the irregular pulse of nature. Natural variability in an ecosystem may prevent the recognition of substantive changes or give false alarms. Though ecosystem processes such as nutrient cycling, primary productivity and recruitment into the system are cyclical. They are also highly irregular. They display variations annually, seasonally and diurnally. Recognition of abnormalities is subject to the temporal scale of observations and the availability of long term monitoring information. False alarms may be easily sounded because of poor understanding of the dynamics of the system and the interactions among its components.

Secondly, one must recognize that there are no strictly objective criteria for judging the well being or ideal state of an ecosystem. The ideal state is inevitably based on some combination of desirable attributes that are not objectively selected. Several components in the ecosystem may actually have opposing definitions. More often than not, no single configuration of the ecosystem meets the biological, social, ecological and economic needs in the system.

The third dilemma is posed by the quest for indicators. A choice of what to monitor among the many components and processes occurring in the system has to be made. The chosen indicators must have some integrative properties that will reflect changes in more than one aspect of the system (Garcia and Staples 2000). These indicators must not be based on overly simplistic assumptions about the nature of the biological and ecological processes and human and ecosystem behavior. Indicators must be used in simple but robust systems of tracking instability. It must, however, be noted that indicator-based systems are not a complete substitute for more comprehensive sets of information that are needed and conventionally used to manage natural resource systems. However, indicator-based systems will greatly reduce the constant need for a comprehensive information base for making resource management decisions.

In all these, the issue of scale has to be addressed. Local communities and local government units are recognized as the primary stakeholders and participants in the management of natural renewable resources. However, the natural boundaries of ecosystems and the processes that support and stress these ecosystems may transcend the boundaries of these local management units. This is especially true for aquatic ecosystems where the concept of a continuum is well appreciated. Thus, efforts to arrest the decline in resources and loss of biodiversity for ecosystems such as coral reefs demand that research and assessment activities, and management interventions are carried out at the local, national and regional scales.

Indicators and the management of aquatic ecosystems

The development of indicators has been called for in Chapter 40 of the Earth Summit Agenda 21. The Conference on Sustainable Development (1993 and 1994) took this further by emphasizing the need for a "Menu of Indicators" that will serve as the basis for early warning systems, establishing cost effective data collection, monitoring and assessment of trends, and informed decision-making, particularly for natural resource systems (Garcia and Staples 2000). Carefully selected indicators may facilitate the processes and increase the effectiveness of the awareness-building efforts. Trends in indicators may also trigger changes in policies as well as approaches to managing ecosystems.

Potential applications of indicators

Indicators are useful in several ways. It may be worthwhile to mention a few types of indicators and their applications. This list is not exhaustive, but rather illustrative of the sorts of indicators that need to be identified as part of the menu of indicators for coral reef ecosystems.

Assessment indicators – are useful in choosing priority areas that need management interventions. Continuous monitoring of these indicators assists in evaluating the success of the implementation of the management programs and signifies when corrective action in the management plan is necessary.

Indicators of threat or risk – provide a means of anticipating and possibly preventing potential disasters. Indicators may help understand the complex interactions and assist in dealing with the sources of threats.

Success-likelihood indicators – are means of optimizing the results of a management intervention. Successful rehabilitation and sustainability of degraded aquatic ecosystems will depend on a number of biophysical and socio-economic factors (e.g., availability of fish, invertebrates and algae to replenish the system, their success in restoring the natural resources, potential for changes in human behavior that have initially led to the ecosystem decline, etc.). Indicators of these preconditions for success are useful in designing and implementing management initiatives.

For indicators to be effective, they must bring about a change in the behavior of users of the resource. In response to indicators, users of the resource must be willing to change their behavior, for example by reduction in harvest or compliance to regulations to improve habitats (e.g., the establishment of "no take zones").

Examples of static and dynamic uses of indicators in aquatic resources management

The use of indicators for management is a recent development for aquatic ecosystems and most have focused on the biophysical aspects of the system. Indicators may be used as static measures to assess the state of ecosystems. A simple example would be the adoption of the lake trout (*Salvelinus namaycush*) as an indicator of health of offshore oligotrophic waters in the intensively studied Lake Superior and Huron of the Great Lakes (Edwards et al. 1990). The continued presence of this environmentally sensitive species was an indication of the absence of man-made stresses from eutorphication, toxic substances, and harvesting.

Another example would be the Index of Biological Integrity (IBI). This set of indicators was widely adopted by state and federal agencies as a tool for water resources management in the US. The method employs an array of biological metrics derived from individual fish, fish populations and fish community assemblages in the rivers and lakes. Biological metrics are akin to economic indicators used in econometric analyses. Twelve metrics were identified under three categories: 1) species richness and composition; 2) trophic composition; and 3) fish abundance and condition. Scores given to each of the 12 metrics are summed and used to rate the condition (i.e., excellent, good, fair, poor or very poor) of the ecosystem (Karr and Chu 2000).

For coral reef ecosystems, several indicators have been developed for rapid assessment techniques for the purpose of management. Percentage of live coral cover, abundance and diversity of both coral and reef fish species, production from the fisheries, and the presence of various forms of stress to the ecosystem are some of the ones identified for biophysical conditions. Such indicators are generally used to report the status of reef ecosystems (Wilkinson 1999).

Maximum Sustainable Yield (MSY) and the Maximum Economic Yield (MEY) used by the fisheries sector are also examples of dynamic indicators used in natural resources management. MSY is defined by Caddy and Csirke (1983) as the limit reference point beyond which immediate and substantial action should be taken to protect harvested stock. MEY (Gulland 1969) is the point where the community derives the greatest net profit from the fishery. More recently, ESY or Ecologically Sustainable Yield has been identified as desirable. ESY is the yield an ecosystem can sustain without shifting to an undesirable state (Zabel et al. 2003). These are indicators of fishery potential as well as a development and management target. Unlike the indicators previously mentioned, MSY, MEY and ESY are more robust in that they integrate biophysical and socioeconomic aspects of the system.

Sets of indicators collected over a time period may be used dynamically. For instance, the trajectory of fish catch values after the imposition of gear restrictions may be compared with a trajectory set as a management goal. Dahl (1996) gives an example for populations of fish and pollution indicators. The deviations in trajectories may be used to make correction in either the management activity or the management goal. Linton and Warner (2003) present examples of indicators used for integrated coastal zone management in the Caribbean.

Marine protected areas and the management of coral reefs

Of the management approaches available for coral reefs, the designation of marine protected areas (MPAs) or fisheries reserves are conservation strategies that have received much interest and support globally. In fact, the designation of such reserve areas has expanded dramatically over the last few decades (Alder et al. 2002). Marine reserves are strongly advocated by many resource managers and biologists because they offer potential benefits to coastal fisheries and marine resources management, including the enhancement and restoration of fishery yields, protection of reproductive potential and maintenance of biological diversity (Hoagland et al. 2001). For fisheries that target highly mobile single species with little or no by-catch or habitat impact, MPAs provide few benefits compared to conventional fishery management tools (Hilborn et al. 2004).

The success stories of community-based management of reefs such as Sumilon and Apo islands in the Philippines further highlight this point. The designation of 20 per cent of a reef area as a "no take" zone resulted in a rehabilitation of the reef and increased fisheries yield (Alcala and Russ 2002). Designation of MPAs has become an intrinsic part of fisheries management pursued within the framework of integrated coastal zone management (ICZM) efforts.

To illustrate the importance of indicators for coral reef management, we present some examples of the applications of indicators for the designation and management of MPAs. The issue of scale needs to be highlighted because MPAs focus on local communities, yet the benefits and the risks of these marine reserves (e.g., sources of pollution, destructive harvesting of resources, poverty and environment policies, sources of recruits into the system, etc.) may not be strictly limited to the local communities. Furthermore, management units are defined relative to the scale of the reef areas being considered.

Indicators of levels of fishing on reefs

Coral reef fisheries provide food and livelihood to tens of millions of people throughout tropical and subtropical seas. A large proportion of these people survive on marginal incomes. Studies on the effect of fishing on coral reef resources published by Polounin and Roberts (1996), Birkeland (1997), McManus (1997), Hollingworth (2000), and Alcala and Russ (2002) all agree that declining catches from reef fisheries result from over-fishing.

Indicators of levels of fishing

There are hundreds of types of coral reef fisheries, and various combinations of methods and effort levels affect reefs in complex ways. However, it is possible to roughly classify the status of many reef fisheries into three stages (Table 1) with the following indicators.

Characteristic market species. This is probably the most immediate indicator of the state of a reef fishery. Relatively unstressed coral reefs support numerous large species that are easy to harvest. Because these species are generally of high value, it is desirable to maintain their populations and to ensure that large individuals are perpetually available for harvesting. Many species common on near-pristine reefs, such as giant clams, conchs and sharks, are characteristic of fisheries classified as by Stage I.

In more heavily fished reef systems (Stage II), large, high-value predatory fish such as groupers and snappers become uncommon, and there is a tendency for lower value species, such as parrotfish, wrasses and rabbitfish to predominate. The shift from high-value to lower-value species, both within the ecosystem and on the market, indicates "ecosystem overfishing" (Pauly 1979).

In some situations, a reef fishery becomes an employer of last resort. Under intense coastal crowding, open access to fisheries, and the absence of alternative livelihoods, the numbers of participants in coastal fisheries tends to increase until the average fisher receives little or no net income (Pauly et al. 1989; Pauly 1990). This is a situation that predominates in reefs in a Stage III fishery. Immature parrotfish, wrasses and butterfly fish are species characteristic of this stage. Reef and market species have not only shifted from high to lower value species, but fish that were not initially caught for consumption have been included in the regular catch (e.g., very small juveniles and butterflyfish).

In a Stage III fishery (McManus et al. 1995) there is a decline in the *median size of the catch*, in the *value per fish* and in the *catch per unit effort (CPUE)* based on legal means of fishing. CPUE is recorded, for example, as the weight of the fish caught per hour of fishing. Additionally, one can often identify the *use of destructive fishing methods*, which are harmful to the environment (e.g., blasting and poisoning) or the fishers themselves (e.g., make-shift hookah devices).

Two other indicators for levels of fishing may be identified with the availability of remotely sensed data. These are:

Devegetated haloes. The presence and size of haloes may be used as an indicator of the stage of a fishery. The haloes are areas around coral patches that are kept

clear of vegetation by herbivorous fish or invertebrates such as sea urchins (Randall 1965; Pennings 1998). They are particularly visible on reef flats, where seagrass predominates and where interspersed patches of coral may be subject to coral-algal phase shifts. Fishing of piscivorous fish is expected to result in larger haloes, as herbivorous fish range farther from coral shelter and/or become more abundant under reduced predation.

Harvest of herbivorous fish and/or invertebrates in a Stage III fishery may lead to the disappearance of the haloes as vegetation closes in on the coral patches. This is particularly evident on the heavily fished Bolinao reef flat in the Philippines, where aerial photographs clearly show former halos filled in with various densities of seagrass (McManus et al. 1992).

Type of algae settling on coral. On near-pristine reefs, dead coral generally becomes covered with calcareous encrusting algae that appear to encourage coral settlement and growth (Yap and Gomez 1988). However, in the absence of the normal suite of large herbivorous fishes in Stage III fishing, green filamentous algae (e.g., *Enteromorpha*) tend to proliferate on dead coral. This process may be followed by the settlement of brown frondose algae (McClanahan 1997). The spectral signatures for zooxanthellae in living coral, recently dead coral, encrusting red calcareous algae, green algae and brown algae are markedly different and can be detected by multispectral scanners (McManus and Noordelos 1998).

Many examples of each of these stages of coral reef fisheries are to be found in major coral reef regions of the world. Some Pacific Islands and the Great Barrier Reef in Australia are in Stage I, although some overfishing may still occur, e.g., in parts of Fiji. Stage II fisheries predominate in the Caribbean and in east Africa. Stage III coral reef fisheries are most common in South Asia and Southeast Asia.

Application of this assessment indicator to the management of MPAs

Some MPAs are established for the purposes of rehabilitating a coral reef and increasing yield from the fishery. By designating a "no take" zone, fishers sacrifice a part of their fishing ground on the assumption that this will improve the yield and sustainability of the remaining fishing areas. The indicators described above are useful to evaluate the success of the MPA by initially assessing a fishery before the establishment of a protected area and subsequently monitor its changes.

Indicators of threats to coral reefs

The Reefs at Risk analysis of threats to coral reef systems is a map-based indicator analysis of threats to the world's coral reefs (Bryant et al. 1998). These same indicators were used for Southeast Asia and published in Burke et al. (2000). The Reefs at Risk analysis considers information from four major potential sources of threats to reefs: coastal development; overexploitation and destructive fishing practices; inland pollution and erosion; and marine pollution. These data are used to rate the level of threat to coral reef areas.

The analysis also considers the presence or absence of management initiatives in classifying reefs to different threat categories. The indicators used in the Reefs at Risk analysis are explained in more detail below.

Threat indicators

Coastal development. Increased human activity in the coastal zone, a condition that translates into greater levels of stress to a reef system, is associated with the rate of coastal development. Population size is a primary indicator of human impact. The presence of infrastructure and activities (e.g., airports, military bases, tourist zones and mining activity) that escalate erosion, siltation and eutrophication in an area are included in the analysis.

Marine pollution. Spillage from ocean vessels are a major threat to coral reefs. Oil spills expose coral reef habitats to toxic substances and slowly smother organisms that inhabit them. The size of ports is an indication of the size of ships and the frequency of their visits to an area. Data on shipping lanes and sites known to have narrow passages also help identify locations where grounding accidents are likely to occur. The presence of oil tanks and wells are noted.

Table 1. Characteristics of a coral reef fishery according to the three main stages.

	Stage I	Stage II	Stage III
Characteristic species	Snappers, groupers, sharks, moray eels, giant clams, conch	Mature parrotfish, wrasses, siganids	Immature parrotfish, wrasses, siganids, butterfly fish
Median sizes	> 100 cm	25-100 cm	8-25 cm
Presence of passive gear (e.g., hooks, traps, etc.)	Frequent	Moderate	Rare
Occurrence of blasting or poisoning	Occasional	Common	Frequent
CPUE (legal methods)	High	Moderate	Low
Value per fish	High	Moderate	Low
Occurrence of devegetated haloes	Moderate	Large	Small
Algae on dead coral	Calcareous	Calcareous and green filamentous	Green filamentous
Examples	Australia	Kenya	Philippines, Jamaica

Over-exploitation. This term is used interchangeably with overfishing. The previous discussion on coral reef fisheries has detailed the relationship between the condition of a reef fishery and the associated consequences on the reef coral, algae and fish communities. Given the close relationship between the level of exploitation and eventual reef condition, an indicator of threat based on over-exploitation is included. The information in the analysis is based on the opinion of experts who were asked to identify where destructive fishing practices occur.

Inland pollution and erosion. Agriculture, logging and mining activities inland can affect reefs. The relative erosion potential (REP) is used as the primary indicator for this threat. REP is computed based on satellite data giving the relative slope, land cover class and precipitation in an area. The values are adjusted based on information on river flows.

The results of the Reefs at Risk analysis are based on a series of distance relationships correlating mapped locations of human activity (e.g., ports, towns, oil wells, coastal mining activities and shipping lanes) with predicted risk zones of likely environmental degradation. Detailed sub-national statistics on population density, size of urban areas, land cover type, rainfall and topography are included to help estimate potential runoff within watersheds from inland deforestation, land clearing and agriculture.

Distance rules defining threat zones have been established for each component indicator using information on the known locations of more than 800 reef sites documented as degraded by human activity through one of the four factors considered in this analysis. Minimum distances are established through expert review and input and by determining the most conservative set of rules that, when taken in aggregation for any one of the four threat categories, include at least two-thirds of all known degraded sites affected by

Table 2. Threat indicators and decision rules used to classify reefs for the Reefs at Risk analysis.

THREAT FACTOR: COASTAL DEVELOPMENT			
Indicator	**Qualifier**	**High**	**Medium**
Cities	Population over 5 million	Within 30 km	30-60 km
Cities	Population over 1 million	Within 20 km	20-40 km
Cities	Population over 100 000 with little sewage treatment	Within 10 km	10-25 km
Cities	Population over 100 000 with moderate sewage treatment	-	Within 10 km
Settlements	Any size	-	Within 8 km
Airport/ military bases	Military and civilian airports	-	Within 10 km
Mines	Any type	Within 10 km	-
Tourist resorts	Including diving facilities	-	Within 8 km
THREAT FACTOR: MARINE POLLUTION			
Indicator	**Qualifier**	**High**	**Medium**
Ports	Large size	Within 20 km	Within 50 km
Ports	Medium size	Within 10 km	Within 30 km
Ports	Small size	-	Within 10 km
Oil tanks and wells	Any size	Within 4 km	Within 10 km
Shipping threat areas	Known major shipping routes with areas of relatively narrow passage	-	Defined zone
THREAT FACTOR: OVEREXPLOITATION AND DESTRUCTIVE FISHING			
Indicator	**Qualifier**	**High**	**Medium**
Population density	Coastal population density exceeds 100 persons per sq km	Within 20 km	-
Population density	Coastal population density exceeds 20 persons per sq km	-	Within 20 km
Destructive fishing	Expert identified areas where blast or cyanide fishing occurs	Within 20 km	-
THREAT FACTOR: INLAND POLLUTION AND EROSION			
Indicator	**Qualifier**	**High**	**Medium**
Model Relative Erosion Potential (REP)	Based on the relative slope, land cover class and precipitation in an area	Scaled to model river flow	Scaled to model river flow

Source: Bryant et al. 1998.

activities related to the category. Table 2 presents the component indicators used and the decision rules established to grade any one reef as under "medium" or "high" threat. Areas not defined as under high or medium threat default to low threat.

Reefs are initially classified by individual threat factors. Results from the four factors are further integrated using the decision rules in Table 3. Draft risk maps were revised and scrutinized at a global workshop attended by coral reef experts from around the world. Scientists also mapped areas under high threat from destructive fishing practices and areas of intense shipping with narrow passages or "shipping threat areas" – two additional data sets incorporated into this analysis. Overall, the Reefs at Risk indicators accurately classifies as "at risk" over 80 per cent of sites identified by ReefBase 2.0 (McManus and Ablan 1997) to be degraded by humans. In some cases reefs mapped as "at risk" were relatively healthy due to good planning and management by local governments and people, or because natural factors rendered these reefs less sensitive to the impact of human activity. In other cases, a review of the literature and expert opinion show that degradation is actually more severe than the indicator suggests.

Application of this map-based indicator of threat to the management of MPAs

This initial indicator-based assessment of threats to reefs was conducted on a global scale. The information is intended to raise awareness of the need for proper management to ensure the survival of coral reefs. By superimposing the threat maps on the locations of protected areas, the study has concluded that globally, more than 400 marine parks, sanctuaries and reserves contain coral reefs but most of these sites are very small. If protection is considered as an insurance against total destruction, reefs are inadequately insured globally. More than 150 MPAs are less than one square kilometer in size and at least 40 countries lack any marine protected areas for conserving their coral reef systems (Bryant et al. 1998).

For Southeast Asia, a finer scale analysis indicates that, on average, 8 per cent of a country's reef area is inside a MPA. Only 7 per cent of these are managed well. The management status of almost half of the 646 MPAs is unknown (Burke et al. 2000). Similar analyses are on-going for other regions (i.e., the wider Caribbean, East Africa and the Pacific). The results are relevant to trans-boundary coral reef management issues (e.g., pollution, destructive fishing, legislation, incentives, sources of recruits into the system, biodiversity, etc.) and plans to manage reef areas sustainably.

Success-likelihood Indicators

Difficulties in defining reef ecosystem boundaries

There may be a disparity between boundaries of reef resources and the jurisdiction limits of resource managers. The natural boundaries of reef resources, like all aquatic resources, are difficult to define. They depend on the physical structure of the reef, the distribution of particular species of interest and the variable scales at which processes and interactions that support the ecosystem operate. However, management boundaries correspond to existing political and administrative systems.

In most cases, the natural boundaries are wider than those of the local management units and the hierarchy of jurisdiction boundaries do not match the boundaries defined by nature. Exploitation of resources may not be solely due to activities of the local residents, given the open access nature of most coral reef fisheries. Therefore, the issue of scale becomes highly relevant in evaluating success-likelihood indicators.

Indicators of connectivity and vulnerability of reef areas

Recovery of reefs subject to intense fishing pressure hinges on the availability of new recruits and their success in replenishing resources removed from a reef. Resource managers need information on the dynamics of the source and eventual sink of recruits to design marine reserves, estimate the potential contribution of restocking to rehabilitation efforts, understand mechanisms that maintain biodiversity, and maximize gains from a fishery. A reef, which is highly dependent on other reefs, will be managed differently from one that is primarily self-recruiting (Tuck and Possingham 2000).

Connectivity among reef systems may lead to situations where different local or national groups harvest the same stock of resources. Thus, management regimes in one area may be ineffective because of competing uses for the resource elsewhere. Such connectivity also has implications for the vulnerability of sink reefs when the relative sources which supply recruits experience massive damage.

A combination of information from genetic markers, growth and reproductive characters of populations, current patterns, tagging experiments and an analysis of otolith microstructures provide the best set of biological indicators for reef connectivity and vulnerability. Complementary information on fish movements may be obtained from tagging experiments and age structure analyses. The following indicators of connectivity have been identified.

Estimated numbers of migrants per generation (N_{em}) or some other measure of exchange. Values of estimates of exchange, such as N_{em}, are derived from genetic markers. The frequencies of alternative forms of a gene are calculated for each population. Comparisons between these frequencies from two different populations are the basis for the estimates of the

Table 3. Decisions rules used to integrate the results from the four threat factors in the Reefs at Risk analysis.

Threat category	Decision Rule
High	High threat in at least one of the threat factors
Medium	Medium threat in at least one of the threat factors
Low	Low threat in all four threat factors

Source: Bryant et al. 1998.

number of migrants (N_{em}) between them. Average N_{em} for marine organisms is quite low (Ward 2000). However, caution must be exercised in the interpretation of genetic data since this will be greatly dependent on the assumptions used in the analysis and the sampling strategy.

More recently, genetic data analysis methods have been developed to select or exclude populations of origin of individuals (Cornue et al. 1999; Davies et al. 1999). Though untested for marine species, they have the potential to provide estimates of connectivity between reef areas.

Duration of pre-settlement stage, mode of reproduction and mode of existence as adults of target species. The currents do not passively transport larvae (Leis and McCormick 2000). The available data suggest that reef linkage is highly dependent on the life history strategies of an organism (Ablan et al. 2002) and must thus be interpreted with respect to species or life history strategy which is of primary interest to management (e.g., sea turtles, groupers, primary reef building species, etc.). General conclusions on linkage relationships between reefs should be possible with sufficient data from several model organisms.

Entrainment. Natural or man-made structures may produce coastal eddies that significantly reduce transport of eggs or larvae and increase mortality (Cowen et al. 2000).

Condition of possible source reefs. Velocity and direction of currents vary with changes in wind velocity during different times of the year. Seasonal averages are used as the primary indicator of the distance and direction of transport from one reef area to another and identify possible source reefs (McManus and Menez 1998). Assessments of the condition of source reefs are essential to design marine reserves and to estimate the potential contribution of restocking to rehabilitation efforts.

Applications of connectivity indicators to the management of MPAs

Information on the origins, sources and sinks of larval recruitment and genetic heritage that drive coral reef populations and maintain ecosystem biodiversity is crucial for management, particularly because the natural boundaries of these ecosystems are difficult to define. The data are essential to design marine reserves, to decide if restocking or transplantation to augment natural populations is necessary to rehabilitate a system, understand mechanisms that maintain biodiversity, maximize gains and promote sustainability of the resource from the local to the national and regional scales.

Indicators of compliance and legitimacy and their importance to management of MPAs

In addition to the biological and ecological based success-likelihood indicators, the social and behavioral indicators of compliance and enforcement are important for successful management of any natural resource. Most MPAs are developed through community effort or in agreement with communities. The extent to which affected individuals and communities are willing to comply with the "no take" or "limited take" restrictions placed on the reefs or fishing areas can strongly affect the outcome of management regimes.

Evidence from social behavior indicates that morality and moral norms may sometimes influence behavior and economic outcomes more than just drives for personal gains (Etzioni 1988; Frank 1988; Mansbridge 1990; Thaler 1991). For example, a large number of experiments have shown that people do not automatically act as free riders when the opportunity to do so presents itself. Instead, many people persist in investing a substantial proportion of their resources into public goods, despite conditions designed to maximize free riding. The opportunities for free riding by harvesting illegally in "no take" zones is very real in the case of MPAs, but people do not always take advantage.

Many fishermen comply with regulations despite large potential illegal gains and small expected penalties (Kuperan and Sutinen 1998). The extent to which the forces of morality and legitimacy motivate compliance to regulations for managing coral reef resources may be effectively used as success-likelihood for the management of coral reefs. Two such indicators are the levels of *legitimacy* of an MPA and the *extent of non-compliance with the rules* by members.

Legitimacy. It may be measured as the percentage of the community that accepts the management initiative and the respects the authority that implements it.

Extent of non-compliance. Indications of non-compliance include records of violations over time and the percentage of the community who choose to act as free riders.

Conclusion

Resource and ecosystem management is increasingly seen to be as much about managing human behavior as about the ecology and biology of the ecosystem. Integrated natural resource management involves an understanding of the linkages between natural resource systems and socioeconomic systems. Socioeconomic systems impose pressure on natural

resources through various extraction and contamination processes. Given the complexities of natural resource systems, the concept of indicators has grown out of the notion that resource managers and other stakeholders need a relatively simple way of assessing the impacts that humans have on natural resources and factoring these into management decisions and plans for sustainable development.

This paper presents some means by which indicators may be used to: a) assess the condition of a resource; b) actively know and respond to threats; and c) evaluate the success-likelihood of management interventions for sustainable management of coral reef ecosystems. It is clear that indicators are support tools. They can also be used to improve communication, accountability and transparency between multiple stakeholders involved in benefiting from the use of a natural resource system. For indicators to be useful for management there must be a clear linkage between the indicators themselves and the objectives of sustainable natural resource management (Metzner 2001; Garcia and Staples 2000). Thus, indicators for the management of coral reefs need to be developed within the framework of management objectives and in cooperation with the major stakeholders.

Indicator-based systems are not a complete substitute for more comprehensive sets of information used to manage natural resource systems. However, indicator-based systems will greatly reduce the constant need for a very detailed information base for making management decisions.

The issue of different stakeholders promoting their own interest is an important problem. Each stakeholder will typically stress the issues of relevance, appropriateness and legitimacy to them and require an accommodation process. This will often entail a need for sustainability indicators capturing a broad mix of the qualities required by the different stakeholders if indicators are to serve as an efficient communication and management tool acceptable to all stakeholders (Hovgard et al. 2001). There is a large range of indicators that can be developed and used for the management of coral reefs in the context of integrated natural resource management. The indicators to be used will depend on the resources required to develop them, acceptability by stakeholders, the objectives of the management plan for the various natural resources, and the regulatory instruments to be used.

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