Coral Reef Monitoring and Management Using Reef Check

Gregor Hodgson, *Reef Check Global Survey Programme, Hong Kong*

Abstract

In both developed and developing countries, government resources available for coral reef monitoring and management are rarely sufficient for the task. A cost-effective method of increasing monitoring and management resources is to use community members to help. Involving the community in the process increases public support for government management initiatives, increasing compliance and reducing law enforcement costs. The Reef Check programme was designed to meet the need for a simple, rapid monitoring protocol that could be used to measure the health of coral reefs on a global basis. Since 1997, this standard protocol has been used to survey over 500 reefs in 50 countries around the world. The survey results have documented the global extent of overfishing on reefs and in 1998, the bleaching and mortality event that devastated reefs throughout tropical oceans. Publicity from Reef Check has raised the profile of coral reef issues. As the density and frequency of surveys increase, the value of Reef Check as a management tool will rise.

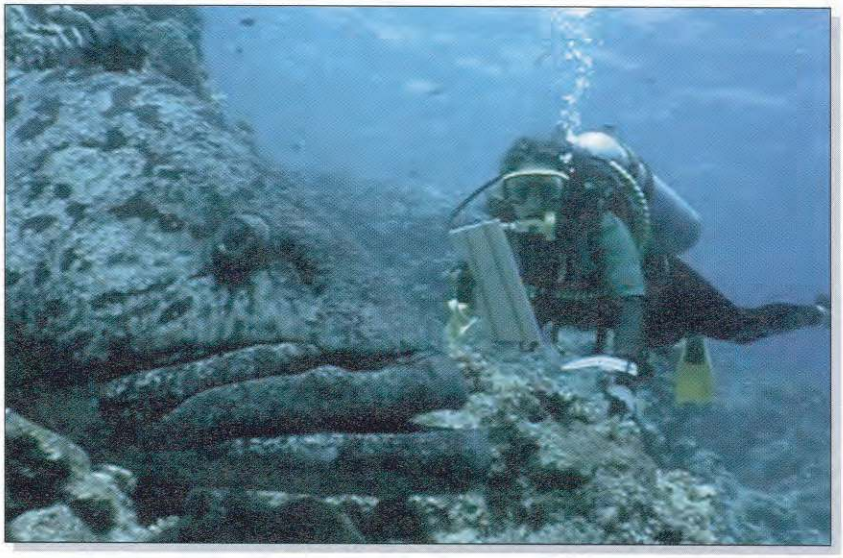


Figure 1
Grouper (Potato cod) are one of the key RC indicator fish. In SE Asia they are a major target of cyanide fishing. A large live grouper such as this may sell for US$ 10,000 in Hong Kong (photo Andy Dunstan, RC Coordinator Eastern Australia)

INTRODUCTION

Coral reefs are found in over 100 countries and territories throughout the tropics. Their beauty is legendary, and they are the second most biologically diverse ecosystem on earth. Hundreds of millions of people depend on reefs for their daily food supply, while tourists flock to white sand beaches from Cebu to Cozumel, that were created by the erosion of calcium carbonate coral skeletons. As the coral ecologist J. Stanley Gardiner put it in 1931, 'There is something in the psychology of mankind to which coral reefs never fail to appeal.'

Unfortunately, during the past 20 years, the love affair between humans and coral reefs has taken a dramatic toll on the health of the latter. By 1993, anecdotal reports of anthropogenic impacts on reefs had reached an alarming level. Poison and dynamite fishing, diver damage, pollution, sedimentation and other impacts were widely reported by long-time divers. But it was unclear how widespread or serious these effects were. The 1993 Colloquium on Global Aspects of Coral Reefs (organised by Robert Ginsburg, a University of Miami geologist) was a turning point for many reef scientists who met to discuss the health of the world's reefs (Ginsburg, 1994). The meeting was most successful in highlighting how sparse the available scientific database was. There was not enough information available to form a picture of the status of the world's reefs.

A number of reasons were identified, including:

- Too few coral reef scientists spending too little time on reefs
- Too few study sites compared to the global distribution of reefs
- Few long-term studies
- Emphasis on basic research rather than health of reefs
- Lack of comparability due to use of different methods.

The solution would be to design a special survey protocol that could be carried out by non-scientists, but that would produce reliable, highly focused data on coral reef health. If enough volunteer groups could be recruited in this international survey effort it should be possible to obtain a synoptic survey of the world's reefs.

To help focus attention on coral reefs, a group of scientists led by Ginsburg declared 1997 to be the International Year of the Reef (IYOR). As one IYOR activity, they asked me to draft a coral reef survey protocol that had special features that would allow it to be carried out by recre-

Figure 2
Every 0.5 m along the 100 m transect line the volunteer RC diver records the number of live and dead coral, as well as other types of substrata, on an underwater writing slate (photo Andy Dunstan, RC Coordinator Eastern Australia)

ational divers anywhere in the world, trained and led by a marine scientist. I designed the protocol and posted it on a list-server for coral reef scientists maintained by The National Oceanic and Atmospheric Administration (NOAA), with a request for peer review. Comments, criticism and advice were received from more than 20 scientists. Following revision, the final protocol for the programme now known as Reef Check was published on a website (www.ReefCheck.org) and participation invited on a completely volunteer basis.

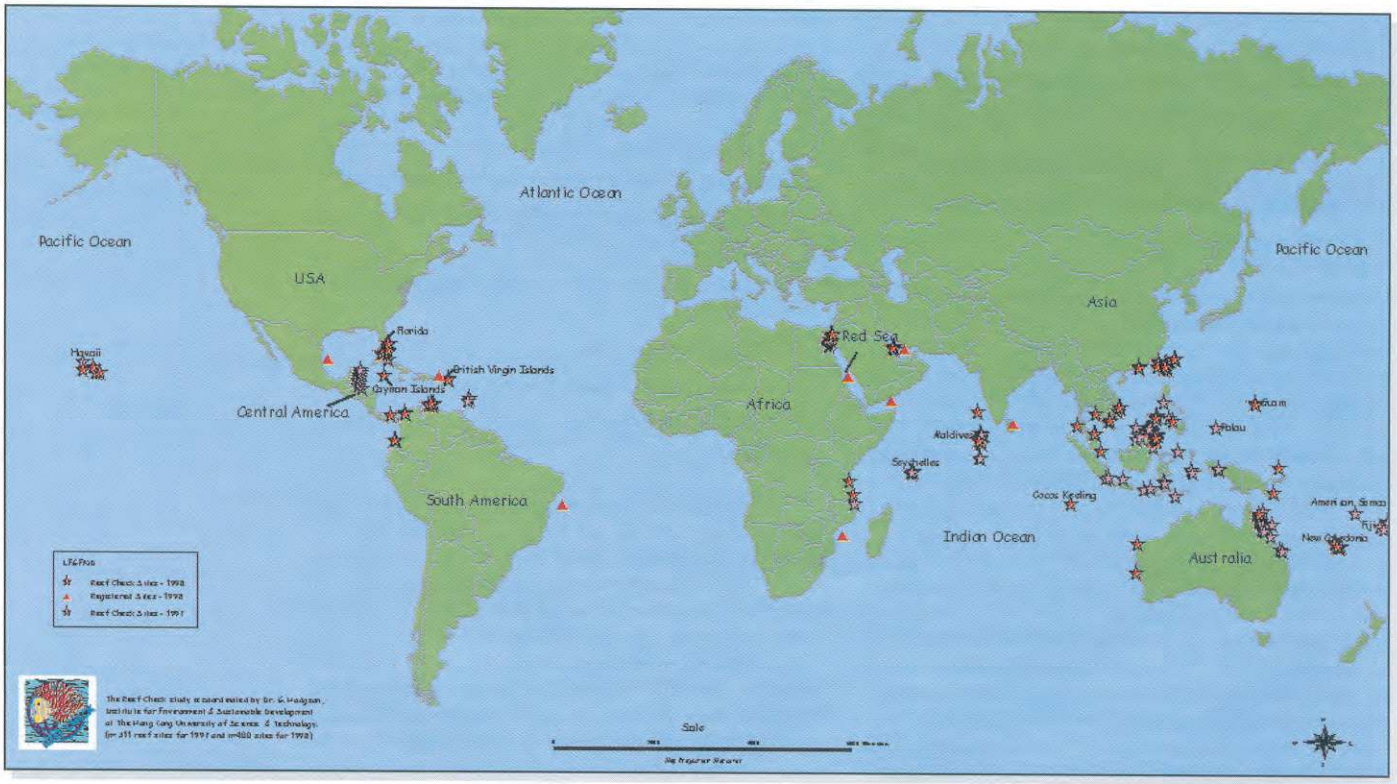
In the beginning, there were two major goals of Reef Check, and a third was added in 1999. The first goal is to raise public awareness about the value of coral reefs, problems facing their health, and solutions to these problems. This goal is quite broad and includes activities ranging from publicity events, press conferences, to training and education at all levels of government, through NGOs and the private sector. The second goal has been to obtain high quality scientific data on the health of coral reefs on a global scale. As the programme has evolved, a third goal has become increasingly important: that is to provide tools to coral reef managers that they need to manage their reefs. This latter goal is a community-based management objective; however, communities may be defined broadly to include a variety of stakeholders, not only local communities. Such stakeholders may include, for example, European recreational divers who travel to the Red Sea to dive on coral reefs with plentiful marine life, American surfers who might like to protect reefs in Fiji, and resort owners who would like to provide high quality dives for their guests.

METHODS

The framework for Reef Check methods was purposely modelled after existing methods such as English *et al.* (1997), to retain some comparability, but the methods include many unique features. One of the problems with most coral reef monitoring protocols is that they are too complicated to be taught to recreational divers and require a long training period (days to weeks). This is because they require taxonomic identification to the species level, a requirement that can only be met when teams of specialists collaborate. Secondly, they were usually designed to measure a large number of parameters that may help to attain a more complete understanding of community ecology and relationships among organisms, but that are not particularly helpful for gaining a rapid assessment of coral reef health. Reef Check methods were designed to collect the minimum information needed to judge coral reef health and to meet the following goals:

- Designed to be carried out by teams of experienced recreational divers trained and led by a scientist
- Since all participants would be volunteers, the training and survey must be fun, but produce reliable, statistically comparable results
- Require only a short training (usually <1 day), and survey period (one reef per day)

Figure 3
Map of 1998 Reef Check survey sites



- Based on counting rather than measuring organisms to allow use by snorklers in shallow water
- Reef health defined by abundance of Key Indicator organisms chosen for ecological role, sensitivity to human impacts, desirability for human consumption, market value and ease of identification (e.g. distinctive shape and colour)
- Key indicators ideally should be global or at least regional in distribution (Indo-Pacific, Red Sea and Caribbean) to allow global and regional comparisons among reefs
- Taxonomy usually limited to family level except in cases of unique species
- Clearly defined procedures and quality assurance and control system
- Eco-holistic, including a variety of fish, invertebrates, plants and human impacts
- Produce results immediately useful to a reef manager.

Site selection is an important aspect of any survey. In 1997, survey teams were instructed to select the best reefs in terms of abundance of indicator organisms. Surveys of semi-exposed reefs with a sloping reef, as opposed to a steep drop-off, were requested. In later years, more different types of reefs have been included. To compare similar types of reefs during the data analysis phase, a site description form with over 30 parameters is used to differentiate them. Information is also requested on distance to nearest river, size of local human populations, and perceptions of human impacts – all extremely important for interpreting the results.

To simplify the data recording and reporting, and as part of the quality assurance and control system, automated spreadsheets were designed for recording all survey results. These are convenient to e-mail to teams. The spreadsheet design includes codes for parameters such as 'HC' for hard coral. If an incorrect code is entered, an error symbol is displayed. In addition, some simple equations were embedded in the spreadsheets (macros) to automatically calculate such results as column totals so that the data entry person could immediately determine if an incorrect number of entries was recorded.

The methods involve surveys carried out along 100 m lengths of reef at two depths: 3-5 m and 6-12 m. The only equipment required is transect lines and an underwater writing slate (teams are encouraged to document their transects with still and video photography). Each 100 m transect is divided into four 20 m replicate sections with 5 m intervals so that there is sufficient data to obtain a mean and standard deviation for each transect. Three surveys are carried out along each transect: a fish, invertebrate and substrate survey. In practice, the same single transect line is used for all three surveys, one after the other. The fish and invertebrate surveys use 5 m wide belts along the four sections, while the substrate survey involves point sampling at 0.5 m intervals along the line transect. The sample size for one complete survey (at two depths) is thus 800 m^2 each for the fish and invertebrate belt transects, plus 320 point samples along 160 m of line transect for the substrate survey. Given the low taxonomic specificity and low number of parameters recorded, the sample size is relatively large and typically yields a statistically robust sample size even in highly biodiverse environments.

The list of indicator organisms (Table 1) includes organisms whose abundance varies in response to human impacts of various types including overfishing, blast and poison fishing, collection for the aquarium trade, organic pollution (nutrification), and collection for the curio trade. It is desirable to retain maximum comparability through the use of the same indicators in as many locations as possible; however, the fact is that each indicator organism is not found everywhere, even within a region. Thus the list has been adjusted

Table 1. Reef Check Indicator organisms for Overfishing (OF), Dynamite Fishing (DF), Cyanide Fishing (CF), Aquarium Fish Fishing (AF), Organic Pollution (OP) and Curio Collection (CC)

ORGANISM	INDICATOR FOR					
	OF	DF	CF	AF	OP	CC
GLOBAL						
Lobster	x					
Grouper (>30 cm)	x	x	x			
Fleshy algae		x				
Hard coral				x	x	
Dead coral					x	x
Recently broken coral		x				
Sponge					x	
Banded coral shrimp				x		
Long-spined black sea urchins	x				x	
Butterfly fish	x		x	x		
Sweetlips	x	x	x	x		
Snapper	x	x				
Trash (describe type and size)						
INDO-PACIFIC ONLY						
Barrimundi cod	x	x	x	x		
Humphead wrasse	x	x	x			
Bumphead parrotfish	x	x	x			
Giant clams		x				x
Edible holothurians (2 species)		x				
Crown of thorns starfish						?
Triton shell						x
Pencil urchin Heterocentrotus						x
CARIBBEAN ONLY						
Nassau Grouper	x					
Parrotfish (>20 cm)	x					
Pencil urchin						x
Triton shell						
Flamingo tongue						x
Gorgonians (sea fan, sea whip)					x	x

to meet the needs of biogeographically unique locations. Special lists with replacement indicators have been developed in such locations as Hawaii, the Galapagos and the Arabian Gulf. To aid quality assurance, team leaders were able to download identification photos of all indicator organisms, laminate and carry them underwater.

RESULTS

In 1997, the first global survey of coral reefs was carried out by teams of recreational divers trained and led by marine scientists during the period between 14 June and 31 August at 315 reef sites in 31 countries and territories spread around the world. It is important to recognise that this survey, which included more than three

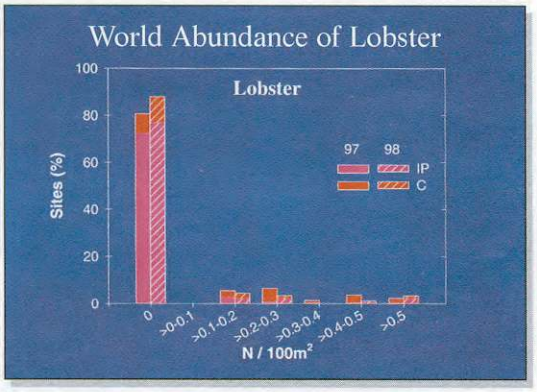


Figure 4a
Percentage of sites divided among seven lobster abundance classes normalised to number of lobster per 100 m² of reef. Zero lobster were recorded at over 80% of sites in both 1997 and 98. IP = Indopacific, C = Caribbean

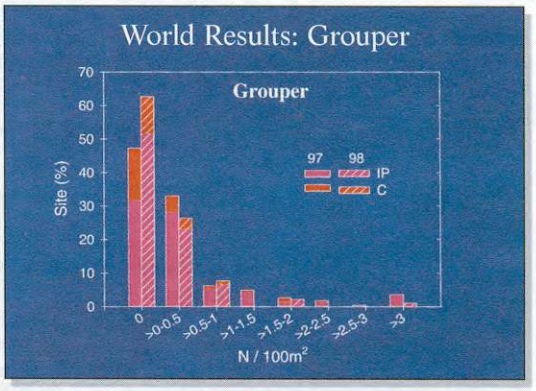


Figure 4b
Percentage of sites divided among eight grouper abundance classes normalised to number of grouper per 100 m² was recorded at about 90% of the sites.

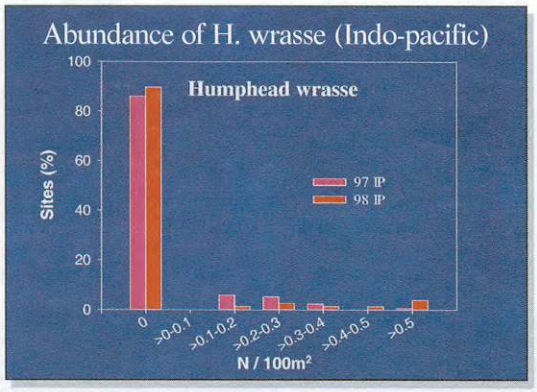


Figure 4c
Percentage of sites divided among seven humphead wrasse abundance classes normalised to number of fish per 100 m² of reef. Zero fish per 100 m² of reef were recorded at over 80% of sites in both 1997 and 98

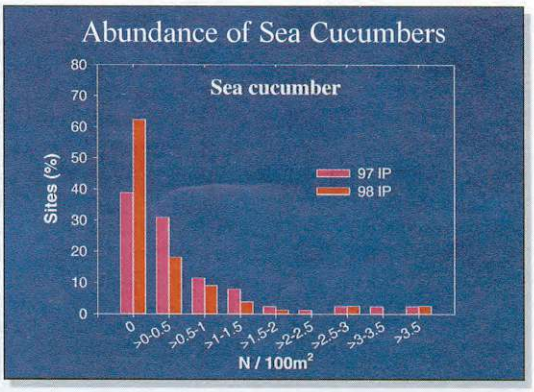


Figure 4d
Percentage of sites divided among nine sea cucumber abundance classes normalised to number of animals per 100 m² of reef. Less than one animal per 100 m² of reef was recorded at over 80% of sites in both 1997 and 98

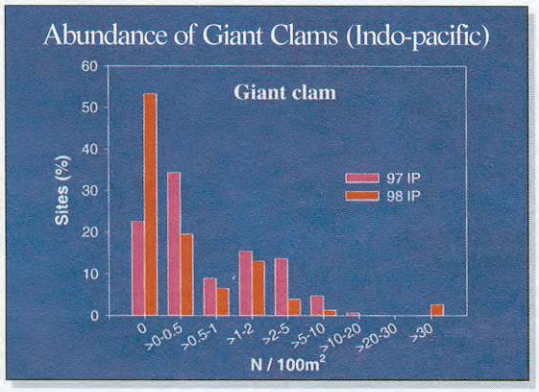


Figure 4e
Percentage of sites divided among nine giant clam abundance classes normalised to number of clams per 100 m² of reef. Low numbers of clams were recorded at most sites in both 1997 and 98; however, several hundred small clams were recorded at some sites

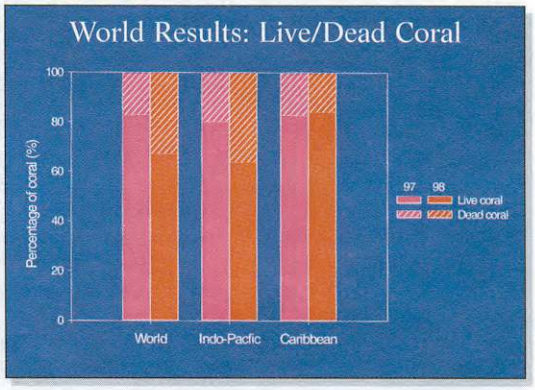


Figure 4f
The percentage of total coral cover that was alive and dead. The increase in dead coral in 1998 was mainly caused by losses due to global bleaching which severely affected the Indian Ocean

times the target number of reefs, was attained without any funding. Each team was responsible for funding its own operations. The survey was repeated during an extended 6-month survey period in 1998 (Figure 3). In 1999, the programme was opened to year-round activity and the number of countries increased to 50, while the survey sites exceeded 500.

The first year's results were a shocking indictment of overfishing as the major impact on coral reefs (Hodgson, 1999). Unfortunately, these initial findings have been confirmed by subsequent surveys. On most reefs, many of the indicator organisms were simply missing: zero lobster, grouper, giant clams etc. (Figures 4a-e). No reefs showed high numbers of most indicator organisms, suggesting that few if any reefs had been unaffected by fishing and gathering. None of the reefs could be considered pristine. Even reefs within Marine Protected Areas showed low numbers of indicators, suggesting that many of these were 'paper parks' with little effective management (Hodgson, 1992).

In addition to reconfirming the 1997 results on overfishing, the 1998 survey demonstrated the value of regular monitoring by an international network of teams using one standard method. This is because a global coral reef bleaching and mortality event occurred in 1998 that was unprecedented in severity, geographic extent and water depth where reefs were damaged. When corals are stressed by high temperature, ultraviolet light or other environmental changes, they lose their symbiotic algal cells, and appear white (the white skeleton is actually visible through the transparent tissue). Depending on the intensity and duration of the stress, the corals may recover or die. 1998 was an El Niño year and the hottest since 1860 when records were first kept.

Bleaching began in the Indian Ocean and the South Pacific in January, and then followed the sun. Beginning in July, during the northern hemisphere summer, bleaching affected Southeast Asia, the Arabian Gulf, Red Sea and the northern Caribbean (Wilkinson, 1998). Although some Reef Check surveys were carried out before the sea temperature rose in each of these areas, 30% of survey sites reported some bleaching, with high mortality in the Indian Ocean and parts of Asia (Wilkinson *et al.*, 1999). Up to 90% of shallow water corals were killed in parts of the Indian Ocean, and high mortalities were recorded down to -40 m. The severity of the event was shown by the death of corals up to 1000 years old in several parts of the world including Vietnam and the Great Barrier Reef. The 1999 survey results are expected to show the final tally of destruction from this dramatic forecast of the effects of future global warming. From an ecological standpoint, it appears that coral reefs are a sensitive indicator of global warming. An important political outcome of this event is that coral reefs are now part of the global climate change debate.

EDUCATION AND PUBLICITY

In addition to producing useful scientific results, the programme was successful in achieving its second goal of raising public awareness about coral reefs. In fact, for some scientists who do not accept the fact that volunteers can reliably survey reefs, this is the most valuable achievement. This was carried out in two ways. First, an international press conference was held each year, followed by national press conferences. Media coverage was given by all of the major international television networks including BBC, CNBC and CNN as well as national networks such as NHK (Japan), CCTV (China), NBC (USA), ZDF (Germany). Print media coverage was

Figure 5
In the Arabian Gulf reefs are less well developed than in Australia and experience large variations in temperature and salinity. A RC diver records fish as he swims along the 100 m belt transept (photo Roger Uwate)

Figure 6
Coral reefs in southern Japan are exposed to many pressures. Japan RC coordinator records invertebrates along a belt transept

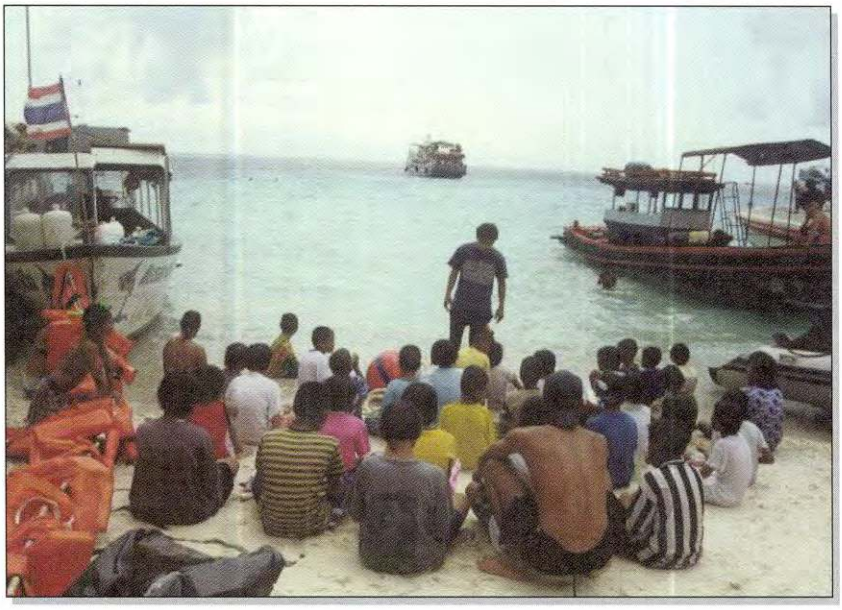


Figure 7
RC Coordinator Anne Miller began a reef education programme called Reef-World (www.reef-world.com). Here in Thailand, a local RC trainer teaches children about reef ecology

extensive, and often front-page in dozens of languages. Individual teams contributed photos and video which were distributed to the press. Local television stations filmed documentaries of activities in many locations including Hong Kong, Belize, Indonesia and the Red Sea. As these activities progressed, they were further spread and amplified by posting of monthly updates of activities through the coral list-server and on the website. One goal that has so far eluded Reef Check is the filming of a feature-length documentary for international distribution.

PROVIDING TOOLS FOR CORAL REEF MANAGEMENT

The third goal of the programme was added in 1999 when it became clear that there was a large and growing demand for Reef Check to be used for more than just a single annual survey of reef health. There is a fundamental need to give communities a complete set of tools and training so that they can manage their own reefs. Progress towards making Reef Check available through existing coastal management and coral reef programmes has been rapid, but far more work is needed to expand the network and provide the training needed to use the tools.

The first step was to make some technical changes to adapt the Reef Check methods to the new objective of long-term monitoring that would best serve local coral reef management needs. Guidelines on necessary additions of spatial and temporal replicates were published on the web in 1999 (Hodgson and Stepath, 1999). These changes are especially important for monitoring the highly mobile fish populations. The second step was to make use of existing programmes to spread Reef Check to communities around the world.

In 1998, the Global Coral Reef Monitoring Network (GCRMN) chose the Reef Check protocols to serve as that programme's community-based monitoring methods. GCRMN is sponsored by the United Nations International Oceanographic Commission and several countries. By linking the two programmes under the International Coral Reef Initiative umbrella, a complementary partnership was formed wherein GCRMN could focus on working with government agencies while Reef Check could target NGOs. In practice, this means that the network of national coordinators is shared, and all GCRMN training starts with Reef Check methods and proceeds to more detailed methods of use to highly trained government technical teams. In the future, it is envisaged that each coral reef country will have a large number of Reef Check sites, monitored by local residents as well as other stakeholders, with smaller numbers of sites monitored in more taxonomic detail by government teams. The Reef Check sites thus act as an early warning system.

Several existing bilateral coastal management projects and numerous government agencies and non-governmental organisations have started to incorporate Reef Check into their monitoring and management work. This process of institutionalisation of Reef Check has occurred with the help of the United Nations Environmental Programme, UN Seacoast Training Project, UNESCO, World Bank, US Agency for International Development, US NOAA and numerous non-governmental organisations such as Worldwide Fund for Nature, the Coral Reef Alliance, Coral Caye, Reefkeeper, CANARI, Frontier and many others.

DISCUSSION

The 1997 survey was designed to be biased to include many sites in good condition, and most were located far from cities and pollution sources. The low percentage cover of pollution indicators (sponges and fleshy algae) suggested that sewage pollution was not a serious problem at most of these sites. Taken together with the conclusions on overfishing, these results indicated that previous views regarding human impacts on reefs on a global scale (Johannes, 1975) may be outdated, or may have unduly emphasised the importance of pollution in comparison to overfishing. This is a logical conclusion because most of the world's reefs are not located near cities, therefore sewage and industrial pollution are unlikely to have major impacts on most reefs. In contrast, as nearshore fisheries have declined around the world, long-distance fishing fleets have been built and dispatched to far corners of the world. The impacts of overfishing of key fish species are now known to change the entire structure of reef communities, in some cases leading to a physical breakdown of the reef (McClanahan, 1995; Roberts, 1995; McClanahan *et al.*, 1996).

The scientific results highlighted the importance of the 'shifting baseline syndrome' (Sheppard, 1995). There are few quantitative data describing what populations of reef organisms were like several hundred years ago, before widespread fishing. In general, changes that occur over a human life span are recognised, and reported at least anecdotally, by fisherman or divers. But when changes have occurred long ago, or slowly over several hundred years, it is difficult to guess what the 'pristine baseline' may have been like. Terrestrial examples of this phenomenon are common and familiar. Jackson (1997) has documented how overfishing led to diminished fish populations in Jamaica over 100 years ago and he suggests that this situation is common. In addition, he believes that no truly pristine reefs remain because, in addition to widespread fishing, populations of large herbivores such as turtles, dugongs and manatees, which would strongly influence coral reef ecology, were historically much higher than they are today. The biological explanation for why it is so easy to fish out coral reefs has been given by Birkeland (1997), who has recommended that no commercial harvesting for export be allowed on any reefs.

Reef Check results have been provided freely to various organisations involved in documenting and assessing changes to coral reefs. These include the International Center for Living Aquatic Resources' ReefBase which is the largest and best developed database on coral reefs. Reef Check results were also used to help build the Reefs at Risk assessment of threats to coral reefs from various sources around the world (Bryant *et al.*, 1998). This model is now being refined to provide a regional assessment of risk.

The recent bad news from coral reef monitoring has caused some to question why additional monitoring is needed when it is clear that reefs are in trouble. A permanent commitment to a global monitoring network is extremely important for the following reasons:

- To check the status of remote sites that can guide management goals
- To record variation in trends of key parameters so as to be able to assess the statistical and ecological significance of future changes
- To assess the effectiveness of management measures
- To assess regional and global changes such as bleaching and diseases.

The Reef Check programme appears to be working to achieve the goals of education and raising public awareness, and is starting to make progress with providing the

tools for community-based management of coral reefs. As more teams are added and the numbers of sites increase, the value of the programme for management will increase tremendously.

CONCLUSIONS

Several important lessons have been learned from implementing Reef Check. One of the most important is the power of the internet as a tool in ecological research. By 1996, astrophysicists and geneticists had been collaborating on the internet for years, but few ecologists had made use of this important tool to gather data. Hundreds of people were attracted to the Reef Check programme through rather modest free advertising on a small scientific list-server and a website. An estimated US$2 million worth of work was carried out on a volunteer basis.

Another important lesson is that it is possible to motivate people to carry out a great deal of difficult volunteer work in fund-raising, organising, training and surveys if they feel it is fun, useful to them and helps coral reefs. Therefore the volunteer aspect of Reef Check appears to have been a key factor in its success. If the programme had been designed to pay people to survey reefs, the surveys would have stopped when the funds ran out.

While no formal surveys have been taken, it appears that people who participate in the programme become strong supporters of sustainable management of coral reefs. By developing a political constituency, the programme helps to build support for existing and future government management programmes.

As with any new idea, scepticism was initially expressed by some scientists regarding the value of a programme like Reef Check that uses non-scientists to collect data. As time has passed, increasing numbers of doubters have joined the hundreds of volunteer scientists who have participated, and given their time and expertise to support the work. Many have commented that they have gained a great deal from the experience of acting as team scientists. Through the process of leading the training and surveys, they can directly experience their value to the community just by answering questions on coral reef ecology posed by a diverse audience that may include doctors, engineers and businessmen, as well as students. Scientists have also realised that this is an excellent method of increasing public appreciation and support for funding of scientific research.

Monitoring and management have costs, and neither developing nor developed country governments will ever be willing to commit resources to fund large monitoring networks using detailed methods typically employed in academic ecological research. Therefore, to be successful in implementing much-needed coral reef monitoring and management networks, cost-effectiveness is critical. In places where coral reef monitoring has been tested and established, a model is emerging that works well in both developing and developed countries. This model involves a tiered design with at least two monitoring layers: a Reef Check-like programme that relies on volunteers from the community and a more intensive programme (more detailed taxonomy and more parameters). In practice, the Reef Check programme can act as an early-warning system that guides more detailed surveys by scientific or technical teams. For example, if an anomaly is detected at a reef site, one management action might be to require a follow-up survey by the scientific team. The combination of the two tiers provides a cost-effective mix of monitoring strategies that can meet the needs of managers.

Most coral reefs are located in developing countries. Few are in a position to design and implement national coral reef monitoring and management plans. A great deal of technical and financial assistance will be needed to implement these critically important programmes. Despite the dramatic nature of the coral reef crisis that threatens the health and lives of millions of people, the development agencies, particularly the Global Environmental Facility (GEF), have so far been unable to break away from their traditional mode of country-by-country, project-by-project operation. What is desperately needed is a change in thinking at GEF, and a commitment to a multi-year, multi-million dollar, global support programme for coral reef monitoring and management. By using the existing GCRMN/Reef Check network of government and NGO coordinators, huge cost-savings can be achieved.

Monitoring programmes have been, and are still being, designed primarily by academic scientists, with little input from managers, and without respect to a management plan. Such plans are likely to produce a lot of data of great interest to scientists, but of little use to managers. Monitoring programmes should be developed adaptively, in the context of serving management needs that will change with time. Therefore, Reef Check methods should retain flexibility. While it is important that the core methods retain stability, users are encouraged to add indicator organisms and other parameters so that the methods can be matched to local management needs. This also allows local teams to find a proper balance between asking too much of volunteers, and allowing them to become bored due to typically low numbers of indicator organisms recorded during surveys.

Coral reef management involves managing both coral reefs and people, and the problems facing coral reefs are generally the same everywhere in the world; overfishing, sewage, industrial pollution and sedimentation. The solutions are similar, and so can easily be disseminated in generic form via the internet, but will need to be adapted to match the local conditions in each area. In the future, additional effort will be devoted to developing a web-based management system. A deficiency in the current programme is that feedback on the meaning of the results from a national, regional or global perspective is slow in coming. A web-based system will be devised that allows users to compare their results with those obtained from other reefs in the region as well as in previous years. This instant feedback should serve as positive reinforcement to teams. In addition, the system will include a series of management guidelines with optional actions that might be taken to respond to problems detected by the current survey. The system should be both educational and of practical use to managers, particularly those far from sources of advice.

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ABOUT THE AUTHOR

Gregor Hodgson had already studied sharks and sea lions when he graduated from the University of California. He spent three years with the Peace Corps studying coral reefs in the Philippines under coral biologist Professor Francisco Nemenzo. This was followed by his PhD. study on the effects of sedimentation on corals at the University of Hawaii. After two years as Assistant Editor of *Asia Technology* for Dow Jones in Hong Kong, he joined the International Center for Living Aquatic Resources Management, in Manila, to help write coastal management plans for several SE Asian sites. At the start of the huge airport and port development project in Hong Kong in 1991 he joined the UK engineering firm, Binnie Consultants, to design and carry out one of the most intensive marine monitoring projects ever attempted, focused on protecting valuable marine life from the world's largest dredging operation. In 1996, he joined the Institute for Environment and Sustainable Development at Hong Kong's University of Science and Technology to help develop proposals and carry out integrated coastal management projects throughout SE Asia. He also began the global survey of coral reefs.

IF YOU HAVE ANY ENQUIRIES REGARDING THE CONTENT OF THIS ARTICLE, PLEASE CONTACT:

Gregor Hodgson
Reef Check Global Survey Programme
GPO Box 12375
Hong Kong

Fax: +852 2887 5454
E-mail: gregorh@pacific.net.hk
Web site: www.reefcheck.org