Coral Reef Education, Monitoring and Management Using Reef Check

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Abstract

Government resources available for coral reef education, monitoring and management will never be sufficient for the task in any country. A cost-effective method of increasing resources is to use community-members to help. Involving the community in the process increases public support for reef science and government management initiatives, increasing compliance and reducing law enforcement costs. The Reef Check program 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 1000 reefs in more than 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 increases, the value of Reef Check as a management tool will rise.

Introduction

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

In short, science "as usual" was not adequate to track the rapid changes apparently taking place on far-flung reefs around the world. 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. In 1996, I designed a set of survey methods and these became the basis for the monitoring program called Reef Check.

There are three goals to Reef Check: education, monitoring and management. The education goal is achieved by providing training to government staff, the private sector and NGOs in coral reef ecology and monitoring, as well as through publicity events such as press conferences, beach clean-ups and group "dive-ins." Public awareness is raised about the value of coral reefs, problems facing their health, and solutions to these problems. The second goal has been to obtain high quality scientific data on the health of coral reefs on a global scale. As the program has evolved, a third goal has become increasingly important: that is to provide coral reef managers with the tools needed to manage reefs. For Reef Check, stakeholders include any community with an interest in coral reef conservation, not only those communities located near reefs. Therefore the implementation of community-based monitoring and management through Reef Check may involve diverse stakeholders such as, European recreational divers who travel to the Red Sea, American surfers who enjoy snorkeling on Fijian reefs, and dive resort owners who would like to provide high quality dives for their guests. In summary, the Reef Check network has been designed to provide a two-way flow of information -- data collected by teams around the world and sent to a central processing facility, and education and interpretation distributed to the teams from the center.

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)
- 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 color)
- Key indicators ideally should be global and 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 reef slope, 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 email 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 are 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 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.

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 - estimate area		x				
Sponge					x	
Banded coral shrimp *Stenopus hispidus*				x		
Long-spined black sea urchins *Diadema spp*.	x				x	
Butterfly fish	x		x	x		
Sweetlips – Haemulidae	x	x	x	x		
Snapper -- Lutjanidae	x	x				
Trash (describe type and size)						
Indo-pacific only						
Barrimundi cod *Cromileptes altivelis*	x	x	x	x		
Humphead wrasse *Cheilinus undulatus*	x	x	x			
Bumphead parrotfish *Bolbometopon muricatum*	x	x	x			
Giant clams *Tridacna* spp	x					x
Edible holothurians (2 species)	x					
Crown of thorns starfish *Acanthaster planci*					?	
Triton shell *Charonia tritonis*						x
Pencil urchin *Heterocentrotus mammilatus*						x
Caribbean only						
Nassau Grouper *Epinephalus striatus*	x					
Parrotfish (>20 cm)	x					
Pencil urchin *Eucidaris spp.*						x
Triton shell *Charonia variegata*						
Flamingo tongue *Cyphoma gibbosum*						x
Gorgonians (sea fan, sea whip)					x	x

Results

Science

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 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 (Fig. 1). In 1999, the program was opened to year-around activity and the number of countries increased to 50 while the survey sites exceeded 500 (Hodgson, 2000). At the time of writing, several additional island nations have joined Reef Check 2000.

The first year's results provided clear evidence of widespread overfishing as the major impact on coral reefs (Hodgson, 1999). Unfortunately, these initial finding have been reconfirmed by subsequent surveys. On most reefs, most high value indicator organisms were simply missing: zero lobster, grouper, giant clams etc. (Fig. 2). 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 the global coral reef bleaching and mortality event in 1998 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 Sotheast 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 showed a 15% global loss of living coral cover as the final tally of destruction from this dramatic forecast of the effects of predicted increasing 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 program was successful in achieving its second goal of raising public awareness about coral reefs. In fact, for the minority of 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 RTK (Japan), CTV (China), NBC (USA), GBF (Germany). Print media coverage was extensive, and often front-page in dozens of languages with major stories in publications such as *USA Today*, *The Independent* (London), *Le Figaro* (France), and *Sydney Morning Herald* (Australia). Individual teams contributed photos and video that 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.

Providing tools for coral reef management

The third goal of the program 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 programs 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 fish populations which are so mobile. The second step was to make use of existing programs 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 program's community-based monitoring methods. GCRMN is sponsored by the United Nations International Oceanographic Commission and several countries. By linking the two programs under the International Coral Reef Initiative umbrella, a complementary partnership was formed wherein GCMRN 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, UNDP 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 emphasized 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 recognized, 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 recommended that no commercial harvesting for export be allowed on any reefs.

Reef Check results have been provided freely to various organizations 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 in Southeast Asia.

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 program 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 increases, the value of the program 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 program through rather modest free advertising on a small scientific list-server and a website. An estimated US$2 million worth of work has been carried out each year on a volunteer basis.

Another important lesson is that there are motivated people who care about coral reefs throughout the world. They are willing 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 program had been designed to pay people to survey reefs, the surveys would stop when the funds ran out

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

As with any new idea, skepticism was initially expressed by some scientists regarding the value of a program 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 e.g. answering questions on coral reef ecology posed by a diverse audience that may include doctors, engineers, 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 program that relies on volunteers from the community and a more intensive program (more detailed taxonomy and more parameters). In practice, the Reef Check program 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 programs. 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. Despite the fact that Reef Check has shown that even without funding, a global program can be carried out, the agencies are locked into a "pre-internet" mode of project development. What is desperately needed is a change in thinking at GEF, and a commitment to a multi-year, multi-million dollar, global support program for coral reef education, monitoring and management. By using the existing GCRMN/Reef Check network of government and NGO coordinators, huge cost-savings can be achieved because most of the work is carried out by volunteers.

It is now time that each coral reef country should design a national coral reef monitoring program. Up to now, monitoring programs have been designed primarily by academic scientists, with little input from managers, and without respect to a management plan. Such programs are likely to produce a lot of data of great interest to scientists, but of little use to managers. Monitoring programs 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 program 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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Illustrations:

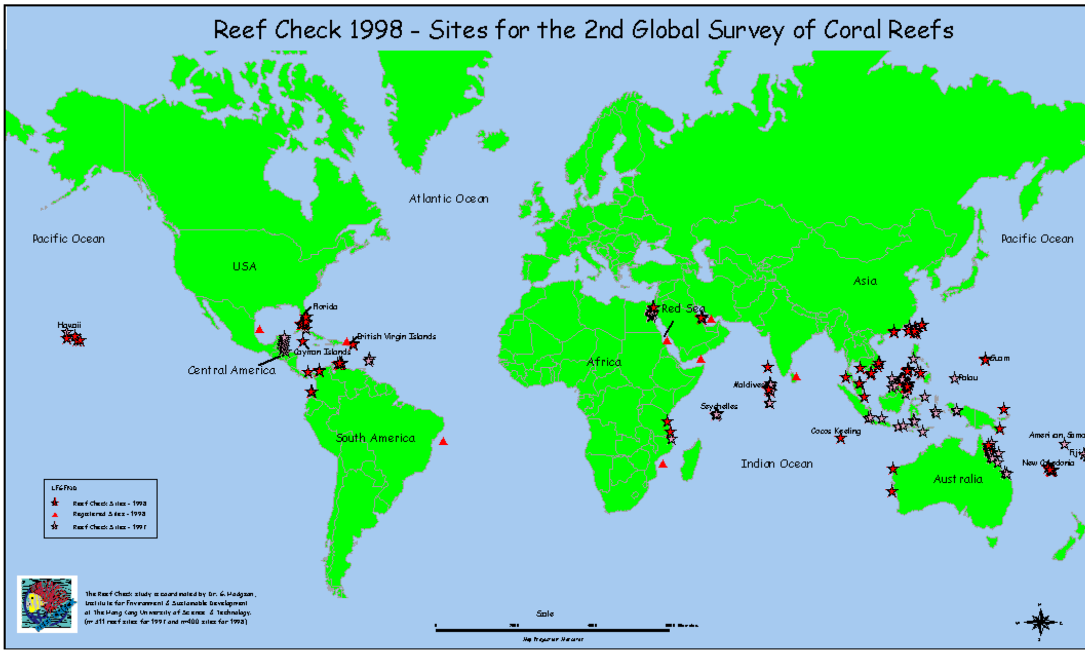

Fig. 1 Map of 1999 Reef Check survey sites.

Fig 2a. Percentage of sites divided among seven lobster abundance classes normalized to number of lobster per 100 m^2 of reef. Zero lobster were recorded at over 80% of sites in 1997 - 99. IP = Indopacific, C = Caribbean.

2b. Percentage of sites divided among eight grouper abundance classes normalized to number of fish per 100 m^2 of reef. Less than one grouper 100 m^2 of reef was recorded at over 90% of sites in both 1997 - 99. IP = Indopacific, C = Caribbean.

2c. Percentage of sites divided among nine sea cucumber abundance classes normalized to number of animals per 100 m^2 of reef. Less than one animal per 100 m^2 of reef was recorded at over 80% of sites in 1997 - 99.

2d. Percentage of sites divided among seven humphead wrasse abundance classes normalized to number of fish per 100 m^2 of reef. Zero fish per 100 m^2 of reef was recorded at over 80% of sites in 1997 - 99.

2e. Percentage of sites divided among nine giant clam abundance classes normalized to number of clams per 100 m^2 of reef. Low numbers of clams were recorded at most sites in 1997 - 99, however, several hundred small clams were recorded at some sites.

2f. 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.