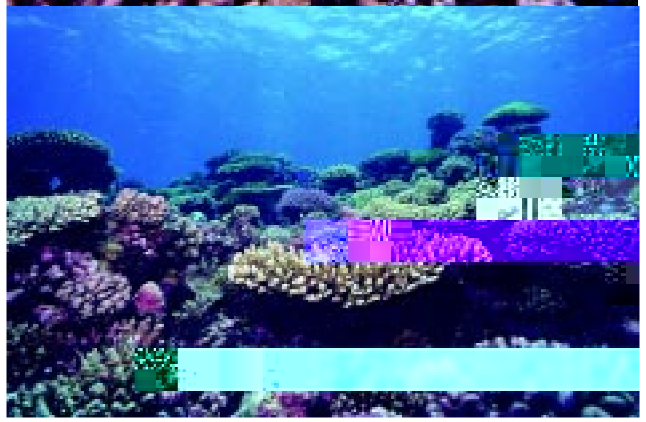

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As a Union, IUCN seeks to influence, encourage and assist societies throughout the world to conserve the integrity and diversity of nature and to ensure that any use of natural resources is equitable and ecologically sustainable.

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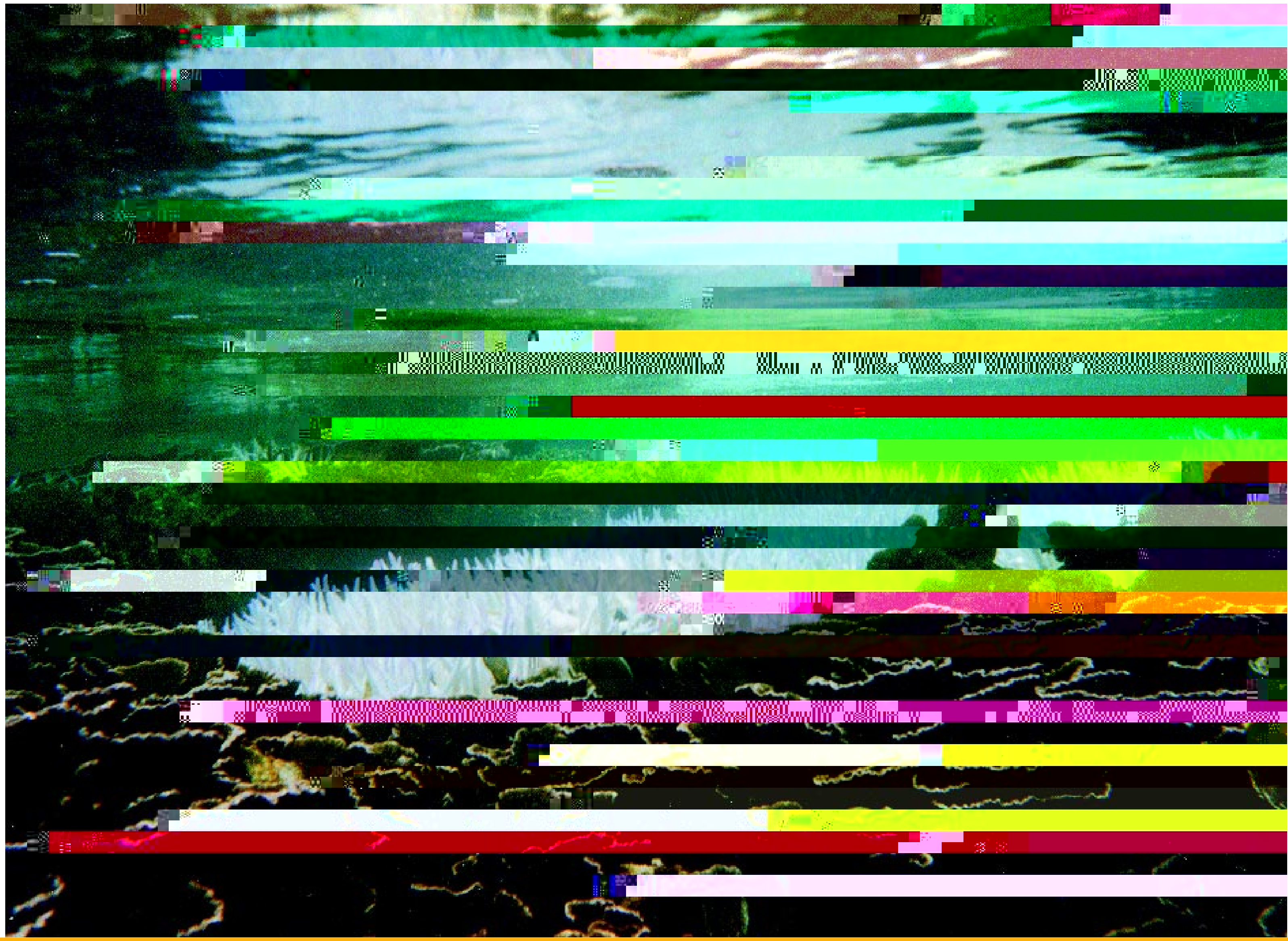
# Management of Bleached and Severely Damaged Coral Reefs

Susie Westmacott, Kristian Teleki, Sue Wells and Jordan West



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## General information on organizations

***The Convention on Biological Diversity*** is an international legally-binding agreement that was opened for signature at the Earth Summit in Rio de Janeiro in 1992 and entered into force in 1993. It is the only global treaty that addresses the three levels of biological diversity: genetic resources, species and ecosystems. It is also the first to recognize that conservation of biological diversity is a common concern of humankind, that investments in conserving biodiversity will result in environmental, economic and social benefits, and that economic and social development and poverty eradication are priority tasks.

The Convention is thus a key component of the commitment by the countries of the world to implement sustainable development policies. Its triple objectives are to conserve biological diversity, to use the components of biological diversity in a sustainable way, and to share equitably the benefits arising out of the use of genetic resources.

Over 175 countries and the European Community have ratified the Convention. They have committed themselves to developing national biodiversity strategies and action plans and to integrating the conservation and sustainable use of biodiversity into decision-making across all economic sectors.

***The U.S. Agency for International Development (USAID)*** is the U.S. government agency responsible for worldwide humanitarian and development assistance. USAID's programs foster sustainable development, provide economic assistance, build human capacity and democratic governance, and provide foreign disaster assistance. Environment programs are committed to improving conservation of significant ecosystems, reducing the threat of global climate change, and promoting sustainable natural resource management. For more information, visit http://www.usaid.gov. This publication was made possible through support provided by the Global Environment Center of USAID. The opinions expressed herein are those of the authors and do not necessarily reflect the views of USAID.

***WWF, the World Wide Fund for Nature***, is a large and experienced independent conservation organization, with 4.7 million supporters and a global network active in 96 countries. WWF is known as World Wildlife Fund in Canada and the United States of America.

The goals of WWF’s marine conservation programme are:

- To maintain the biodiversity and ecological processes of marine and coastal ecosystems
- To ensure that any use of marine resources is both sustainable and equitable
- To restore marine and coastal ecosystems where their functioning has been impaired.

WWF has recently established the CoralWeb initiative ”Coral Reef Ecosystems in Action” in order to conserve the world’s outstanding coral ecosystems and their biodiversity. CoralWeb addresses the crisis that faces coral reefs from an ecoregion perspective, and will take ecological, economic, social and policy factors into account.

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# Contents

# Acknowledgements

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The first draft of the text was sent to a wide audience for review and their comments have as far as possible been incorporated into this final version. Their comments were not only useful and greatly appreciated, but provided us with a broader vision for transmitting our message. Our thanks go in particular to the following reviewers: Riaz Aumeeruddy, Barbara Best, Martin Callow, Julie Church, Herman Cesar, Stephen Colwell, Helen Fox, Patty Glick, Edmund Green, Thomas Heeger, Gregor Hodgson, Irene Kamau, Olof Lindén, Tim McClanahan, Rolph Payet, Arthur Paterson, Lida Pet Soede, Rod Salm, Lothar Schillak, Charles Sheppard, Paul Siegel, Mark Spalding, Al Strong, Alan White. Our thanks also go to Jean Pascal Quod, Arjan Rajasuriya and Thomas Heeger for providing us with additional photos, Virginia Westmacott for the illustrations, Jeffrey Maganya, Amina Abdallah and the staff at IUCN-EARO and the staff at the Cambridge Coastal Research Unit who assisted with administration and logistics.

# List of Acronyms

| | |
|---|---|
| CBD | Convention on Biological Diversity |
| CITES | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| COP | Conference of the Parties |
| CORDIO | Coral Reef Degradation in the Indian Ocean |
| EIA | Environmental impact assessment |
| GBR | Great Barrier Reef, Australia |
| GCRMN | Global Coral Reef Monitoring Network |
| ICM | Integrated Coastal Management |
| ICRI | International Coral Reef Initiative |
| IPCC | Intergovernmental Panel on Climate Change |
| MPA | Marine Protected Area |
| NGO | Non Governmental Organisation |
| SBSTTA | Subsidiary Body on Scientific, Technical and Technological Advice of the CBD |
| SIDA/SAREC | Swedish International Development Agency Research Programme |
| SST | Sea Surface Temperature |
| UNEP | United Nations Environment Programme |
| UNFCCC | United Nations Framework Convention on Climate Change |

# Foreword

Coral reefs are one of the most threatened ecosystems in the world. Rivalling terrestrial rainforests in their biological diversity, and providing major economic benefits from fisheries and tourism, coral reefs ecosystems are of global concern. In addition, reefs provide many vital functions in developing countries, especially in Small Island Developing States.

Until recently, stresses caused by human activities – such as land-based sources of pollution and destructive fishing practices – were considered to be the primary dangers to coral reefs. While these problems still persist, the last two decades have seen the emergence of yet another, potentially much greater threat. Coral reefs have been affected, with increasing incidence and severity, by *coral bleaching*, a

# Executive Summary

This booklet was produced to provide guidance for managers, policy makers and all those who are concerned about the severe reef degradation caused by coral bleaching and a range of other impacts.

Coral bleaching is caused by high sea surface temperatures and high levels of sunlight (UV), which affect the physiology of the coral and cause a whitening effect, or 'bleaching'. This loss of colour is due to the loss of symbiotic algae (*zooxanthellae*) upon which the coral polyp depends for much of its food. Prolonged bleaching conditions (for over 10 weeks) can eventually lead to death of the coral polyp.

Sustained high water temperatures (1–2$^{o}$C above normal maximums) during 1998 caused the most geographically extensive bleaching event ever recorded. The Indian Ocean was one of the worst affected regions, with coral death as high as 90% over large areas of reef. The Pacific and Caribbean regions were also affected, but they did not experience the same level of coral mortality.

Other human impacts continue to threaten the survival of coral reefs. Coastal development, poor land use practices, over exploitation of marine resources and destructive fishing methods — as well as waste disposal and pollution from ships — can all negatively affect the state of the reefs. Together, these impacts, especially when combined with increased coral bleaching, pose a serious threat to the survival of the world's coral reefs.

The Intergovernmental Panel on Climate Change (IPCC) has predicted an increase of 1–2°C in sea surface temperatures over the next 100 years, such that coral bleaching events will become a regular event in the next 30–50 years. Hence, the following types of management strategies will be crucial to safeguard coral reefs.

**1. Marine Protected Areas (MPAs)** will play a key role by helping to maintain sources of coral larvae to damaged areas. MPAs can also protect those areas where corals are struggling to recolonise damaged areas. Management actions in relation to MPAs, that will contribute to reef regeneration include:

- Identifying reef areas with least damage within MPAs and reviewing, and revising where necessary, zoning schemes and boundaries to ensure that healthy reefs are strictly protected.
- Ensuring that existing MPAs are effectively managed.
- Developing a more strategic approach to the establishment of MPA systems, including consideration of *sources* and *sinks* and inclusion of a wide geographic spread and variety of MPA types.

**2. Reef fisheries** may be negatively affected on reefs that have suffered major mortality and are losing their physical structure (and thus unable to support a diverse and abundant fish community). A precautionary approach can be taken by giving specific attention to the following:

- Establishing no-fishing zones and limitations on fishing gear to protect breeding grounds and provide fish with a refuge.
- Considering specific protection measures for species that can contribute to reef regeneration, such as algal grazers, or that might be affected by coral bleaching, such as coral-eating fishes.
- Enforcing legislation prohibiting destructive fishing practices.
- Monitoring the catch composition and size to evaluate the success of management strategies and implementing new strategies if necessary.
- Developing alternative livelihoods for fishing communities as needed.

Monitoring will enable the managers and policy makers to track changes on the reef and assess the success of management programmes. Care must be taken to design a programme that fits within the personnel and financial capacity available. In many cases, there are existing programmes that can be adopted. Meanwhile, additional research is urgently needed so we can more fully answer key questions about the ecological and socio-economic impacts of coral bleaching.

Managers can prepare for bleaching events and even aid reef recovery, but the global community needs to act now to tackle the issue of global climate change. Action at all levels from local communities and stakeholders to national governments and decision makers is required immediately to address not only the issues related to coral bleaching, but also the general state and plight of coral reefs everywhere.

This booklet provides guidance for managers, policy makers and all those whose lives are tightly connected with the well being of coral reefs and who are deeply concerned about reef degradation caused by bleaching and a range of other impacts. Coral reefs are among the most important marine ecosystems, providing food, serving as habitat for other commercial species, supporting the tourist industry, supplying sand for beaches, and acting as barriers against wave action and coastal erosion. Ironically, the worst bleaching has taken place in countries with the least capacity and resources to address it, and with the greatest need for healthy reefs as a

Photo: Susie Westmacott

**Reef in the Maldives, Indian Ocean, prior to 1998 coral bleaching event.**

event in the Indian Ocean as a case study, we examine this phenomenon within the context of other sources of reef degradation in order to provide guidance for managers and stakeholders. We also review the latest research and current scientific opinion on the predicted trends in and outcomes of coral bleaching. Drawing on this information, the booklet suggests precautionary measures to be taken to minimise the impact of future bleaching events and makes suggestions for positive actions that may aid reef recovery. Some of this research is still in its infancy, so careful consideration must be given to which strategies will be most effective for addressing particular issues at a given location. Managers are encouraged to make use of the information and the additional resources presented here to formulate a response appropriate to their specific circumstances.

# Coral Bleaching

## What is coral bleaching?

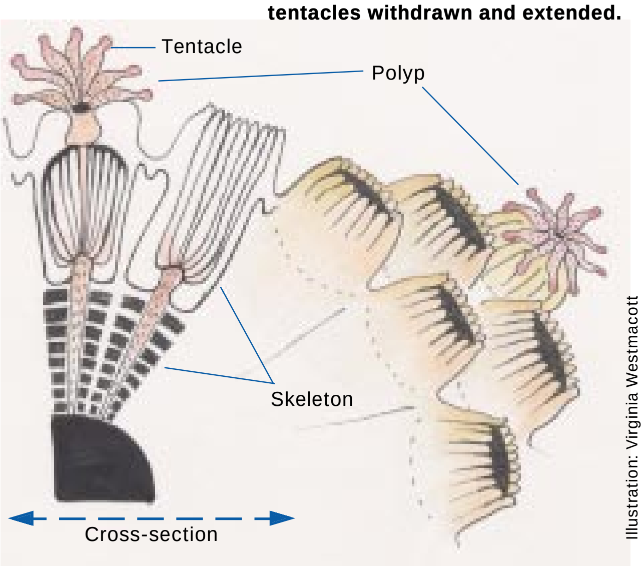
Most corals are small animals (called *polyps*) that live in colonies and form reefs. They obtain food in two ways: first, by using their tentacles to catch plankton and second, through tiny algae (called *zooxanthellae*) that live in the coral tissue. Several species of zooxanthellae may occur in one species of coral (Rowan and Knowlton, 1995; Rowan *et al.* 1997). They are generally found in large numbers in each polyp, living in *symbiosis*, providing the polyps with their colour, energy from photosynthesis and as much as 90% of their carbon requirements (Sebens, 1987). Zooxanthellae receive essential nutrients from the coral and transfer up to 95% of their photosynthetic production (energy and nutrients) to the coral (Muscatine, 1990).

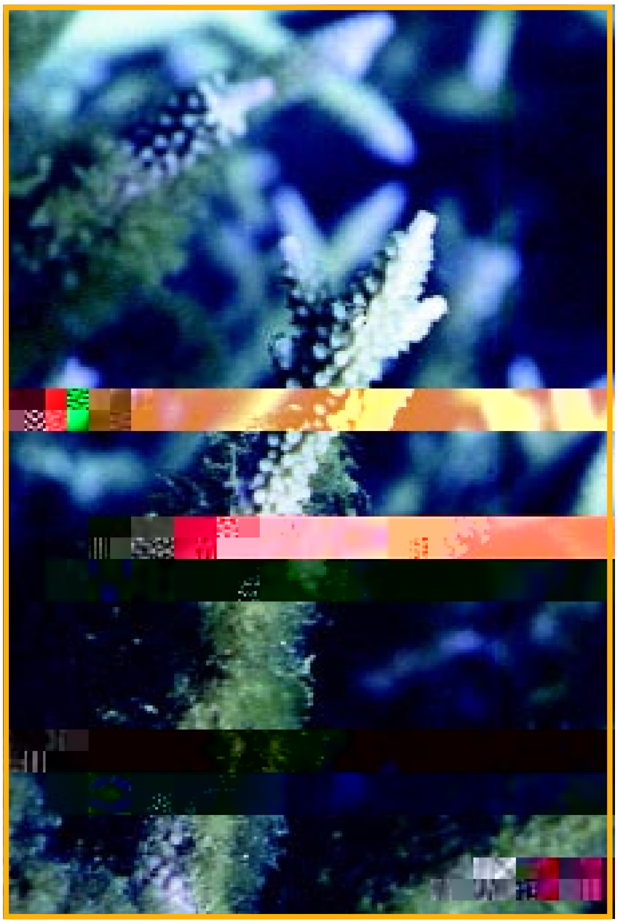
In reef-building corals, the combination of photosynthesis by the algae and other physiological processes in the coral leads to the formation of the limestone (calcium carbonate) skeleton. The slow build-up of these skeletons, first into colonies, and then into a complex three-dimensional framework allows the coral reef to harbour numerous species, many of which are important to the livelihoods of coastal people and communities.

Corals 'bleach' (i.e. go pale or snowy-white) as a result of a variety of stresses, both natural and human-induced, which cause the degeneration and loss of the coloured zooxanthellae from their tissues. Under normal conditions, zooxanthellae numbers may fluctuate seasonally as corals adjust to fluctuations in the environment (Brown *et al.* 1999; Fitt *et al.* 2000). Bleaching may even be a regular feature in some areas. During a bleaching event, corals may lose 60 – 90% of their zooxanthellae, and the remaining zooxanthellae may lose 50–80% of their photosynthetic pigments (Glynn, 1996). Once the source of stress is removed, affected corals may recover, with zooxanthellae levels returning to normal, but this depends on the duration and severity of the environmental disturbance (Hoegh-Guldberg, 1999). Prolonged exposure can lead to partial or complete death of not only individual colonies but also large tracts of coral reef.

The actual mechanism of coral bleaching is poorly understood. However, it is thought that in the case of thermal stress, increased temperature disturbs the ability of the zooxanthellae to photosynthesise, and may cause the production of toxic chemicals that damage their cells (Jones *et al.* 1998; Hoegh-Guldberg and Jones, 2000). Bleaching can also occur in non-reef building organisms such as soft corals, anemones and certain species of giant clam (*Tridacna* spp.), which also have symbiotic algae in their tissues. As with corals, these organisms may also die if the conditions leading to bleaching are sufficiently severe.

**Cross-section of a coral colony and its poylps, showing tentacles withdrawn and extended.**

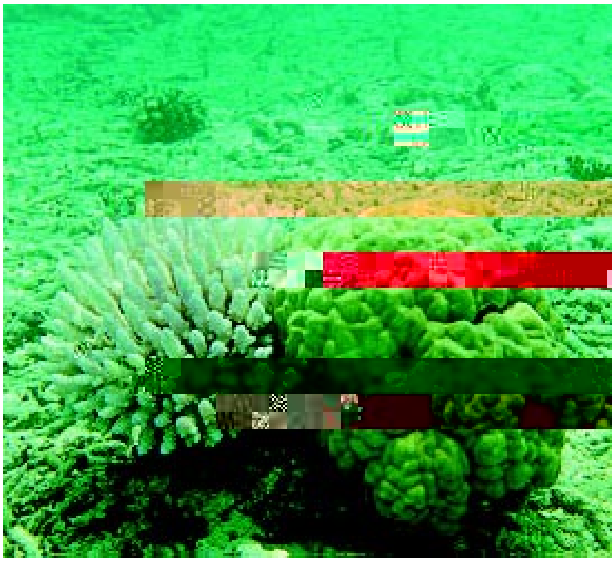


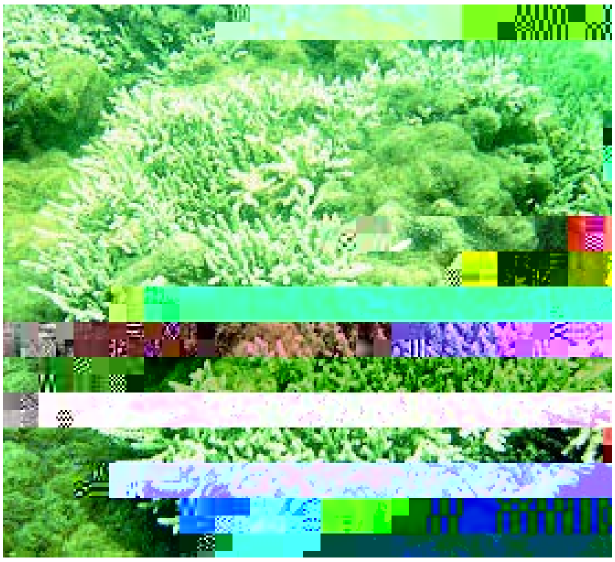




**The tip of this braching coral colony (*Acropora* sp.)is bleached but alive; the lower portion has died and is now overgrown with algae.**

The bleaching response is highly variable. Different bleaching patterns can be found between colonies of the same species, between different species on the same reef and between reefs in a region (Brown, 1997; Huppert and Stone, 1998; Spencer *et al.* 2000). The reason for this is still unknown, but the variable nature of the stress or the combination of stresses is probably responsible, along with variations in the species of zooxanthellae and densities within the colonies. Different species of zooxanthellae are able to withstand different levels of stress, and some zooxanthellae have been shown to adapt to specific coral species; this could account for variability of bleaching on a single reef (Rowan *et al.* 1997).

Bleached coral colonies, whether they die totally or partially, are much more vulnerable to algal overgrowth, disease and reef organisms that bore into the skeleton and





**Coral species differ in their responses to bleaching stressors. This photo was taken during the 1998 bleaching event: the colony on the left (*Acropora* sp.) has bleached whereas the one on the right (*Porites* sp.) has not.**

weaken the structure of the reef. As a result, if mortality is high, bleached reefs rapidly change from their snowy white appearance to one of a dull grey-brown as they become covered with algae. Where the impacts of bleaching are severe, extensive overgrowth by algae can prevent recolonisation by new corals, dramatically altering patterns of coral species diversity and causing a restructuring of the community.

## What causes coral bleaching?

Stressors that cause bleaching include unusually high sea temperatures, high levels of ultraviolet light, low light conditions, high turbidity and sedimentation, disease, abnormal salinity and pollution. The majority of large-scale coral bleaching episodes over the last two decades have been linked to the presence of increased sea surface temperatures (SSTs), and in particular to *HotSpots* (Hoegh-Guldberg, 1999). A strongest El Niño recorded up to that time, followed by a moderate event in 1987 and another strong event in 1992 (Goreau and Hayes, 1994). Coral bleaching has also occurred in non-El Niño years, and it has been recognised that other factors besides elevated SSTs could be involved, such as wind, cloud cover and rainfall (Glynn, 1993; Brown, 1997).

Large scale bleaching episodes can usually be attributed to fluctuations in SSTs, whereas small scale bleaching is often due to direct anthropogenic stressors (e.g. pollution) that act on small, localised scales. Where both warming and direct human impacts occur together, each may exacerbate the effects of the others. If average temperatures continue to increase due to global climate change, corals will likely be subjected to more frequent and extreme bleaching events in the future. Thus, climate change may now be the single greatest threat to reefs worldwide.

## Where has bleaching occurred?

Records of coral bleaching go back as far as 1870 (Glynn, 1993), but since the 1980s, bleaching events have become more frequent, widespread and severe (Goreau and Hayes, 1994; Goreau *et al.* 2000). In 1983, 1987, 1991 and 1995, bleaching was reported in all tropical areas of the Pacific and Indian Ocean as well as the Caribbean Sea.

At present, there is no standard method to quantify coral bleaching, and there has been some debate over whether inexperienced observers have overestimated the scale and severity of recent events (Glynn, 1993). Furthermore, in recent years, there have been more observers providing bleaching reports from more areas of the world than ever before (see Wilkinson, 1998). However, even during active coral research in the 1960s and 1970s, only 9 major coral bleaching events were recorded, compared to the 60 major events recorded in the 12 years from 1979 to 1990 (Glynn, 1993).

The coral bleaching event in 1998 was one of the most geographically widespread that has ever been witnessed and led to the highest level of coral death on record, especially in the Indian Ocean region. SSTs rose above coral tolerance thresholds for a longer period (more than 5 months) than had previously been recorded (Goreau *et al.* 2000; Spencer *et al.* 2000). Branching corals were the first to be affected, whereas massive corals, which initially appeared to be able to withstand the extraordinarily warm SSTs, were affected as the severe conditions continued.

Areas affected in the Indian Ocean region included large areas of reef along the coastlines of: East Africa; the Arabian Peninsula, with the exception of the northern Red Sea; the Comoros Archipelago; parts of Madagascar; the Seychelles; Southern India and Sri Lanka; the Maldives and the Chagos Archipelago. In most of these places, many corals were unable to survive the event, and coral mortality ranged from 70–99% (Linden and Sporrong, 1999; Wilkinson *et al.* 1999).

Reefs in the southern Indian Ocean around Reunion, Mauritius and South Africa were also affected although the conditions were not as severe or prolonged. Most corals eventually returned to their healthy state. This was thought to be due to monsoon conditions at the time, which caused cloud cover that reduced the levels of sunlight (and thus ultraviolet light) reaching the shallow water corals (Turner *et al.* 2000a).

The Eastern Pacific was the first area to be affected, starting in September 1997, and the conditions were the most severe this region had experienced since records of this kind have been kept; SSTs remained above the threshold for over 5 months (Goreau *et al.* 2000). Interestingly, those areas that had recovered from earlier bleaching events in 1983, 1987, 1992, 1993 and 1997, survived this recent event, while those areas that had not been previously affected were severely affected this time (Goreau *et al.* 2000).

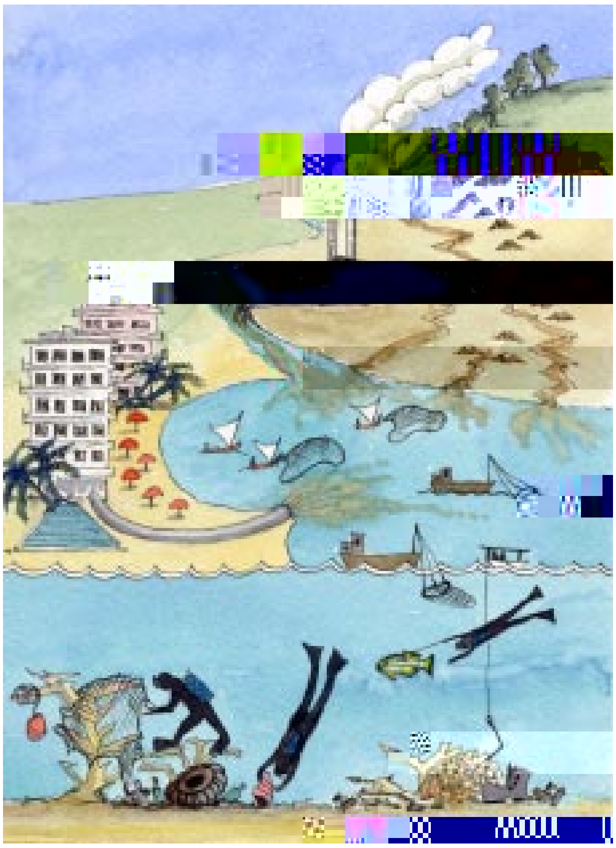
In the Western Pacific, SSTs remained above the threshold for up to 5 months in some places. Parts of the Great Barrier Reef were bleached, with coral mortality reaching 70–80% at some sites (Goreau *et al.* 2000) while other sites had mortalities of 17% or less (Wilkinson, 1998). Some reefs in the Philippines, Papua New Guinea and Indonesia also suffered, although many central Indonesian reefs survived due to the upwelling of cooler deep waters.

In the Caribbean and Northern Atlantic, bleaching peaked during August and September 1998, with abnormally warm waters lasting 3–4 months (Goreau *et al.* 2000). Subsequent damage by hurricanes in some locations may have increased the severity of this impact (Mumby, 1999). Reports indicate that 60–80% of the colonies were affected, but in many cases, bleaching was followed by substantial recovery (Goreau *et al.* 2000).

This overview of the 1998 bleaching event underscores how variable bleaching can be in terms of geographic extent, regional severity, and even small-scale patchiness. The amount of bleaching — versus the amount of actual mortality — can also be highly variable even within a single reef system. Examples from the Caribbean and Southern Indian Ocean indicate that extensive bleaching can sometimes be followed by significant recovery. We still have much to learn about these patterns of variability and about the nature of the bleaching phenomenon. Our challenge here, however, is to use existing knowledge of coral reef ecology and best management practices to develop strategies for maximising 'successful' recoveries in the future. In order to do so, we must first consider other threats to coral reefs so they can be considered in relation to coral bleaching.

# Other Threats to Coral Reefs

Bleaching from climate change is not the only threat to coral reefs. Scientists and managers have been concerned for many years that increasing stress from human activities is contributing to the decline of the world's reefs (Brown, 1987; Salvat, 1987; Wilkinson, 1993; Bryant *et al.* 1998; Hodgson, 1999). Recent estimates indicate that 10% of the world's coral reefs are already degraded beyond recovery and another 30% are likely to decline significantly within the next 20 years (Jameson *et al.* 1999). A 1998 analysis of *potential* threats to coral reefs from human activities (coastal



**The range of threats to coral reefs from human activities.**

fish stock). Use of cyanide and other poisons to catch aquarium fish also has a negative impact.

- Waste disposal from both industrial and municipal sources leads to increased levels of nutrients and toxins in the reef environment. Disposal of raw sewage directly into the ocean causes nutrient enrichment and algal overgrowth. Nutrient-enriched wastes from sewage or other sources are particularly damaging, as they cause a

# What Does the Future Hold in Store?

Major disturbances to reefs, whether localised or global in scope, raise questions about the future of coral reefs:

- Will reefs recover after a mass mortality, and if so, when?
- What will reefs look like in the future? Will they look the same as they did before?
- What can we expect from global climate change?
- Will this disturbance happen again?

These are difficult questions, but current research is starting to provide some answers.

## Coral reef resilience

Coral reef resilience is defined as the capacity of an individual colony, or a reef system (including all its inhabitants), to buffer impacts from the environment and maintain the potential for recovery and further development (Moberg and Folke, 1999). It appears that severe or prolonged negative impacts can progressively reduce resilience to subsequent impacts. This can inhibit the recovery of coral reefs following a disturbance and may lead to a shift from a coral-dominated to an algal-dominated system (Done, 1992; Hughes, 1994). Research is still underway on the resilience of reefs and their inhabitants, as even less is known about how the recovery rates of populations of species other than corals (McClanahan *et al.* in press). Meanwhile, a logical goal for managers and policy makers is to employ basic principles of sustainable use and appropriate management in order to conserve resilience. These are proactive measures to maximise a coral's, and a coral reef's, resistance to disturbance and boost resilience for maximum recovery after the disturbance has passed.

The history of disturbances on a reef contributes to its structure because reefs are naturally dynamic ecosystems. During recovery, species interact and change their levels of abundance and roles within the community structure. As a result, reefs may evolve into communities that are substantially different from those existing prior to the bleaching event, and yet still be diverse and thriving ecosystems.

The return of a coral reef ecosystem to a functional state after mass bleaching mortality will depend on successful reproduction and recolonisation by remaining corals and by corals from outside the ecosystem (see Done, 1994, 1995). Corals reproduce both sexually and asexually. Sexual reproduction involves the fertilisation of coral eggs by sperm to form free-swimming larvae. The larvae are well adapted for dispersal and, depending on species and conditions, can seed the reef where they originated, nearby reefs, or reefs hundreds of kilometres away (Richmond, 1997). Dispersal requires appropriate oceanographic currents to seed downstream reefs and is essential for the maintenance of genetic diversity amongst coral populations and coral reefs.

Recruitment is the process by which juvenile corals (known as *recruits*) undergo larval settlement and metamorphosis to become part of the adult population and

Photo: Susie Westmacott

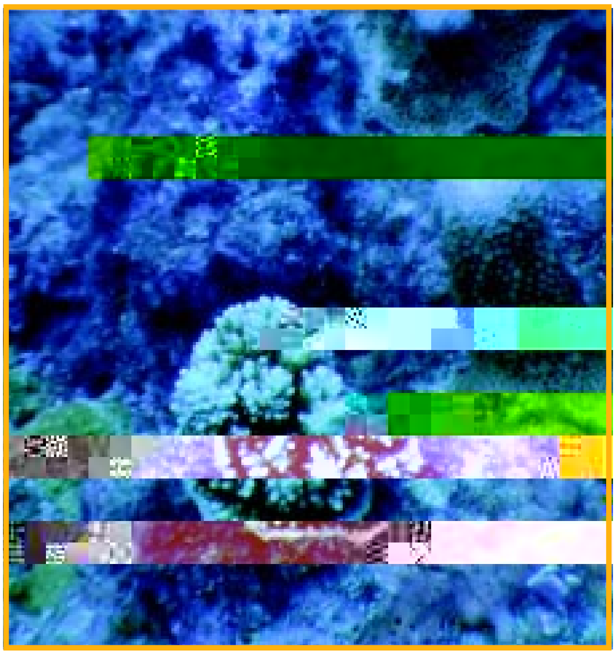


Photo: Ben Stobart

**Juvenile corals growing on an area of dead coral on a damaged reef. Bonaire, Caribbean (left), Seychelles (right).**

the reef community. Coral larvae settle out from the water column onto a suitable substrate; the presence of suitable substrate is critical to the success of recruitment. Good settlement sites tend to have the following characteristics (Richmond, 1997):

- A stable bottom type – the substrate must not be composed of loose sediments or unconsolidated material.
- Water motion at the site of settlement must be minimal to calm, although under certain conditions, high water motion may encourage growth.
- Salinity must generally be above 32 ‰ and below 38–40 ‰.
- A source of light for the zooxanthellae to photosynthesise.
- Limited sedimentation in the water column (ideally clear water) to reduce the chances of smothering and for the adequate transmission of light.
- An absence of macro (large) algae (as opposed to turf algae) that would compete for space with corals and inhibit the settlement of larvae.

Once settled, the coral has to compete with other faster growing organisms such as algae and encrusting invertebrates and avoid predation by coral-eating fish. The failure of reproduction (for example, if all the sexually mature corals on a reef die from bleaching) and localised recruitment will likely slow the recovery of severely damaged reefs (Richmond, 1998). However, coral cover may return eventually through asexual reproduction.

Asexual reproduction occurs when coral fragments become detached from the parent colony, usually due to physical impact from, for example, wave action or storm surge. Fragments are very vulnerable to physical damage and can easily lose their thin layer of live tissue if rolled against the bottom by water movement. However, if the fragment lands on a suitable substrate, it may re-attach itself and develop into a new colony.

A reef where the majority of the corals have died, but which has retained its structure, can still provide a stable, suitable substrate for coral recruits and fragments to settle and grow. Thus, the maintenance of dead corals is still of value. Dead corals are vulnerable to organisms that bore into them and weaken the structure of the reef. Strong waves or storm surges can cause major damage to reefs that are in this state, transforming a once complex structure into a rubble field unsuitable for coral settlement. However, red coralline algae can help to cement the reef, reducing breakage and providing an adequate substrate for the settlement of larvae.

## Global climate change and coral reefs

In the past 200 million years, reefs have adapted to numerous changes; however, over most of this period, there was no pressure from humans. Reefs are now faced with a combination of threats from over exploitation, pollution and especially global climate change. All of these threats are increasing, and human activities are causing the acceleration of global climate change to rates that may make it difficult for coral reefs to adapt.

Global climate change is likely to have six main impacts on coral reefs:

**1. Sea level rise**

Most unstressed coral reefs should be able to keep up with predicted sea level rise, estimated to be 50 cm by the year 2100 (Intergovernmental Panel on Climate Change, 1995). Reef flats that are exposed at low water, which limits their upward growth, may benefit from such a rise. However, corals weakened by temperature increase or other factors (see below) may be unable to grow and build their skeletons at 'normal' rates. If so, low-lying islands will no longer be afforded the protection from wave energy and storm surges that their surrounding coral reefs currently provide. This is of major concern to nations such as the Maldives in the Indian Ocean, and Kiribati and the Marshall Islands in the Pacific Ocean, where land masses have average heights of less than three metres above sea level.

**2. Temperature increase**

Increases of 1–2°C in sea temperature can be expected by 2100 (Bijlsma *et al.* 1995). Many areas of the tropics have already seen an increase of 0.5°C over the last two decades (Strong *et al.* 2000). Although these are seemingly small changes, they translate into an increased likelihood that, during the warmer periods of normal seasonal fluctuations, temperatures will exceed the tolerance levels of most coral species. This would lead to an increased frequency of bleaching (Hoegh-Guldberg, 1999). An increase in temperature may mean that areas currently outside the range of coral reefs will become suitable for coral growth, resulting in a shift in the geographic distribution of reef building populations. However, it will be some time before this can be confirmed; and should it prove true, other environmental factors at higher latitudes may not be conducive for reef growth. Furthermore, elevated SSTs affect the sensitivity of

**Coral reefs have thrived under past climatic conditions, temperature, UV and current patterns.**

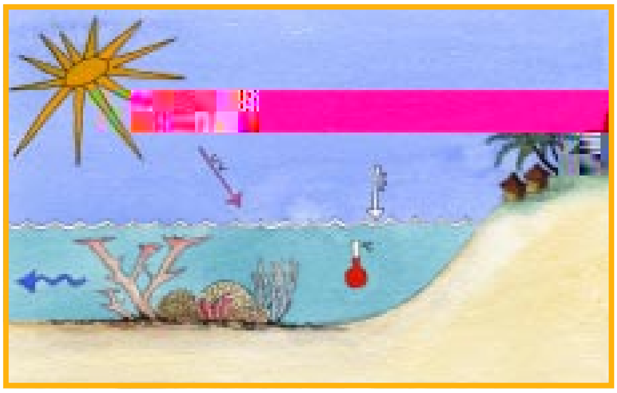


Illustration: Virginia Westmacott

**Increased sea temperatures, storminess, carbon dioxide and UV levels, as well as changing current patterns, resulting from global warming now threaten coral reefs.**

Illustration: Virginia Westmacott

zooxanthellae, such that light that is essential for photosynthesis causes damage to the cells (Hoegh-Guldberg, 1999). Corals may thus become more vulnerable to increased levels of UV radiation due to depletion of the ozone layer.

3. **Reduced calcification rates**
   Global emissions of greenhouse gases have raised concentrations of carbon dioxide in the atmosphere and in the oceans to a level that may gradually reduce the ability of coral reefs to grow through normal calcification processes. High concentrations of carbon dioxide increase the acidity of the water, which reduces calcification rates of corals. It is predicted that calcification rates may be reduced by an estimated 14–30% by the year 2050 (Hoegh-Guldberg, 1999). This will reduce the capacity of reefs to recover from events such as coral bleaching as well as compromise their ability to keep pace with sea level rise and ecological shifts.

4. **Altered ocean circulation patterns**
   If changes in large-scale ocean circulation patterns develop, they could alter the dispersal and transport of coral larvae (Wilkinson and Buddemeier, 1999). This could have impacts on the development and distribution of reefs worldwide.

5. **Increased frequency of severe weather events**
   Alterations to annual atmospheric patterns could result in changes in the frequency and intensity of storms and cyclones, as well as changing patterns of precipitation. Increased storms could cause increased damage not only to coral reefs, but to coastal communities as well.

If trends continue as forecasted, coral bleaching will be a regular feature in 30–50 years time (Hoegh-Guldberg, 1999). Increased frequency of bleaching will force corals to adapt. Adaptation may occur in two ways:

- The physiology of corals may change to become more tolerant to higher temperatures.
- There may be mortality of populations or species of corals and zooxanthellae that are unable to cope with higher temperatures – and these less tolerant species will disappear (Warner *et al.* 1996; Hoegh-Guldberg, 1999).

Further information on potential adaptation scenarios is given in Hoegh-Guldberg (1999).

Reefs as a whole, however, are durable ecosystems, as evidenced by geological history. Major disturbances in the past have resulted in the disappearance of various coral species, but others have survived and evolved into new species. Fossilised coral structures are often visible in cliffs, sometimes far inland. Reefs have thus undergone immense changes in structure and composition over time, whilst remaining recognisable as reefs (Veron, 1995). Therefore, careful management of reefs — even those that have been severely damaged — is very worthwhile, as it could well tip the odds in favour of persistence of these long-lived systems.

**Box 1. Recovery following outbreaks of Crown of Thorns Starfish.**

The Crown of Thorns Starfish (COTS) (*Acanthaster planci*) has devastated large areas of the Great Barrier Reef (GBR) in Australia as well as other reefs in the Pacific. The first record of a COTS outbreak (thousands to tens of thousands) dates back to the late 1950s, when large numbers of starfish were observed in the Ryukyu Islands, Japan. Not long after, in the early 1960s, outbreaks were reported on Green Island and several nearby areas of the GBR. By the time COTS outbreaks were occurring further south on the reefs off Townsville 10 years later, the northern part of the GBR was already recovering. It was feared that the structure of the Reef would be totally destroyed, exposing the North Queensland coast to increased levels of wave action and erosion. This did not happen. Whilst outbreaks of COTS may destroy some individual corals, they have not destroyed the Reef itself. During the last outbreak in the late 1970s and 1980s, starfish affected approximately 17% of the 2900 reefs that make up the GBR. Of those, only 5% of reefs were classified as having severe outbreaks.

Subsequent studies conducted on the GBR and in Guam indicated that coral cover took 12 to 15 years to return to pre-outbreak levels. Although coral cover returned after this period, the composition of the coral communities had changed, and the reefs were now comprised largely of fast growing species such as branching (e.g. *Acropora*) and plate corals. Recovery of the original species composition and diversity is expected to take much longer because the replacement of the slow growing and long lived massive corals (e.g. *Porites*) takes up to 500 years for very large individuals. However, complete recovery will eventually occur if there is no further disturbance.

Source: Bradbury and Seymour (1997), CRC Reef Research (1997) and Moran (1997) depend on reefs for their livelihoods. The economy of the Maldives, for example, has traditionally been based on fisheries and tourism, both of which are linked directly to the reefs, which have been severely affected by bleaching. Thus, there are good reasons for continuing management efforts in order to:

- Ensure optimal conditions for reef recovery.
- Ensure sustainable reef fisheries.
- Ensure the continuation of the tourism industry.

Reef recovery will vary from reef to reef according to the unique set of circumstances at each location. Under suitable conditions, reefs may well be able to return to thriving, diverse communities, providing direct benefits in terms of fisheries, tourism and recreation and indirect benefits, such as coastal protection and scientific research (see Box 1).

# Marine Protected Areas and Damaged Reefs

Despite the mortality that has followed some bleaching events, particularly that of 1998, there has never been total elimination of all living corals in any area. Even in the severest cases, scattered colonies and small patches of reef have survived. Furthermore, new coral recruits are often observed within a year after the event. This provides a starting point for reef recovery and a hope for the future.

**Areas of live coral will act as a source of larvae for areas affected by the bleaching.**

**Box 3. Effect of coral bleaching on Marine Protected Areas in the Seychelles.**

Coral bleaching had a severe impact on MPAs in the Seychelles, and live coral cover was reduced to less than 10% on most reefs around the inner islands (Turner *et al.* 2000b). Funding for management of the park currently depends entirely on visitor entrance fees and, if visitor numbers fall, income to the Marine Parks Authority will decline.

Visitors to Ste Anne Marine Park and Curieuse Marine Park have been declining in number since 1996 (i.e. since before the bleaching event). The Marine Parks Authority is now looking for new attractions for visitors, in order to ensure sufficient income to maintain the parks. Visitor centres are being planned, breeding pens for giant Aldabra tortoises are being constructed and picnic areas are being improved. In addition, terrestrial activities in the MPAs – such as nature trails and

will greatly increase the effectiveness and success of the management of MPAs (Walters *et al.* 1998), as will the incorporation of MPAs into an integrated coastal management (ICM) framework. MPA managers should be involved in ICM planning and implementation, to promote the needs of coral reefs and to encourage the creation of conditions that will lead to reef recovery. Damaged coral reefs affect visitor numbers to an MPA, as well as the livelihoods of those who depend on the MPA for employment, such as naturalists, guides, and park staff (see Box 3). If the MPA is dependent on visitors for revenue, this aspect of management will need to be reviewed and the potential for promotion of attractions other than coral reefs, assessed.

**3. Develop a more strategic approach to the establishment of MPA systems.**

For the development of national and regional MPA systems, a more strategic approach may be required to take into account *source* and *sink* reefs and the dispersal patterns of coral larvae. Research into current patterns of larval dispersal will be useful; however, unfavourable

# Fisheries and Coral Bleaching

Coral reefs support a wide range of valuable fisheries, including both fish and invertebrate species. Utilisation by humans may occur on a large commercial scale or on a small artisanal scale. The primary purpose of some fisheries may be the harvest of food, while other fisheries may involve the collection of merchandise for the curio and aquarium trades. All of these enterprises could potentially be affected by coral bleaching. While most fisheries research to date has focused on edible fish, we can nevertheless use current theory to deduce the potential impacts of bleaching and reef degradation on reef fisheries in general. After a review of basic fisheries theory, we will employ the precautionary principle to make some general recommendations.

The impact of coral bleaching on a fishery may follow the generally accepted theories on habitat-fish interactions on coral reefs (Pet-Soede, 2000). Apart from exploitation itself, several factors contribute to the composition of fish communities on a reef, all of which are related to the physical structure and complexity of the reef itself.

First, competition for food is one important factor determining fish diversity and abundance. On a healthy reef, diversity and abundance of food is high and this has a direct positive effect on fish diversity and abundance (Robertson and Gaines, 1997). On a degraded reef, dead coral is soon overgrown with algae which are eaten by herbivores such as parrotfish (*Scarus* spp.), and the population of such species may increase. Heavy grazing by these species sometimes damages the reef structure, causing erosion of the coral skeletons, but they also keep algal growth in check. Also, the increase in populations of these commercially valuable fish can be an economic benefit.

Second, the reef provides a suitable environment for reproductive activities and larval settlement of fishes, and these will in turn determine the adult community structure (Medley *et al.* 1983; Eckert, 1987; Lewis, 1999). A healthy complex reef structure will maximise the variety and numbers of spaces for successful reproduction.

Finally, the reef provides shelter and protection from predators, particularly for small fish species, and this affects their survival patterns and abundance as adults (Eggleston,

**Live coral (left) provides a suitable habitat for a diverse and abundant fish community unlike a degraded reef (right).**

algae overgrowing dead corals (Goreau *et al.* 2000; McClanahan and Pet-Soede, 2000) (see Box 4).

- An additional potential impact, as yet unconfirmed, is that coral bleaching could lead to an increase in ciguatera poisoning. Ciguatera toxins are produced by microscopic single-celled algae (dinoflagellates) that grow especially well on the surface of larger, fleshy reef algae. When fish graze on the algae, the toxins can become concentrated in their bodies and cause poisoning in humans. The phenomenon appears to be linked to disturbance of coral reef ecosystems, perhaps due to increased overgrowth by large algae (which provide more surface area for dinoflagellate growth) on degraded reefs (UNEP, 1999a; Quod *et al.* 2000).

Changes to a reef as a result of coral mortality could affect the fish yield, the type of fishery, and the spatial distribution

Many local communities will have few alternative livelihoods and little potential for adaptation to these new conditions. Increasing understanding, co-operation and a feeling of

## Management actions

Even in the absence of bleaching, sustainable management of fisheries is a challenging task, as large numbers of people are involved, many with no other sources of income or protein.

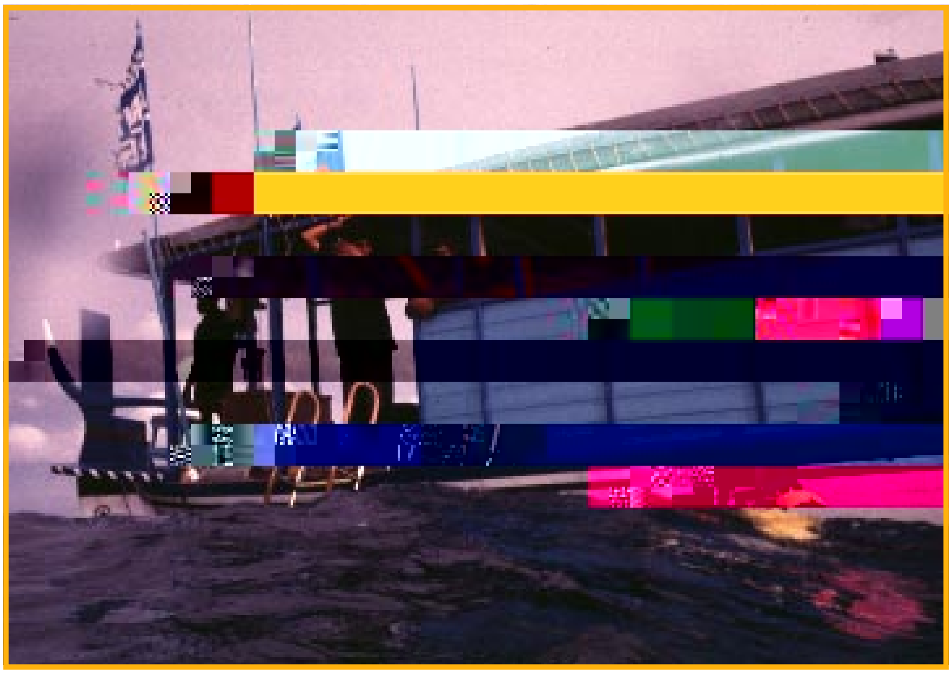


Photo: Susie Westmacott

In the Maldives, where diving ia a major source of income to local people, the tourist industry is taking a major role in assisting with reef management.

internationally (e.g. Coral Cay Conservation, Frontier, Raleigh, Earthwatch, Reef Check). In the Bonaire Marine Park, Netherlands Antilles, for example, there are yearly visits from both REEF and CEDAM, and those visits form an integral part of the Park's monitoring programme (see sections on *Monitoring and Research* and *References and Resource Materials*).

3. **Diversifying the tourism industry.**
In order to monitor changes in tourist visitation to reefs, regular surveys should be carried out, for example, in airport departure lounges where tourists wait for their flights. Several countries already carry out such surveys through the government department responsible for tourism. Survey questions can be specific to diving and snorkelling and other directly reef-related activities, or they can cover broader tourism activities. Monitoring changes in the tourism market will indicate whether marketing of alternative tourism activities is required to maintain the industry. For example, terrestrial based tourist activities could be the focus while damaged reefs are given a chance to recover; however, care must be taken to ensure that coastal development for such activities does not itself cause additional damage to

Clean, beautiful beaches will help to maintain tourism in areas where reefs have been damaged.

Photo: Kristian Teleki

reefs. Much greater attention may need to be paid to the landscape value of an area, clean beaches, clear waters for water sports, etc. It may be necessary to seek new or alternative dive sites (e.g. with dramatic underwater scenery or populations of large fish).

4. **Reducing impacts from tourism operations in general.** Where reefs have been bleached and degraded, the management of the surrounding tourism activities is essential. The following impacts, among others, should therefore be reduced or eliminated (see also sections on *Other Threats to Reefs*, *Marine Protected Areas*, *Fisheries* and *Integrated Coastal Management*):

- Direct contact from diving and snorkelling (by walking on or knocking into the reefs); providing information to divers and educating them about the potential damage they can cause may be sufficient to eliminate damage. In addition, offering divers free buoyancy workshops may also help to improve their buoyancy control underwater, and making glove-wearing illegal also inhibits intentional touching of reef organisms.
- Over use of a reef or dive site; relocating dive sites or limiting numbers of divers at popular dive sites can reduce damage to reef areas that are in the process of recovering.
- Physical damage from boat anchoring; anchoring of boats (dive, fishing, pleasure craft, etc.) – can be managed by designating anchorage zones, providing alternatives, such as moorings, and enforcing other regulations relating to environmentally sound anchoring.
- Near shore contamination from waste disposal (e.g. sewage from resorts); it may be appropriate for coastal resorts to treat wastewater on site or to use it in the maintenance of their gardens so that excess nutrients will be used by the plants.
- Sedimentation and pollution from construction (e.g. piers and jetties, harbours and marinas); guidelines are available for many construction and engineering activities, and methods have been developed to reduce their impact. These can be promoted and implemented by making them conditions of the approval for planning or of the Environmental Impact Assessment, through legislation and permit systems, and through incentive measures.

5. **Encouraging tourists to contribute financially to recovery and management efforts.** Managing coral reefs, whether they are healthy or recovering from damage, requires adequate financial resources that are often lacking in the countries worst affected. The tourism industry, which in many areas is dependent on or makes extensive use of coral reefs, should contribute to the costs of management. Individual divers and tourists can assist through payment of park entrance and other fees or by making donations. As Box 6 shows, tourists are often willing to contribute

**Mooring buoys prevent damage to reefs from boat anchors.**

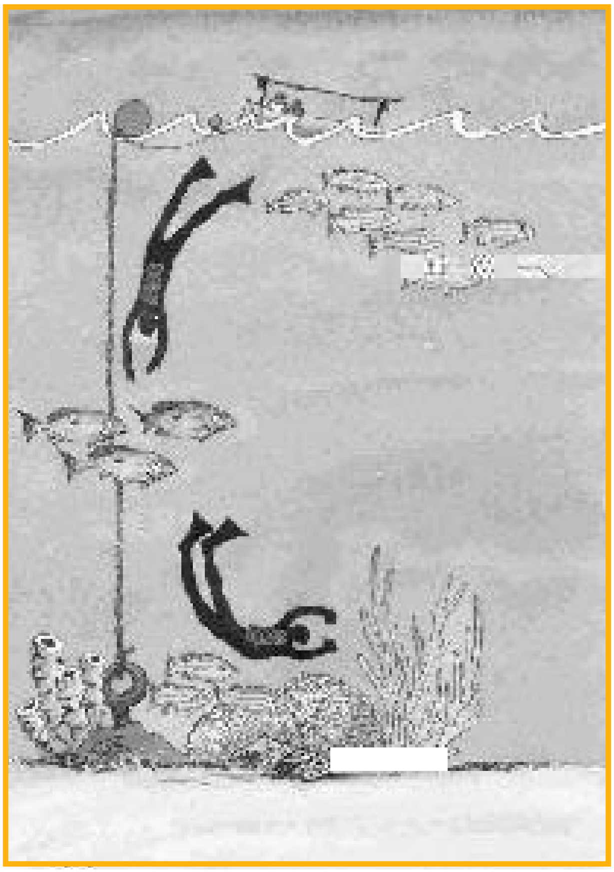


Illustration: Virginia Westmacott

**Box 6. Asking divers to pay for reef conservation.**

Divers show considerable 'willingness to pay' for good quality reefs. In the Maldives, a survey following the bleaching event of 1998 showed that each tourist would be willing to pay an additional US$87 on top of their actual holiday cost to be able to visit healthy rather than degraded reefs. Since around 400,000 tourists visit the Maldives a year, this would translate to a total of US$19 million during 1998 and 1999 (Cesar *et al.* 2000).

Similar surveys in Zanzibar in 1996 (before the bleaching) and 1999 (after the bleaching) showed a willingness to contribute towards reef management of US$22 per diver in 1999 compared to US$30 in 1996. This change could be related to not only the decline in reef quality (a 20% decrease in hard coral cover from November 1997 to November 1998 at certain sites (Muhando, 1999)), but also to other factors such as the type of tourist visiting this country. The only difference between the divers interviewed in 1996 and 1999 was that the former were less experienced divers; their income and other socio-economic variables were comparable which suggests that the difference in willingness to pay could be related to either reef quality and/or to their level of experience. In Mombasa, divers were on average willing to contribute US$43 to maintain reef quality, their level of experience was generally higher than those interviewed in Zanzibar, and they made many more dives. These factors could account for their willingness to pay more than divers in Zanzibar.

Source: Westmacott *et al.* (2000b)

substantial sums if they are assured that the money will be used for reef conservation. The socio-economic profile of the visiting tourist, as well as the quality of the reefs and other attractions, will be important factors when assessing how much tourists might pay for reef management activities. Thus, surveys should be carried out in each area to determine these factors before user fees are introduced.

6. **Conveying information to the public through outreach and education.**

The tourism industry can play an important role in education and outreach activities. These might include:

- Fact sheets on the "dos and don'ts" of enjoying coral reefs and on the relationship between climate change and coral bleaching, which can be included in the information packets that hotels provide to their guests.
- Colourful and informative posters that can be sold in local tourist shops or park offices.
- Training courses for tourist operators on how to educate tourists on reef biology and threats to reefs.
- Free boat tours of MPAs and slide show lectures for members of the community, especially those who deal extensively with visiting tourists, so that they will feel a sense of stewardship toward their reefs and will help to educate tourists that they meet.

# Integrated Coastal Management and Coral Bleaching

Coral reefs, particularly fringing reefs, are often found close to the coast and may lie just metres from the shoreline. Rapid population growth and increasing demand for industry, tourism, housing, harbours and ports are resulting in extensive coastal development. As mentioned earlier, these have a major impact on coral reefs and, as with other human activities, are likely to impede recovery of reefs that are affected by bleaching. The health of adjacent ecosystems, such as seagrass beds and mangroves, also has an important bearing on the health of coral reefs. Furthermore, maintaining the aesthetic value of the coast, including clean beaches and water, and unspoiled landscapes, will become increasingly important if coral reefs themselves become less attractive to tourists. Addressing these issues will require careful attention to planning and regulation of coastal development and waste disposal, and may best be addressed by integrated coastal management (ICM).

ICM considers the coastal zone and its associated watershed as a single unit and attempts to integrate the management of all relevant sectors (Bijlsma *et al.* 1993; Post and Lundin, 1996; Cicin-Sain and Knecht, 1995). Many countries have initiated or are implementing ICM programmes at local and/or national levels. Belize, for example, has found this a particularly useful framework for addressing threats to coral reefs (Box 7). In Tanzania (another country where coral reefs are vital resources that have also been affected by bleaching), a national ICM policy is under development, and local site-specific ICM programmes are being implemented to

**Box 7. Managing the Belize Barrier Reef through an ICM approach.**

Belize has one of the most extensive reef ecosystems in the Western Hemisphere, comprising one of the largest barrier reefs in the world, three atolls and a complex network of inshore reefs. These have been affected by several of the recent bleaching events although, in general, the country benefits from some of the most healthy reefs in the Caribbean. The Great Barrier Reef Marine Park in Australia was viewed as a potential model for management of the country's reefs and associated ecosystems. However, the need for management of land-based activities was recognised as fundamental, and the ICM approach was adopted as a general framework.

The ICM programme has been underway since 1990, and an institutional structure has been established to co-ordinate management activities in the coastal zone. Measures laid out under the national Coastal Zone Management Plan are of direct benefit to reefs and include: a zoning scheme for the coastal zone, incorporating MPAs; fisheries management measures; a national mooring buoy programme; legislation and policy guidelines; policies to address offshore industries and shipping; research and monitoring programmes; education and public awareness campaigns; measures for community participation; and a financial sustainability mechanism.

Source: Gibson *et al.* 1998

**Replanting mangroves can build up the coast's natural protection against erosion and reduce sedimentation onto nearby reefs as seen here in Mauritius.**

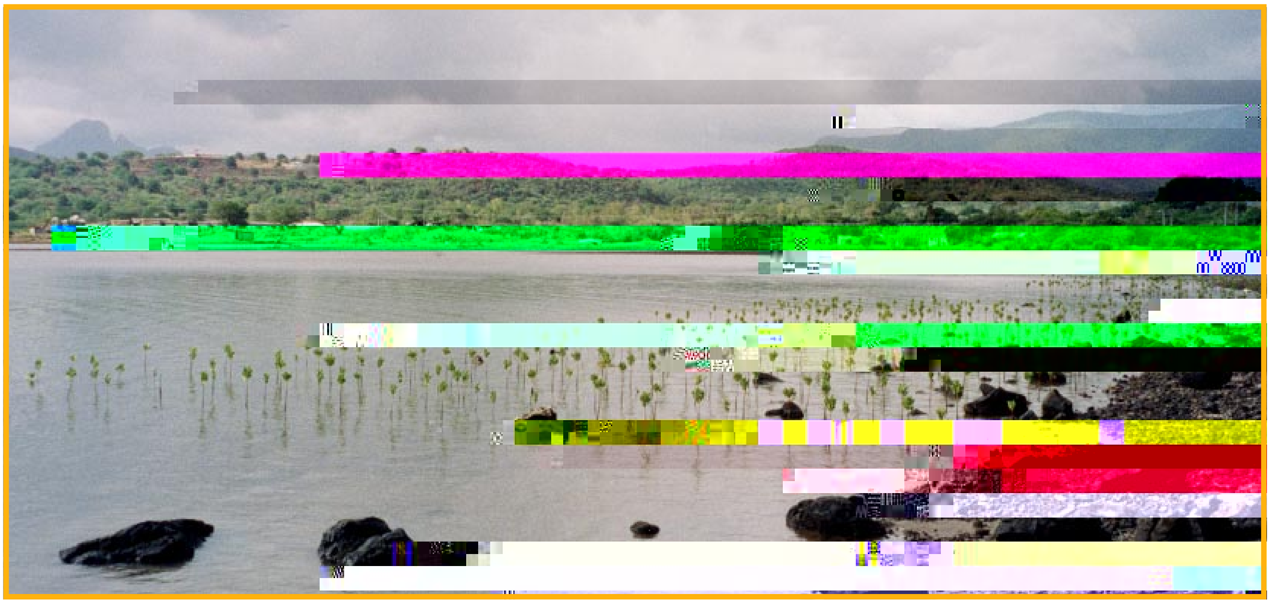


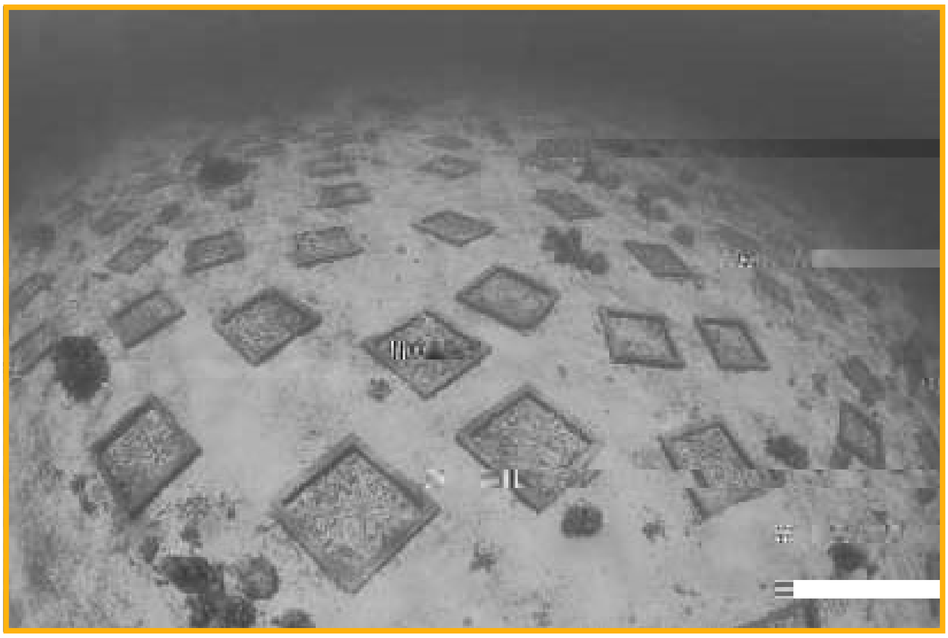
Photo: Susie Westmacott.

test planning and co-ordination mechanisms on the ground (Francis *et al.* 2000). The states of the Western Indian Ocean have shown particular political commitment to the establishment of ICM programmes through a number of Ministerial level meetings (Lindén and Lundin, 1997).

This booklet has covered MPAs, fisheries and tourism in in full here, and managers and decision makers are referred to the sources of information given at the end of this booklet. A good legal framework for regulation of commercial shipping now exists, as a result of the efforts of the International Maritime Organisation. However, not all countries have the domestic legislation, resources or capacity to develop and implement the necessary measures. These include contingency and rapid response

# Restoration Techniques

Restoration techniques can be used to aid and speed recovery of damaged reefs by enhancing or supplementing natural processes of resilience. However, it is essential to look at the scale involved when considering whether to restore reefs affected by bleaching mortality. Many rehabilitation efforts have not proved effective or feasible on a large scale ($km^2$), either economically or ecologically. There is also little point



Coral farm on Olango Island, Philippines: the small enclosures shelter the transplanted coral fragments.

Photo: Thomas Heeger

Women from the local village prepare coral fragments for transplanting into enclosures.

Photo: Thomas Heeger

**Box 9. Coral farming in the Philippines.**

In 1997, a low-cost coral farm with the primary aim of reef rehabilitation was set up with the assistance of the village people in Barangay Caw-oy, Olango Island, Cebu, Philippines. Six thousand fragments were cut from corals on nearby reefs and transplanted to a reef with low coral cover. After 4 months, 87% of the coral fragments had survived, and fish populations on the farm are reported to have increased. The farm is also providing a livelihood to local people through the sale of coral colonies for rehabilitation of damaged reefs in other areas of the Philippines. The profits are used for community projects such as scholarships, first aid rooms and street lighting.

The cost of rehabilitating one hectare of reef, using 2 fragments per square-metre (12.5% cover) was US$ 2,100. Since, the potential revenue from one hectare of a healthy reef in the Philippines has conservatively been estimated at US$ 319 – 1,113 a year (White and Cruz-Trinidad, 1998), using this method, reef rehabilitation would be potentially economically viable after a few years. This would be especially true if local fishermen find better livelihood alternatives in coral farming and shift from destructive fishing techniques.

Source: Heeger *et al.* (1999, 2000)

chosen with care, to avoid damage to other reefs. The best source is probably those reefs that are certain to suffer major damage in the future from dredging, land reclamation, effluent discharge or activities that cannot be stopped or for which there is no mitigation.

**Farming corals**

Several attempts have been made to farm corals, mainly in Southeast Asia (see Box 9) (Franklin *et al.* 1998). Unlike straight coral transplantation, in the case of 'coral farms', the fragments are transplanted to a protected site and 'grown out' to a certain size before being used for other purposes. Successful coral farms could provide a source of corals for rehabilitating damaged reefs and could be used as underwater attractions for snorkellers (Alcock, 1999). Further investigation into coral farming is required to reduce costs and increase success rates. Studies in Australia have shown that mortality rates may be as low as 2–5% and that the removal of up to 50% of the biomass of a 'donor' coral colony may have no effect on its growth (Alcock, 1999).

## Management actions

Since active reef restoration is generally expensive and not always successful, managers must assess the situation carefully before initiating such a programme and consider a number of factors:

1. What are the ***objectives*** of the restoration project? Are the reefs being restored for biodiversity conservation, tourism, fishing, protection from coastal erosion or purely for research? The objectives will help to determine the methods to be used.
2. What is the ***scale*** of the restoration project? Is the degraded area a specific location (i.e. anchor scar or boat grounding), a section of the reef or an entire reef complex? If the degraded area is large (e.g. following a major bleaching event), careful thought must be given as to where restoration efforts should be directed in terms of current patterns (encouraging downstream coral seeding but avoiding upstream sources of pollution) and exposure to potentially damaging wave action, sources of pollution and turbidity.
3. Once the objectives and scale have been considered, the ***cost*** of the project needs to be evaluated, taking into account the most effective use of any available funds (see Spurgeon (1998) for more details).
4. What is the ***success rate*** of the method being proposed? Which method will be most ***cost-effective*** at the site? It is important that the method selected does not cause additional injury to the reef.
5. What will be the ***long-term viability*** of the programme? To ensure some measure of success, the project should continue long enough for the restoration progress to be monitored.
6. Is there scope for the ***local community and reef users*** to become involved? Active participation by those whose livelihoods are linked to the reefs will increase the chances of success (see Box 9).

# Monitoring and Research

## Monitoring

A well-designed monitoring programme is a very important tool for tracking changes on bleached reefs and for monitoring the general condition of those still unaffected. Monitoring should start simply, be adaptive and flexible, and be designed to meet management goals. Local organisations, universities and non-governmental organisations (NGOs) can carry out some of the best monitoring. These groups have the flexibility to design their monitoring programmes within their own capacity and are able to work with local people, which is an important factor in determining the long-term sustainability of monitoring programmes. There are also now a number of regional and global reef monitoring programmes available with accompanying guidelines, handbooks and training activities. Reef managers can also access some of the global temperature monitoring programmes, such as that underway through NOAA. The two principal global programmes both pay particular attention to bleaching:

- **Global Coral Reef Monitoring Network (GCRMN)**
  The GCRMN focuses on government level (or professional) monitoring. Once fully in place, the global network will consist of fifteen independent regional networks, or sub-nodes, in six regions around the world.

Photo: ARVAM

Coral cover being assessed after bleaching using a line transect.

Photo: Erik Meesters

Left: New coral growth, such as recruits, being measured with a quadrat.

Via these regional networks, the GCRMN promotes sound scientific methods for monitoring and assists with the provision of training. For example, two nodes have been established in the Indian Ocean – one in Sri Lanka, servicing the countries of South Asia, and one in Mauritius, covering the island nations of the Western Indian Ocean. The data collected are stored in regional databases and used in national reports on reef status. The national results are collated into *Status of the Reefs* reports that will be published every two years; the first status report was produced in 1998 (Wilkinson, 1998). GCRMN is currently developing a manual for assessing socio-economic parameters relevant to coral reefs, which will be very useful in the context of coral bleaching.

- **Reef Check**
  Reef Check is a protocol for rapid assessment of reefs, and is specifically designed for non-professionals and volunteers. Initiated in 1997, it is carried out annually on a worldwide basis and now involves a large pool of enthusiastic volunteer SCUBA divers and free divers in over 40 countries. A network of regional, national and local co-ordinators match up teams of experienced recreational divers with professional marine scientists. The scientists are responsible for training, leading the surveys and ensuring accurate data collection. The Reef Check methods employ carefully selected indicator organisms based on those advocated by the GCRMN. The methodology can be learned in one day and involves a strict quality control system. Thus, Reef Check represents the 'community-based' monitoring protocol of the GCRMN. Further information is available in Hodgson (1999, 2000) and on the Reef Check website (see *References and Resource Materials* section).

There are a number of key issues to consider when developing a monitoring programme in relation to bleaching or other serious damage on reefs:

1. What regional or national monitoring programmes are available in the area? These should be contacted through web sites or directly through the programme co-ordinators (see *References and Resource Materials* section). Reef Check's methods are available on their web site, and GCRMN outlines its protocol online. Both may be able to facilitate funding or initial support. Other organisations or programmes in a region may also be able to provide assistance.
2. What are the objectives of the monitoring programme? These should be clearly defined, as they will influence the methods selected. The methods themselves should be simple, but flexible and adaptive, so that as resources become available, more detailed information can be collected, or more sophisticated methods used.
3. The first step should be a rapid assessment of the bleached or damaged area, the results of which can then be compared to any available pre-impact data.
4. Biological, physical and socio-economic data should be collected, so that recovery can be related to the broader environmental and social context. Biological data describe ecosystem health and might include coral cover and diversity, fish abundance and seagrass density.

Physical data should include measurements of temperature, turbidity, sedimentation and nutrients. Socio-economic data include a wide range of parameters, such as number of fishermen and catch, visitation levels and diver numbers, income levels, employment rates and sewage disposal. Particular care must be taken in selecting methods for socio-economic monitoring, and it is important to seek advice on this important component of a monitoring programme.

5. The monitoring methods selected must suit the available financial and human resources and must not require skills beyond the capacity of the available personnel. A simplified level of monitoring that is reliable and accurate is better than either no monitoring or a complex programme that exceeds the organisation's capacity and results in unreliable data. In most cases, highly trained personnel are not necessary to collect the basic information needed to track changes due to bleaching.
6. The selection of monitoring sites must take into account the management strategies being used in protected and non-protected areas, and whether such sites should be on so-called *source* and *sink* reefs.
7. Adequate time must be allowed in work programmes for both the data collection and data analysis. The data collected should be compared with any previously collected data, and should be contributed to regional and global monitoring programmes as appropriate.

In many countries, lack of capacity within a management agency is a major constraint to setting up monitoring programmes. Several of the global and regional programmes organise training courses as required and may be able to

# Addressing Global Climate Change – the Ultimate Challenge

The suggestions made in this booklet will help managers to prepare for bleaching events or aid reef recovery after bleaching and other impacts have occurred; however, the problem of coral bleaching will become increasingly severe if accelerated global warming continues. According to the Intergovernmental Panel on Climate Change (IPCC), average SSTs in the tropics are expected to increase by about 1–2°C over the next 100 years (Watson *et al.* 1996). The bleaching event of 1998 has already shown that coral reef conservation can no longer be achieved without consideration of the global climate system.

In 1998, the 4th Conference of the Parties to the Convention on Biological Diversity (CBD) expressed its deep concern at the extensive and severe coral bleaching event and its possible relationship to global climate change. In response, the Executive Secretary of the CBD convened an Expert Consultation on Coral Bleaching in October 1999. The Experts produced a report and a set of recommendations on priority areas for action. This report was presented to the CBD's Subsidiary Body on Scientific, Technical and Technological Advice (SBSTTA-5), which further expanded on the proposed actions. The SBSTTA then forwarded their suggestions to the 5th Conference of the Parties to the CBD (COP-5), which (in May 2000) endorsed the Expert's recommendations and passed a decision to:

- Integrate coral reefs into the marine and coastal living resources element of their programme of work.
- Urge Parties, other Governments, and relevant bodies to develop case studies on coral bleaching and to implement response measures including research programmes, capacity building, community participation and education.
- Implement a specific work plan on coral reef conservation in cooperation with organisations such as the United Nations Framework Convention on Climate Change (UNFCCC), the Intergovernmental Panel on Climate Change (IPCC), the International Coral Reef Initiative (ICRI), and the Global Coral Reef Monitoring Network (GCRMN) and other international bodies.
- Urge the UNFCCC to take all possible actions to reduce the effect of climate change and to address the socio-economic impacts on the countries most affected by coral bleaching.

There is a clear link between the coral bleaching issue and the stated objectives of the UNFCCC. Article 2 of the UNFCCC explicitly acknowledges the importance of natural ecosystems and urges Parties to address climate change in a manner that will "allow ecosystems to adapt naturally to climate change". Through a resolution in October 1999, ICRI further encouraged the UNFCCC to address the coral bleaching phenomenon. In November 2000, the UNFCCC Conference of the Parties (COP-6) will consider actions to deal with the adverse effects of climate change, to facilitate transfer of technologies, and to develop capacity building programmes.

Photo: Edmund Green

**Healthy and diverse reef in the Turks and Caicos, Caribbean.**

A concerted effort is needed to ensure that progress in these areas continues. Addressing global climate change requires national and individual commitments to altering current life styles that have led to worldwide changes. As members of the global community, we must speak out loudly in support of international efforts to reduce harmful emissions of greenhouse gases. Coral reef managers and scientists should submit frequent reports on coral bleaching to their local policymakers and to their Convention delegates, expressing ongoing concern for the effects of climate change on coral reefs and other ecosystems, and calling for continued attention to the problem in international forums.

# References and Resource Materials

## Coral Bleaching, Climate Change and Reef Recovery

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