CORAL REEF DEGRADATION IN THE INDIAN OCEAN

Status reports and project presentations 1999

CORAL REEF DEGRADATION
IN THE INDIAN OCEAN
Status reports and project presentations 1999

Published by
CORDIO
SAREC Marine Science Program
Department of Zoology
Stockholm University
106 91 Stockholm
Sweden

ISBN 91-630-8329-9

Maps by Jeanette Bergman Weihed, Tellurit Datorgrafik
Produced by Niki Sporrong Enkla Ord, Uppsala
Layout by Tryckfaktorn AB, Hans Melcherson
Printed by Erlanders Gotab, 1999

Foreword

Corals as organisms and coral reefs as structures and ecosystems have fascinated scientists for centuries. Charles Darwin became well-known among natural scientists long before the publication of *The Origin of Species*, partly because of his studies of coral reefs and coral islands. Undoubtedly, this fascination for coral reefs is a direct result of the tremendous diversity of species, exemplified by the overwhelming number of fish of all shapes and colours, that inhabit the world's richest marine ecosystem.

Fundamental to the existence of coral reefs is the symbiosis between the reef-building coral polyp and the algae, known as zooxanthellae, that resides within the tissue of the polyp. From an ecological point of view, coral reefs provide opportunities to observe interactions, such as predation, competition and synergism, between reef-dwelling organisms, which furthers our understanding of community ecology. The formation of structures like reefs and islands of coral sand also provide prime examples of interaction between biology and geology.

Films depicting coral reef communities have become very popular with the general public. This has not only made coral reefs more attractive as tourist destinations, it has also increased the general awareness of how these ecosystems function and how important they are globally. For the human inhabitants of coastal and island communities in tropical and subtropical regions of the world, coral reefs provide the very basis for a sustainable livelihood. However, activities such as dynamite fishing, deforestation causing siltation, intentional use or accidental spill of chemicals, intensive tourism and the capture and trade of ornamental fishes threaten these peoples livelihoods and endanger a large proportion of the world's coral reefs, especially those adjacent to human populations. In addition, thermal pollution from power plants and the chemical industry has contributed to coral damage in some industrialised areas.

When corals become stressed, a typical response is "bleaching" and it occurs when the symbiotic algae are lost from the tissue of the coral polyp. For short periods, the polyp can survive without the algae, but unless the situation that caused the bleaching improves and new algae are incorporated into the tissue, the coral will die. Once dead, the reef is rapidly overgrown by other types of algae and the reef framework is eroded through actions of boring organisms. In certain regions of the world, intact coral reefs act as barriers that protect coastal areas from oceanic waves. When the reef framework is degraded, the reef is no longer able to prevent the passage of oceanic waves and, as a consequence, some islands and beaches may be severely eroded.

The destruction of coral reefs can also result in drastic changes in the fish populations associated with these ecosystems. When a reef is healthy, species of fish that eat coral are abundant. However, when a reef becomes degraded and many of the corals die and become overgrown by algae, corallivorous fish are replaced by fish that are algal grazers. If the reef degenerates further, reef dwelling species of fish may disappear and be replaced by species that are pelagic. Ultimately, biodiversity, in terms of species of fish, shellfish and other reef inhabitants, plummets. This leads to a drastic reduction in the catch of desired reef-dwelling fish by local fishermen that use traditional fishing methods. As a consequence, the food security of those dependent on coral reef fisheries is compromised, thereby increasing the risks of poverty.

There have been reports of coral bleaching in the past. However, the magnitude of the 1998 coral bleaching event, that resulted in massive death of corals in the Indian and Pacific Oceans and the Caribbean Sea, has never been reported before. Despite a strong correlation with extreme temperatures, the exact causes of coral bleaching are not entirely clear. Therefore, it is imperative, because of the importance of coral reefs for the food security and economy of human populations in tropical coastal and island communities of our globe, that understanding the reasons for coral bleaching be given the highest priority. Furthermore, there are general lessons to be learned from this mass mortality of corals as to the nature of stability and sensitivity of complex ecosystems. Such knowledge may prove invaluable in achieving sustainable development in a world experiencing widespread climatic change.

This report provides timely and important information on the extent of coral mortality throughout the Indian Ocean. The data contained within the report will provide a valuable reference point that will enable us to determine the environmental and socio-economic consequences of the 1998 bleaching event. The findings of the report provide an important contribution to the design of future initiatives to alleviate ecological and socio-economic impacts of coral bleaching. The CORDIO program fulfils an important role and merits full support.

Arne Jernelöv
Secretary General, FRN (The Swedish Council for Planning and Co-ordination of Research)

Indu Hewawasam
Environmental Specialist, World Bank

Anders Granlund
Head of Division, Sida (Swedish International Development Co-operation Agency)

Göran A. Persson
Director, MISTRA (Foundation for Strategic Environmental Research)

Lars Kristoferson
Secretary General, WWF-Sweden

Table of contents

Executive Summary

The reports in this volume summarize the extent of damage to the coral reefs of the Indian Ocean caused by the elevated temperatures in 1998. Most of the reports also contain information on the status of reefs 6 to 12 months after the events of 1998, thus describing the fate of dead corals, the first signs of recovery in some areas, and the secondary damage to other organisms dependent on the reef, such as fish. A brief summary of the results is given here.

EAST AFRICA

- Several areas suffered very high coral mortality. For example, surveys in Kiunga and Malindi (Kenya), Misali and Mafia (Tanzania), and Pemba and Inhacca (Mozambique) showed that 90–100% of the corals died after exposure to water temperatures that exceeded 32°C, mainly in March and April 1998. The mortality of corals culminated around mid-May. In some areas, however, corals continued to die until October.
- Following the event in 1998, coral cover appears to have been reduced to between 10 to 50% of previous levels in most areas along the coast of Kenya, Tanzania and northern Mozambique. In some areas the reduction is greater, i.e. up to or above 90%.
- Initial investigations indicate that fish communities associated with coral reefs were affected by the coral mortality and that, in general, herbivorous species increased while corallivorous species decreased.
- In most affected areas, the cover of algal turf on bleached and dead reefs increased significantly. On Kenyan reefs, for example, algal cover in many areas increased up to 200% as a result of the newly available substrate.

INDIAN OCEAN ISLANDS

- Coral mortality ranged from 50–90% over extensive areas of shallow reefs in Seychelles, Comoros, Madagascar and Chagos. In some areas (around Mahe, Seychelles), mortality was close to 100%.
- By the end of 1998, algal turf covered coral reefs throughout much of the region.
- Monitoring of potentially toxic, epiphytic dinoflagellates has shown drastically increased concentrations in areas with dead corals.
- By early 1999, much of the dead coral in Chagos was reported to be eroded to rubble, preventing recolonisation. In Socotra Archipelago, coral rubble has been washed ashore and can be found in piles on the beach.
- Preliminary assessments of the reef fish communities in Chagos indicate that abundance and diversity have decreased to less than 25% of their former levels.

SOUTH ASIA REGION

- Bleaching was reported down to a depth of 40 m in Sri Lanka and 30 m in Maldives, as a result of water temperatures of approximately 35°C during the period April to June, 1998.
- In Sri Lanka and Maldives, nearly 90% of the corals died in many areas. In the Hikkaduwa and Bar reefs of Sri Lanka, close to 100% of the corals died, and by the end of 1998, these reefs were covered by thick algal turf. In May 1999, large areas of reefs in Maldives showed few signs of recovery.
- In India, surveys indicated mortality between 50 and 90% in the reefs in Gulf of Mannar, Andaman Islands and Lakshadweep.
- Assessments of the reef fish communities showed drastic reductions in butterfly fish numbers in Sri Lankan reefs.

Rationale

Coral reefs throughout the tropics suffered extensive mortality during 1998. In large parts of the Indian Ocean, South-East Asia and the Caribbean, more than 50% of the corals died. In several areas the mortality was over 90%. The coral mortality was preceded by massive bleaching, a process when the coral polyps lose their symbiotic algae and become transparent. What the observer sees as white coral is the calcium carbonate skeleton covered by transparent living tissue.

Bleaching is a well-known stress response in corals. It is caused by increased temperatures, low or high irradiance, high UV-radiation, abnormal salinity, sedimentation or bacterial infection. In most cases when massive bleaching is observed on reefs, the cause is probably a synergistic effect of these factors. If the stress is severe or lasts long enough, the corals will die. In 1998, practically all the bleaching and the subsequent mortality in the Indian Ocean occurred between April and June, and coincided with significantly increased sea surface temperatures (Wilkinson *et al.*, 1999).

FISHERIES

Coral reefs are some of the most productive ecosystems on Earth (Grigg *et al.*, 1984), and are certainly the most productive and species-rich environments in the oceans. For example, no other ecosystem, marine or terrestrial, support as many species of vertebrates as coral reefs. A single reef in the Indian Ocean may provide habitats for several hundred fish species within an area of only a few square kilometers. About 25% of the world's fish species are, in some way, dependent on coral reefs for their survival. The reefs provide feeding, spawning and nursery grounds, and shelter. As a consequence, coral reefs support most of the coastal fishing in tropical developing countries, upon which a large portion of the human coastal population depends for their supply of animal protein. The production potential, in terms of catch of fish, has been estimated to between 5 and 25 tons per square kilometer of reef per year. In total, coral reef fisheries has been estimated to yield at least 10% of the world's fish catches and 25% of the fish catches in the developing world (Munro, 1996; Roberts *et al.*, 1998). This contribution is probably significantly higher, as much of the fish caught by small scale traditional fishermen in developing countries are consumed by them and their families, and therefore unaccounted for in the statistics.

TOURISM

Coastal tourism, the single most important income earner in many of the countries of the Indian Ocean, is intimately linked with coral reefs. In countries such as Sri Lanka, Maldives, Seychelles and Kenya, dive and snorkel tourism are important components of the industry. Despite this, no detailed estimations of the direct monetary value of the tourism sector of the reefs in the Indian Ocean exist. The reefs of Florida, however, have been calculated to attract about $ 1.6 billion per year, and tourism on the Great Barrier Reef generates $ 1.5 billion in Queensland alone (Birkeland, 1997; Done *et al.*, 1996).

EROSION

Coastal erosion is rapidly becoming an urgent problem in many countries in the Indian Ocean region. Intact coral reefs protect the coastline against wave erosion. A healthy reef will respond to sea level rise by growth. The fringing coral reef along the coast is not only protecting the coast against erosion, but also protects coastal lagoons and other coastal habitats, such as seagrass beds.

DESTROYING THE RESOURCE

Other values of the coral reefs include their potential value as a source of new pharmaceutical products. Despite the apparent value of coral reefs to humans, most of the reefs around the world are threatened or have already been destroyed by human activities. According to a recent study, 58% of the world's coral reefs are potentially threatened by human activities (Bryant *et al.*, 1998). Reefs near coastal towns and villages, particularly, are under serious stress from land-based pollution and coral mining. Damaged or destroyed coral reefs can be found in 93 countries, most of which are located in South-East Asia, East Africa and the Caribbean. Assessments of the status of reefs carried out in 1997 and 1998, showed that a majority of the reefs were severely overfished and most high-value organisms were missing (Wilkinson *et al.*, 1999).

On the whole, siltation caused by soil erosion and the use of destructive fishing techniques are causing dramatic reductions in diversity and abundance of corals and other reef organisms in most areas around the Indian Ocean. The widespread use of dynamite in fishing in large parts of East Africa, and of poisons in South-East Asia are particularly serious problems. Also, in many countries around the Indian Ocean, poorly managed tourism is a serious source of degradation of coral reefs.

THE CORDIO PROGRAM

The CORDIO program was launched in the last months of 1998, as a response to the coral mortality throughout the Indian Ocean. The aim of the program is to provide information on the extent and speed of coral reef degradation in the Indian Ocean region. The program supports targeted studies and monitoring in several countries in the region. Ecological as well as socio-economic effects are studied. Investigations also focus on natural recovery processes on different reefs, and methods of mitigation of damage and artificial recovery of reefs. Finally, the program supports alternative livelihoods among local human populations affected by the coral mortality. During its intial phase, the CORDIO program is supported by Sida (Swedish International Development Co-operation Agency), FRN (The Swedish Council for Planning and Co-ordination of Research), MISTRA (Foundation for Strategic Environmental Research), WWF-Sweden, and the World Bank through Dutch Trust Funds.

REFERENCES

Birkeland, C. (ed). 1997. *Life and death of coral reefs.* Chapman and Hall, New York.

Bryant, D., Burke, L., McManus, J. and Spalding, M. 1998. Reefs at risk: a map-based indicator of threats to the worlds coral reefs. World Resources Institute, Washington DC.

Donen, T.J., Ogden, J.C. and Wiebe, W.J. 1996. Biodiversity and ecosystem function of coral reefs. In: *Functional roles of biodiversity: a global perspective.* Mooney, H.A., Cushman, J.H., Medina, E., Sala, O.E. and Schulze, E.D. (eds). John Wiley & Sons, Chichester, UK, pp 393–429.

Grigg, R.W., Polovina, J.J. and Atkinson, M.J. 1984. Model of a coral reef ecosystem. III. Resource limitation, community regulation, fisheries yield and resource management. *Coral reefs* 3: 23–27.

Munro, J.J. 1996. The scope of tropical reef fisheries and their management. In: *Reef Fisheries.* Polunin, N.V.C. and Roberts, C.M. (eds). Chapman and Hall, London, pp 1–14.

Roberts, C.M., Hawkins, J., Schueler, F.W., Strong, A.E. and McAllister, D.E. 1998. The distribution of coral reef fish biodiversity: the climate-biodiversity connection. Fourth Session of the Conference of the Parties of the United Nations Framework Convention on Climate Change. Buenos Aires, Argentina, 2–13 November, 1998.

Wilkinson, C., Linden, O., Cesar, H., Hodgson, G., Rubens, J. and Strong, A.E. 1999. Ecological and socio-economic impacts of 1998 coral bleaching in the Indian Ocean: an ENSO impact and a warning of future change? *Ambio* 28 (2): 188–196.

STATUS REPORTS FROM DIFFERENT REGIONS

Coral reef ecosystems in South Asia

Arjan Rajasuriya[1], **Maizan Hassan Maniku**[2], **B R Subramanian**[3] & **Jason Rubens**[4]

[1] *National Aquatic Resources Research and Development Agency, Sri Lanka*

[2] *Ministry of Fisheries, Agriculture and Marine Resources, Maldives*

[3] *Dept of Ocean Development, India*

[4] *Global Coral Reef Monitoring Network, South Asia Programme*

This article is a revised and shortened version of a longer review article presented by Arjan Rayasuria at "International Tropical Marine Ecosystems Management Symposium" in 1998, and later published by South Asia Co-operative Environment Programme (SACEP).

ABSTRACT

In April to June 1998, an El Nino-related increase in sea surface temperatures caused extensive damage to shallow-water coral reefs in South Asia, which resulted in unprecedented coral bleaching. In many reef areas in South Asia, the high coral mortality has greatly overshadowed other observable impacts.

There appears to be an increased awareness in national government sectors, and to some extent among resource-user groups, that better management is required for the future sustainability of coral reef resources in South Asia. Training conducted through the Global Coral Reef Monitoring Network (GCRMN) and the South Asia Co-operative Environment Programme (SACEP) have contributed to enhanced monitoring capabilities. At a national level, new programmes have been initiated in Sri Lanka, Maldives and India. In Bangladesh and Pakistan, new programmes that would broadly fall under the theme of integrated coastal zone management are planned for the near future.

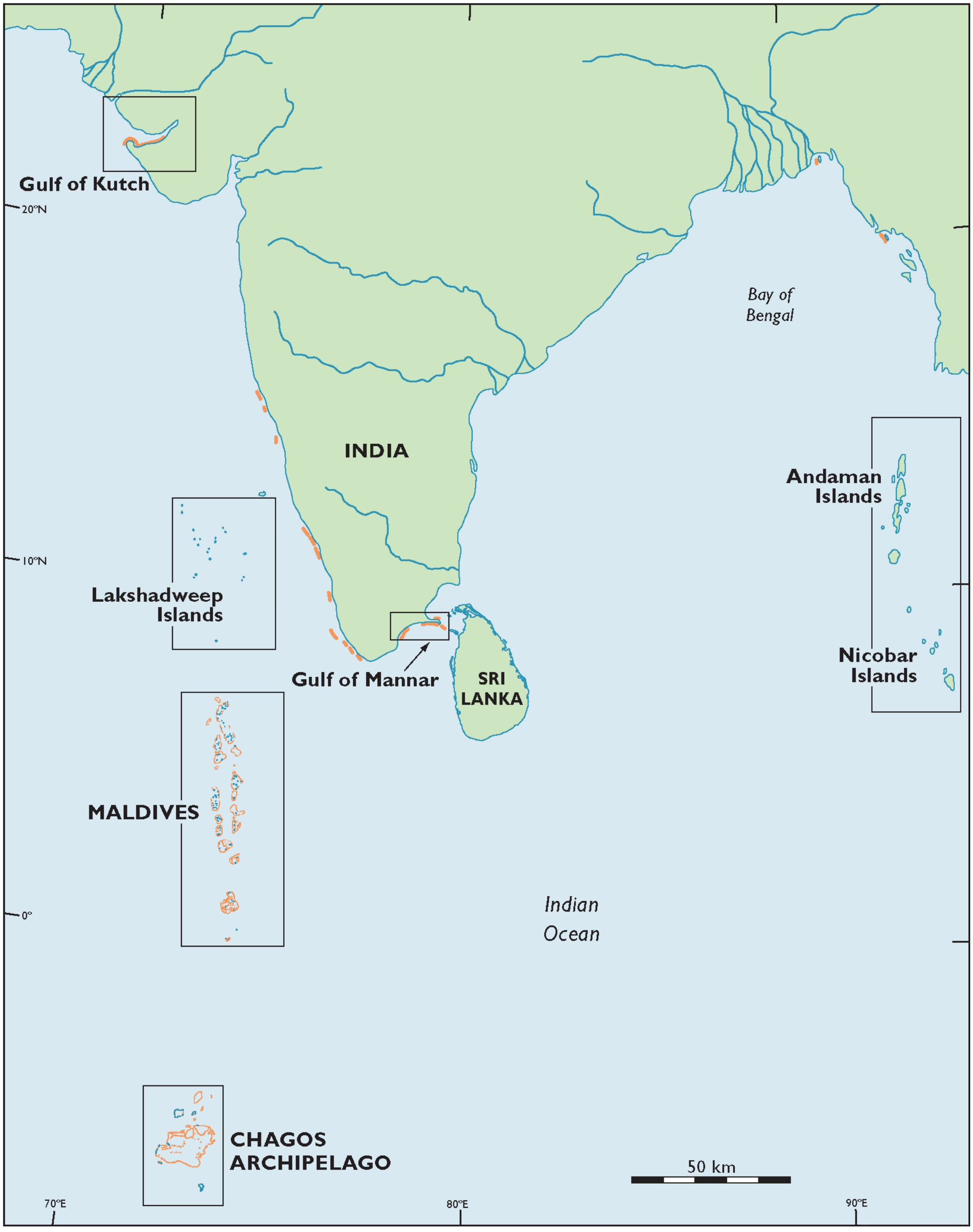
Nevertheless, active management of coral reefs and related resources remains at a relatively low level, mainly due to economic under-development of poor coastal communities, poor planning and co-ordination of development activities, and a lack of trained personnel and equipment. The inability to implement existing laws and regulations continues to be a major cause of reef degradation.

INTRODUCTION

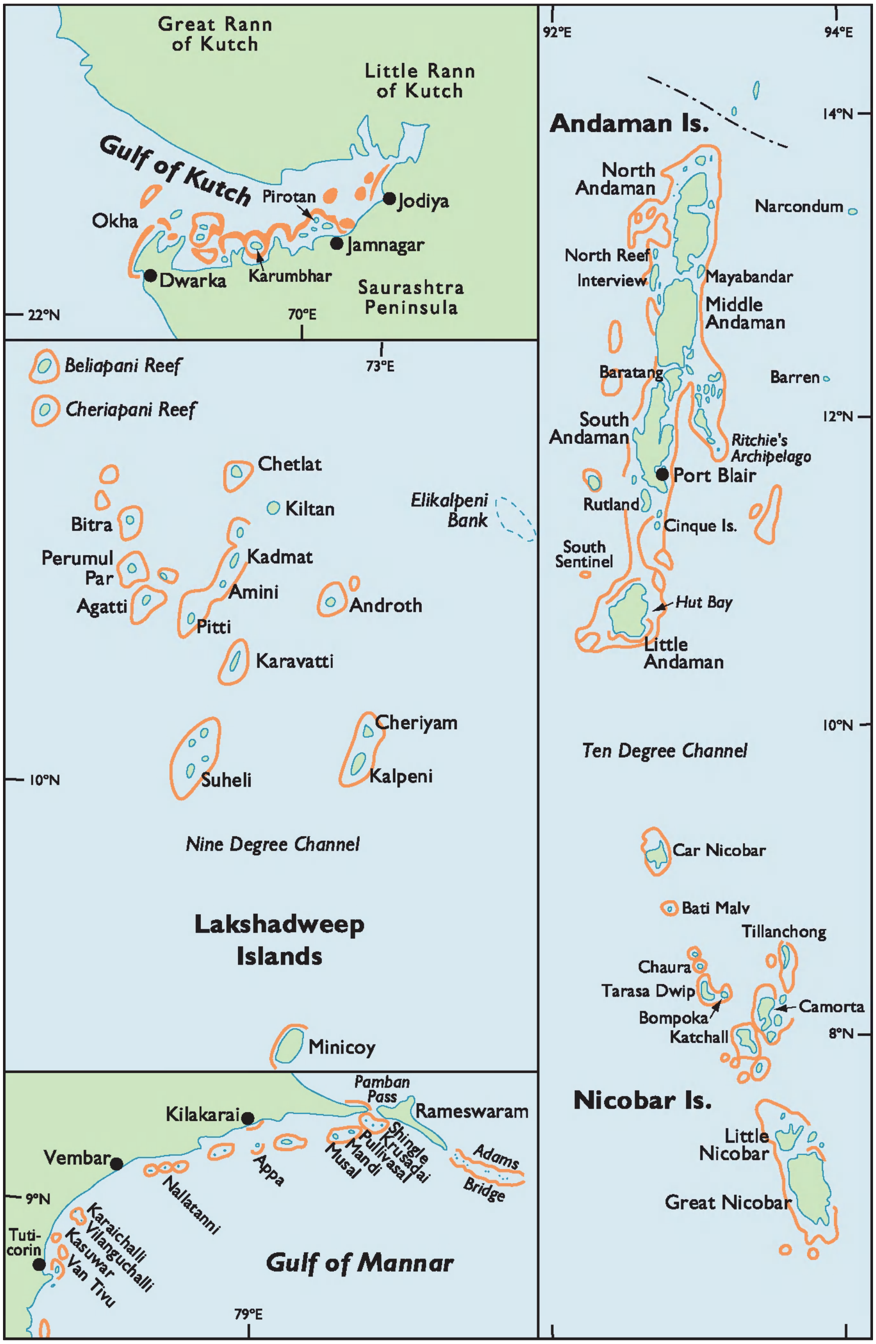
This report reviews the status of coral reefs in South Asia. It summarises progress in implementation of management initiatives and major changes to reef status since the state of affairs reported by White and Rajasuriya at the International Coral Reef Initiative (ICRI) Workshop at Dumaguete City in the Philippines in May 1995. Information has also been obtained from recent workshop proceedings and research reports, and through consultation with relevant government officers and scientists in the region.

In South Asia, the major coral reefs are situated in the Lakshadweep-Maldives-Chagos archipelagos. Extensive fringing coral reefs occur around the Anda-

The South Asia region of the Indian Ocean. Coral reefs are marked with red. More detailed maps are provided for areas of particular interest (see pages 13, 20, 21 and 28).



The coral reefs of India. Mainland India has two main areas of reef development, the Gulf of Kutch and the Gulf of Mannar. Coral reefs also surround the Lakshadweep Islands, the Andaman Islands and the Nicobar Islands. All Indian reefs were affected by the 1998 bleaching event, with mortality as high as 80% of the Andaman and Nicobar reefs.



man and Nicobar islands. Mainland India has two widely separated areas of reef development: the north-west (Gulf of Kutch) and south-east (Gulf of Mannar). Isolated patch reefs are also known to occur along the western coast. In India, coral reef development is largely inhibited by massive freshwater and sediment input. In the north-west, cold upwellings may affect the growth and condition of corals (Scheer, 1984; Stoddart, 1971). In Bangladesh, coral reefs at St Martin's Island are eroding due to high loads of sediment, action of cyclones, storm surges and human activities. Coral reef development in Pakistan is poor, although isolated patches are found to a depth of 20 m (Kazmi & Kazmi, 1997). The Chagos Archipelago, which is British Territory, is reported to have the best coral reefs in the Indian Ocean (White & Rajasuriya, 1995). Many fringing and offshore patch reefs are found around Sri Lanka, with extensive coral reefs in the Gulf of Mannar (Rajasuriya *et al.*, 1995).

Most coral reefs in South Asia were adversely affected by the event of coral bleaching in mid-1998. Extensive damage to reefs has been reported from Maldives, Lakshadweep, Andaman Islands, Sri Lanka and the Gulf of Mannar in India. There is a lack of information on the impact of bleaching in other locations, such as St Martin's Island in Bangladesh.

Coral mining, increased sedimentation, destructive fishing methods, uncontrolled harvesting, increased pressure from tourism and pollution continue to degrade reefs in South Asia. This is mainly due to the rapidly increasing coastal population, and a lack of employment opportunities, alternative sources of employment and of material and trained manpower to implement existing laws and regulations, as well as a failure to establish and manage marine protected areas. The status of reefs within protected and other areas have been summarised in Table 1 & 2.

An important development in coral reef conservation and management in the South Asian region was the establishment of Global Coral Reef Monitoring Network (GCRMN) South Asia in July 1997 by the International Coral Reef Initiative (ICRI). A regional co-ordinator and individual country co-ordinators for India, Maldives and Sri Lanka were appointed to facilitate monitoring, training, networking and management of coral reefs in South Asia. The country co-ordinators are attached to government organisations, namely the Department of Ocean Development (DoD) in India, the Ministry of Fisheries and Agriculture (MFA) in Maldives and the National Aquatic Resources Research and Development Agency (NARA) in Sri Lanka. The South Asia Co-operative Environment Programme (SACEP), which is the secretariat for the South Asian Regional Seas Programme of UNEP, is the focal point for ICRI activities in the South Asian region.

Through the GCRMN programme, two regional training workshops on biophysical and socio-economic monitoring have been held in 1998, in the Maldives and Lakshadweep respectively. Pilot monitoring exercises on the condition of coral reefs and the socio-economic status of local communities have been carried out in the Maldives and the Gulf of Mannar in India. Furthermore, a number of activities have been planned, and pilot monitoring exercises will be carried out in India, Andaman Islands and Lakshadweep, Maldives and Sri Lanka. New initiatives and laws regarding coral reef conservation and management in South Asia are listed in Table 3.

In addition, there are separate initiatives within individual countries on integrated coastal zone management (ICM). In India, financial assistance from the World Bank has been obtained to develop management plans for selected critical habitats, including coral reefs. In Bangladesh, the government has developed appropriate national laws for conservation and management of critical habitats and five projects have been initiated, but many of the laws focus on the conservation of mangroves and wetlands. IUCN is planning to develop a Marine and Coastal Protected Area in Pakistan, and conservation laws for critical habitats are now being drafted under the Biodiversity Action Plan.

Awareness has been increasing in South Asia, particularly through workshops and media during the

Table 1. Status of protected and unprotected coral reef areas in South Asia

Country	Locations/Protected areas	Management status	Current threats
BANGLADESH	St Martin's Island (identified for maximum protection)	No management at present. Action plan proposed.	Coral mining, sedimentation, mangrove cutting, pollution, souvenir collection, tourism and boat anchoring.
CHAGOS	No protected areas. Protection has been recommended.	Reefs are well protected due to the absence of natives and the presence of a military base at Diego Garcia.	Fishing pressure on the outer reefs.
INDIA (mainland)	Gulf of Kutch Marine National Park	Inadequate protection	Sedimentation, coral mining, mangrove cutting, sand mining, population pressure, commercial shell collection, fisheries and industrial development.
	Gulf of Mannar Biosphere Reserve	Inadequate protection. Zoning has been recommended for educational, scientific and recreational activities. A management plan is being developed.	Coral mining, sand mining, pollution, sedimentation and fisheries.
	Reefs outside protected areas	Very weak or none.	Sedimentation, coral mining, mangrove cutting, sand mining, population pressure, pollution, fisheries and industrial development.
ANDAMAN ISLANDS (India)	Wandur Marine National Park (Mahatma Gandhi Marine National Park)	Coral reef resources relatively well protected within the park.	Sedimentation, souvenir collection, tourism and crown-of-thorns starfish.
	Reefs outside protected areas	Weak implementation of laws.	Sedimentation due to dredging and logging, sand mining, erosion, crown-of-thorns starfish, tourism and pollution.
NICOBAR ISLANDS (India)	All of the protected areas are terrestrial. Several sites have been proposed.	Weak.	Sedimentation and crown-of-thorns starfish.
LAKSHADWEEP ISLANDS (India)	One declared National Park. Several sites have been proposed.	Relatively well regulated tourism activities. Activities by locals are less well regulated.	Coral mining, sedimentation and coral destruction due to dredging, and population pressure.
GULF OF KUTCH (India)	National Marine Park	Management plan under preparation.	Coral mining, sedimentation, mangrove damage and fishing.
SRI LANKA	Hikkaduwa Nature Reserve (former Hikkaduwa Marine Sanctuary)	Poor to non-existent.	Sedimentation, pollution, boat anchors, glass bottom boats, pollution and tourism.
	Bar Reef Marine Sanctuary	No management.	Fishing and crown-of-thorns starfish.
	Reefs outside protected areas	Implementation of laws and regulations is weak or non-existent. Collection and export of several species have been banned. Size regulations for spiny lobsters.	Coral mining, sedimentation, destructive and uncontrolled fishing activities, excessive harvesting.

Table 1. (Cont.)

Country	Locations/Protected areas	Management status	Current threats
MALDIVES	15 protected sites Reefs outside protected areas	Well managed. Relatively well managed (island resorts manage their own reef areas). Laws and regulations are implemented. Export of many marine species is prohibited and harvesting is regulated.	None known. Dredging and construction, sewage.
PAKISTAN	No protected areas.	None. IUCN and BAP have identified a need for a Marine and Coastal Protected Area Project.	Sedimentation, coral collection for medicinal purposes and tourism.

Table 2. Status of reefs in South Asia (update from 1995)

Bangladesh	India	Maldives	Pakistan	Sri Lanka
Continuing major impacts from human activities such as coral mining, collection of souvenirs, pollution, increased sedimentation due to mangrove destruction and siltation from major rivers. Reefs around St Martin's Island continue to degrade. Whether coral reefs around St Martin's Island were bleached is not known.	Damaging activities such as coral mining, souvenir hunting, destructive fishing, pollution, and increased sedimentation continue to degrade reefs. The 1998 bleaching event caused extensive damage to reefs in the Gulf of Mannar region, Lakshadweep and Andaman Islands.	Relatively well managed, except some development activities where EIA and monitoring has not been carried out according to the laws. Also, dredging of boat harbours and reclamation for development increase sedimentation and cause damage to reefs. The 1998 bleaching event caused extensive damage to coral reefs in many atolls, and was observed to depths of about 30 m. Shallow reefs lost almost 90% of their live coral cover. Corals that were completely destroyed were mainly branching and tabulate *Acropora* spp, *Echinopora* spp and *Pocillopora* spp.	No new information. Very little has been investigated.	Damaging activities such as coral mining, souvenir hunting, uncontrolled harvesting, destructive fishing practices, tourism impact, pollution and increased sedimentation continue to degrade reefs. The 1998 bleaching event caused extensive damage to coral reefs. Shallow fringing reefs lost nearly 90% of their live coral cover and bleached corals were observed to a depth of 42 m along the east coast. Corals that were completely destroyed were mainly branching and tabulate *Acropora* spp, *Echinopora* spp. and *Pocillopora* spp. The fringing reef around Pigeon Islands in Trincomalee on the northeast coast was not affected, while reefs at Batticoloa on the east coast were.

Table 3. New initiatives and laws in coral reef conservation and management in South Asia

Bangladesh	India	Maldives	Pakistan	Sri Lanka
Government has endorsed the ICM approach to management. Five conservation and management programmes have been initiated through the National Conservation Strategy and National Environment Management Action Plan, but most are concerned with mangrove and wetland protection. Maximum protection has been proposed for coral reefs of St Martin's Island.	An action plan for the management of coral reefs in Andaman, Nicobar Islands and Gulf of Mannar reefs is being prepared. Little Andaman, Great and Little Nicobar and sections of Lakshadweep Islands have been identified for protection. A programme called the Coastal & Marine Area Management Programme with World Bank funding has identified 11 sites with critical habitats for ICM.	Integrated Reef Resources Management (IRRM) has identified four new areas (Vaavu, Meemu, Faafu, Dhaalu Atolls) for marine protected areas. Establishment of Environmental Research Unit at Villingili. Coastal zone mapping project at Baa and Raa Atolls. GEF funded CZM project initiated through Min. of Planning, Human Resources and Environment. National Biodiversity Strategy & Action Plan and Integrated Atoll Development Project under preparation.	IUCN has planned to develop Marine & Coastal Protected Areas. Biodiversity Action Plan is being developed. Systematic surveys of coral reefs are expected in the near future through the implementation of the above plans.	Revised Coastal Zone Management Plan (1997), prepared. New Fisheries and Aquatic Resources Act (1996) passed. Two ICM projects with ADB and GTZ funding initiated in 1998 in the southeastern coastal belt. 23 sites have been recommended for SAM planning under the new CZM Plan. Management plans prepared for Bar Reef Marine Sanctuary, Hikkaduwa M. S. and Rekawa Lagoon on the south coast. Upgrading Hik. M. Sanc. to a Nature Reserve on 14 Aug 1998. Proposal being developed by NARA for the declaration of a Fishery Protected Area at Great & Little Basses Reefs in the southeast. A 3 year study was initiated in late 1995 with support from the Darwin Initiative of UK jointly executed by NARA and Marine Conservation Society of UK for better management of marine ornamental fish sector (workshops have been held for the ornamental fish collectors). Two handbooks have been prepared for better management. Continued support from Sida/SAREC Marine Science programme for NARA in coral reef research for improved management up to the year 2000. Preparation of the National Biodiversity Conservation Action Plan.

International Year of the Coral Reefs in 1997 and the UN International Year of the Oceans in 1998. The environment as a subject has been introduced into school curricula in India, Maldives, Sri Lanka and Bangladesh.

CORAL BLEACHING IN SOUTH ASIA

Coral reefs in all major tropical oceans were adversely affected by bleaching in 1997–1998. This coincided with climate changes and a strong El Niño event. In South Asia, extensive areas of coral reefs were damaged during April and May in 1998, due to elevated sea surface temperatures. For example, sea surface temperatures of the southern and western coastal waters of Sri Lanka increased to about 35°C, which is approximately 5°C higher than normal daytime sea surface temperatures. The increase lasted for about 1–2 months, and resulted in unprecedented coral bleaching in a number of countries in South Asia. The impact was observed at slightly different time frames at different locations. Available information indicates that extensive bleaching of corals occurred in the Maldives, Lakshadweep, Sri Lanka, Gulf of Mannar and the Andaman and Nicobar islands. Whether coral reefs in other areas of South Asia, such as the Gulf of Kutch and the Chagos Archipelago, have been similarly affected is not known.

The extent of bleaching has varied, depending on location, depth, coral condition prior to bleaching, and sometimes on the species itself. During a survey conducted in September 1998 along the East-coast of Sri Lanka, bleached corals were observed to a depth of 42 m. In the Maldives, bleaching has been reported to a depth of 30 m. The most severe impacts of bleaching was observed on shallow coral reefs (to 10 m depth), consisting of branching and tabulate *Acropora* spp. Most of the bleached colonies were severely damaged and died within two or three weeks. Turf and filamentous algae now cover the dead corals. Many other organisms, such as sea anemones and soft corals that contain zooxanthellae, were also bleached.

In the whole region, the impact of bleaching has been similar, with branching and tabulate corals being the most vulnerable (Rajasuriya, in prep). Some coral reef areas have not been affected, probably due to temperature changes caused by local currents and nearby deep-water. In Trincomalee, along the north-east coast of Sri Lanka, where there is a canyon more than 1,000 metres deep close to the shore, corals did not bleach. In the Maldives, some pinnacle reefs situated in deep channels along the rims of atolls were not bleached to the same degree as fringing reefs within the atolls.

In Sri Lanka and the Maldives, some recovery of bleached corals has been observed. Massive coral colonies began to regain their colour about 2 or 3 months after the initial bleaching, and many have now recovered completely (Rajasuriya, per obs and com). Along the southern coast of Sri Lanka, branching *Acropora formosa* has also begun to recover. In spite of this, it may take several years or decades for coral reefs to regain their former status. The damage caused by the bleaching event was greater than any human impact on corals and coral reefs. The recovery of the damaged reefs, however, may ultimately depend on the ability to control chronic problems such as high levels of sedimentation and destructive fishing practises.

STATUS OF REEFS

Bangladesh

St Martin's Island, also known as "Narikel Jinjira Island", is the only coral reef area in Bangladesh. Coral cover is generally low (4–10%). Reef conditions are poor due to high level of sedimentation, cyclones and storm surges, and fluctuations in salinity caused by freshwater input from major rivers. In addition, human activities continue to cause physical damage to living sections of the reef. Among these, coral mining for construction is the main cause of reef damage (White & Rajasuriya, 1995; Mollah, 1997). Furthermore, destructive fishing methods, collection of souvenirs, boat anchoring, pollution and tourist activities threaten the survival of corals around St Martin's Island (Mollah, 1997). However, some undisturbed areas have been identified for maximum protection. There is no information on coral bleaching for Bangladesh.

Chagos

Chagos is located in southernmost part of the Chagos-Laccadive chain of atolls. All atolls and submerged banks have actively growing reefs. It is the largest expanse of undisturbed reefs in the Indian Ocean, as well as some of the richest. The inaccessibility and uninhabited nature of the islands (except Diego Garcia) protect the archipelago. Currently, there is no legal protection, although the Corbett Action Plan for Protected Areas of the Indo-Malayan Realm has identified Chagos as an area with marine conservation needs (Thorsell, 1985; UNEP/IUCN, 1988). For information on bleaching in the Chagos Archipelago, see *"Coral mortality in the Chagos Archipelago."*, page 27.

India

The coral reefs of India are widely scattered (see maps, pages 12–13), from the Gulf of Kutch in the north-west, the Gulf of Mannar, Palk Bay, and the Lakshadweep Islands to the islands of Andaman and Nicobar (ENVIS, 1998; White & Rajasuriya, 1995). Patchy out-crops and deep-water formations can also be found along the western coast.

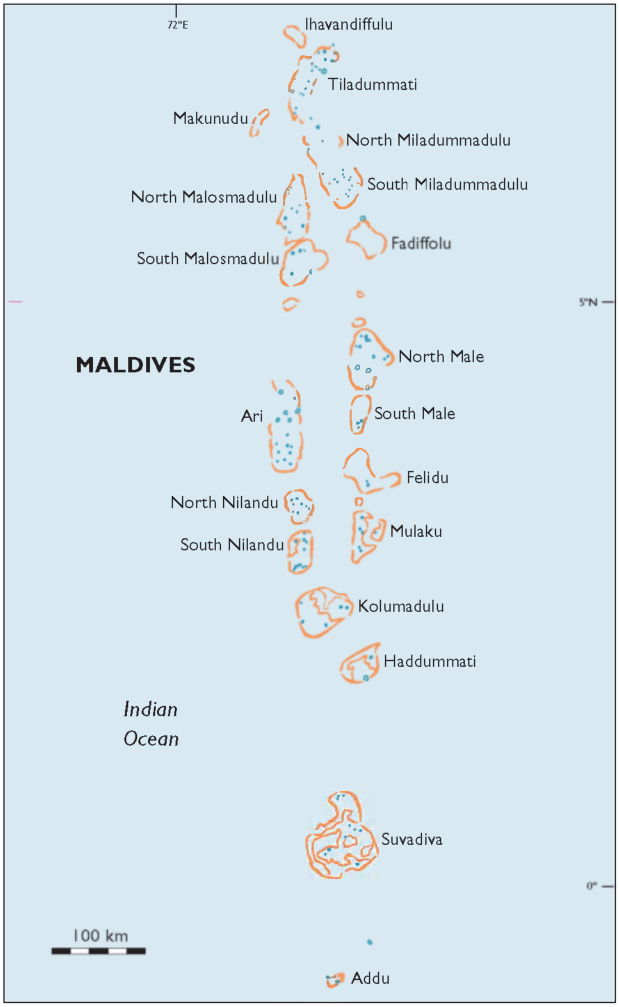
Coral reefs off the mainland coast continue to be exploited for extraction of lime, reef fisheries and collection of ornamental shells, sea fans, seaweed, sea cucumbers, spiny lobsters and sea horses (Hoon, 1997). Agricultural and industrial run-off, pesticides and oil pollution adds to the degradation of mainland reefs. But sedimentation, which is very high in the Gulf of Kutch as well as in the Bay of Bengal, might have the most significant impact. In recent years, sedimentation and pollution have increased in coastal waters due to increasing discharge from land. In the Gulf of Mannar and Palk Bay, coral and sand extraction are persistent problems. Some coral reefs off Tuticorin in the Gulf of Mannar are reported to have disappeared completely due to coral mining (Devaraj, 1997). Extraction of coral also occur in the Gulf of Kutch. Coral reefs have also been damaged by crown-of-thorns starfish (*Acanthaster planci*) and other natural causes, such as the white band disease and boring organisms (Devaraj, 1997).

The recent event of coral bleaching has adversely affected shallow reefs in the Gulf of Mannar, Lakshadweep and Andaman Islands. In the Gulf of Mannar, 85% of the corals were bleached in May–June 1998 (Venkataraman & Jeyabaskaran, in prep). A subsequent survey revealed that mortality was 72.6% (Kumaragura, in prep). Surveys in the Andaman Islands in May 1998, recorded that 65–80% of the corals in different areas had bleached. Repeated surveys in September revealed that coral mortality was higher than 50%. Surviving taxa included *Porites* spp., *Platygyra* spp., *Favites* spp. and *Fungia* spp. (Soundarajan, in prep). A survey of the shallow lagoons of Lakshadweep showed that 74% of the live corals were wholly or partially bleached (Arthur and Madhusan, in prep). In September, another survey of an outer reef slope of Lakshadweep showed that less than 5% of a reef previously known to divers for its abundant coral cover was alive. For information on coral bleaching in the Gulf of Kutch, on the north-western coast of India, see "*Status report India*", page 25.

Maldives

Extensive coral reefs in good condition are found throughout the Maldives (White & Rajasuriya, 1995; Brown, 1997). Corals used to be the main material for construction, but this is gradually being phased out. The current trend is to use cement blocks instead (Naseer, 1997). However, development activities and an increasing use of reef resources continue to have a negative impact on some reef areas.

The increase in sea surface temperatures in 1998 caused extensive bleaching and destroyed large areas of shallow-water coral reefs throughout the archipelago. Preliminary data on live coral cover from surveys of some sites in Maldives in April 1999 show no difference



Extensive coral reefs are found throughout the Maldives (areas marked with red). Large areas of shallow-water reefs were destroyed in 1998.

from post-bleaching surveys in September last year. These sites, on the shallow reef flats of Felidhoo Atoll, still have a live coral cover of between 1 and 3 percent. Algae cover the coral reef area, and observation studies indicate high numbers of herbivorous fish (Zahir, 1999).

Pakistan

In Pakistan, the environmental conditions are unfavourable for coral growth, and corals are not well developed. Isolated, small patches of living coral colonies are found on hard substrates (UNEP/IUCN, 1988). Live corals have been recorded at several locations along the coast, to a depth of 20 m (Kazmi & Kazmi, 1997). Land based pollution, sewage, industrial effluents, sedimentation and dredging appear to be the main problems for reefs in Pakistan's coastal waters, but corals are also collected by local fishermen, to be used in traditional Islamic medicine. Near Churna Island, destructive fishing methods contribute to the degradation of the marine environment (Kazmi & Kazmi, 1997). There is no information available on bleaching in Pakistan.

Sri Lanka

Sri Lankan reefs are mostly fringing or offshore patch reefs. The offshore reefs are in better condition. Live coral cover on some patch reefs, as well as on undamaged near-shore reefs, exceeds 50% (Rajasuriya & White, 1995). Many other near-shore reefs have a low coral cover due to damaging human activities and sedimentation (Rajasuriya *et al.*, 1995; Rajasuriya & White, 1995).

Many coral reefs in Sri Lanka have been severely degraded by human-induced damage. Coral mining, increasing sedimentation caused by poor land-use practices, destructive fishing methods, boat anchoring, tourism-related activities, uncontrolled harvesting and pollution continue to cause damage to reefs (Rajasuriya *et al.*, 1995; Rajasuriya & Wood, 1997). In addition, reefs along the north-west and east coasts are threatened by periodic infestations of the Crown-of-thorns starfish (De Bruin, 1972; Rajasuriya & Rathnapriya, 1994).

The recent event of coral bleaching destroyed large areas of the shallow-water corals along much of the Sri Lankan coastline. However, coral species such as *Montipora aequituberculata* and *Montipora digitata* were hardly affected, and a number of species of columnar (e.g. *Psammacora digitata*) and massive corals (e.g. *Diploastrea heliopora*) were only partially bleached. The shallow coral reefs of both the Hikkaduwa and the Bar Reef Marine sanctuaries in Sri Lanka were adversely affected. Nearly 90% of the living corals were bleached

The coral reefs around Sri Lanka are mostly fringing reefs or offshore patch reefs. The fringing reefs were adversely affected by coral bleaching and in some areas nearly 90% of the corals were destroyed.

and then destroyed. Butterfly fish and other coral dependent species have decreased drastically in the damaged areas. During a recent survey (October 1998) of a reef patch at the Bar Reef Marine Sanctuary, only two butterfly fish were found in an area of 500 m^2 (Rajasuriya, in prep).

Current surveys reveal that branching *Acropora* spp. and *Pocillopora* spp. are very slow to recover. In the shallow waters (to 3 m depth), mortality has been nearly 90% and most are now completely gone. However, other corals, such as *Porites* and *Favia*, have recovered. The situation is the same at Hikkaduwa, Unawatuna, Weligama, Bar Reef Marine Sanctuary and Batticoloa, but Trincomalee on the East-coast was not bleached. In deeper areas, beyond 10 m to about 30 m, most of the corals have recovered. At these depths, even little *Acropora* and *Pocillopora* have recovered. The impact of coral mortality is most obvious for butterfly fish. In the shallows, they are very scarce. Herbivores have increased in the shallow areas, and feed on the turf and filamentous algae that cover the dead corals.

Some *Acropora formosa* that survived at Weligama has been transplanted to the Hikkaduwa Reef. They have caught on well, and butterfly fish are already attracted to the patch.

RESEARCH AND MONITORING

During September 29 to October 2, 1998, the Department of Science, Technology and Environment (DST) of Lakshadweep in association with the Global Coral Reef Monitoring Network (GCRMN South Asia) undertook the first ever Reef Check survey in India, at Kadmat Island, Lakshadweep. Live coral cover at the survey site, which was reported to exceed 80–90% before April 1998, was reduced to less than 5%. In Sri Lanka, the Reef Check was carried out by NARA in association with the Sri Lanka Sub-Aqua Club at Pigeon Island in Trincomalee. There were no bleached corals in Trincomalee. A survey carried of the South-coast in August revealed that Hikkaduwa Marine Sanctuary had lost more than 90% of its live coral. In Maldives, the Reef Check was carried out by the Marine Research Section and the recreational dive organisations.

PERFORMANCE EVALUATION ON CORAL REEF MANAGEMENT IN SOUTH ASIA

In Bangladesh, management is very low or absent and coral reefs around St Martin's Island continue to degrade. Implementation of laws and regulations is extremely difficult due to the lack of resources, alternative employment and trained personnel.

In mainland India, coral reef issues have, until recently, had a relatively low profile compared with other conservation and natural resource issues. There has been a consequent lack of trained, dedicated manpower for managing coral reef-related resources and protected areas. Management regimes in the three marine national parks, Gulf of Mannar, Gulf of Kutch and Andamans (Wandur), have historically been relatively successful in suppressing major anthropogenic causes of degradation such as coral mining. However, less overt sources of degradation such as high nutrient levels and sedimentation continue to erode the condition of reef environments. In recent years, the profile of, and priority accorded to, coral reefs and other coastal resource issues has increased significantly.

In the Maldives, reef researchers in the Marine Research Section monitor the status of reefs, but with their limited resources it is difficult to cover all areas. Implementation of some of the laws on coral mining and other reef related fisheries has also proved to be difficult, due to lack of manpower.

In Pakistan there is increasing awareness of the need for conservation of coastal resources, and plans for marine protected areas are under development, with support from IUCN.

Coral reef management in Sri Lanka is poor, despite government departments with a mandate to manage and conserve reef resources (Rajasuriya *et al.*, 1995; Rajasuriya & White, 1995; De Silva, 1997). A number of projects carried out in the past have come up with publications containing management plans and action plans, but most of the actions recommended in these plans have not been implemented. The Special Area Management Projects carried out at Hikkaduwa Marine Sanctuary and the Rekawa lagoon with support from USAID have not been sustained after the projects were completed in 1996. These two areas have now begun to revert back to their former status. The Bar Reef Marine Sanctuary was declared in 1992, but steps needed to safeguard the coral reefs within the sanctuary have not been taken. Implementation of laws protecting the marine environment is difficult due to lack of alternative employment, trained personnel, financial resources and equipment. Poverty, lack of job opportunities and the absence of alternative livelihoods also makes it difficult to implement conservation laws and regulations, especially with regard to fisheries activities.

In South Asia, there is a clear upward trend in reef management and conservation of coral reef resources, although it is a slow process. Many governments are willing to increase their capabilities in the management and conservation of coral reef resources. Conservation of coral reefs is also a stated policy in resource management plans in all of the coastal states in South Asia.

ACKNOWLEDGEMENTS

We wish to thank the following individuals for their invaluable contribution to this report. Mr S. M. Munjurul Hannan Khan (Bangladesh); Dr E. V. Muley, Dr M. V. M. Wafar, Dr K. Venkataraman, Dr R. Soundararajan (India) and Mr Prasantha Dias Abeygunawardene (SACEP). We also wish to thank UNESCO/IOC, UNEP, DFID, GCRMN, ICRI, IUCN and SACEP for assisting the South Asia region. Any errors or opinions stated in the report remain the responsibility of the authors.

REFERENCES

Ali, A.T. (1997). Status of Communities in the Four Atolls: Their Perceptions, Problems and Options for Participation. Proc. Workshop on Integrated Reef Resources Management in the Maldives, BOBP/REP/76, Bay of Bengal Programme, Madras, 197-210

Arthur R and Madhusan (in prep.). El Nino Southern Oscillation-related bleaching of live corals in Lakshadweep. Draft report by centre for Ecological Research and Conservation.

Brown, B.E. (1997). Integrated Coastal Management: South Asia. Department of Marine Sciences and Coastal Management, University of Newcastle, Newcastle upon Tyne, United Kingdom.

Coastal Conservation Department (CCD) (1990). Coastal Zone Management Plan. CCD and Coastal Resources Management Project of the University of Rhode Island, Colombo, 81p.

Coastal Conservation Department (CCD) (1997). Revised Coastal Zone Management Plan Coast Conservation Department, Ministry of Fisheries and Aquatic Resources Development, Colombo, 121p.

Dayaratne, P., Linden, O and De Silva, M.W.R.N. (eds.) (1997). The Puttalam/Mundel Estuarine System and Associated Coastal Waters: A report on environmental degradation, resource management issues and options for their solution. NARA, NARESA, Sida/SAREC Marine Science Programme, Colombo. 98 p.

De Bruin G.H.P. (1972). The 'Crown of Thorns' starfish *Acanthaster planci* (Linne) in Ceylon. *Bull. Fish. Res. Sri Lanka (Ceylon)*, 23: (1 and 2): 37-41.
De Silva M.W.R.N. (1997). Trials and tribulations of Sri Lanka's First Marine Sanctuary – The Hikkaduwa Marine Sanctuary, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Devaraj, M. (1997). A Brief on the Contribution of The Central Marine Fisheries Research Institute to Research and Knowledge of Coral Reefs of India, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Ekaratne, S.U.K. (1997). Research and Training for Conservation and Sustainable Management of Coral Reef Ecosystem in Sri Lanka: Present Status and Future Directions, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
ENVIS, (1998). Coral Reefs of India: State-of-the–art report. Centre for Advanced Study in Marine Biology. ENVIS publication series 2/98. 52 p.
Hikkaduwa Special Area Management and Marine Sanctuary Coordinating Committee (1996). Special Area Management Plan for Hikkaduwa Marine Sanctuary and Environs, Sri Lanka. Coastal Resources Management Project, Coast Conservation Department, National Aquatic Resources Agency, Colombo, Sri Lanka. 78 p.
Hoon, V. (1997). Coral Reefs of India: Review of Their Extent, Condition, Research and Management Status, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Kazmi Q.B. and Kazmi, M.A. (1997). Status of Research on Corals in Pakistan, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Koya S.I. and Rubens J.P. (1998). Quantitative survey of a single reef in Lakshadweep following the 1998 bleaching event. Circular notice by GCRMN South Asia.
Kumar, K (1997). The Coral Reef Ecosystem of the Andaman and Nicobar Islands: problems and prospects and the World Wide Fund for Nature – India, Initiatives for its Conservation, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Kumaraguru A.K. (in prep.) Baseline survey of coral reef status in the Gulf of Mannar. Interim report submitted to GCRMN South Asia.
Mollah, A.R. (1997). Status of Coral and Associated Resources in Bangladesh, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Ministry of Fisheries and Agriculture (MFA) (1995). Protected Marine Areas in the Maldives (Dive Sites). Marine Research Section, Male, (draft manuscript)
Naseer, A. (1997). Profile and Status of Coral Reefs in Maldives and Approaches to its Management, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Nickerson, D. and Maniku, M.H. (eds.) (1997). Proceedings of the Workshop on Integrated Reef Resources Management in the Maldives, BOBP/REP/76, Bay of Bengal Programme, Madras.
Olsen, S., Sadhacharan, D., Samarakoon, J.I., White, A.T., Wickremaratne, H.J.M. and Wijeratne, M.S. (eds.) (1992). Coastal 2000: Recommendations for A resource Management Strategy for Sri Lanka's Coastal Region, Volumes I and II. CRC Technical Report No. 2033, CCD,CRMP and CRC. Colombo. 81 & 21 p.
Pillai, C.S.G. (1983). Structure and Genetic Diversity of Recent Scleractinia of India, *J. Mar. Biol. Assoc, India,* 25 (1&2): 78-90.
Pillai, C.S.G. (1997). A brief Resume of Research and Understanding of the Reef Corals and Coral Reefs Around India, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Rajasuriya A. and Rathnapriya K. (1994).The abundance of the Crown-of-thorns starfish *Acanthaster planci* (Linne, 1758) in the Bar Reef and Kandakuliya areas and implications for management (abs.). Paper presented at the 2nd Annual Scientific Sessions of the National Aquatic Resources Agency (NARA), Colombo.
Rajasuriya A, De Silva M.W.R.N. and Ohman, M.C. (1995). Coral Reefs of Sri Lanka: Human Disturbance and Management Issues. *Ambio,* 24: 7-8, 428-437.
Rajasuriya A and White, A.T. (1995). Coral Reefs of Sri Lanka: Review of their Extent, Condition, and Management Status, *Coastal Management* 22: 77-90.
Rajasuriya, A. and Wood, E.M. (1997). Coral Reefs in Sri Lanka: Conservation Matters. Marine Conservation Society and National Aquatic Resources Agency. 14p.
Rajasuriya, A. (1998). Coral Bleaching in Sri Lanka. Report prepared by the National Aquatic Resources Research and Development Agency. (unpublished).
Rajasuriya, A. (in prep). The impact of sea surface temperature increase on corals and coral reefs in Sri Lanka.
Ramachandran, K.K and Varma, A. (1997). A review of the Contribution of Centre for Earth Sciences Studies (CESS) Toward Understanding the Totality of Environment of Lakshadweep, in Vineetha Hoon (1997) Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs. Proceedings No. 22, CRSARD, Madras.
Rekawa Special Area Management Coordinating Committee (1996). Special Area Management Plan for Rekawa Lagoon, Sri Lanka. Coastal Resources Management Project, Coast Conservation Department, National Aquatic Resources Agency, Colombo, Sri Lanka. 81 p.
Shepherd A.D. (1995). Maldives: A Framework for Marine Environmental Management. Coastal Management in Tropical Asia, No. 4, March, pp. 1-6, Colombo.
Scheer, G. (1984). The distribution of reef-corals in the Indian Ocean with a historical review of its investigation. *Deep Sea Research,* 31 (6-8): 885-900.

Stoddart, D.R (1971). Environment and history in Indian Ocean reef morphology. In: Stoddart, D.R. and Yonge, C.M. (eds), Regional Variation in Indian Ocean Coral Reefs. Symp. Zool. Soc. London 28: 3-38, Academic Press, London.

Soundararajan R. (in prep.) A brief report on mass bleaching of coral reefs of Andaman and Nicobar Islands. Interim report submitted to GCRMN South Asia.

Thorsell J.W. (ed) (1985). The Corbett Action Plan for Protected Areas of the Indomalayan Realm. In: Conserving Asia's Natural Heritage. Proc. 25th working Session IUCN/CNPPA, Corbett National Park. India. Feb. IUCN, Gland, Switzerland and Cambridge, U.K. pp. 219-237.

United Nations Environment Programme/International Union for the Conservation of Nature (UNEP/IUCN) (1988) Coral Reefs of the World, Volume 2: Indian Ocean, Red Sea and Gulf. UNEP Regional Seas Directories and Bibliographies. IUCN, Gland, Switzerland and Cambridge, U.K./UNEP, Nairobi, Kenya. 1+389 pp., 36 maps.

Venkataraman K and Jeyabaskaran R (in prep.) Present Status and Impacts on coral reefs in the Mandapam Group of the Gulf of Mannar Islands, India. Zoological Survey of India, Chennai.

White, A.T. and Rajasuriya, A. (1995). South Asian Regional Report on the Issues and Activities Associated with Coral Reefs and related Ecosystems. International Coral Reef Initiative, Department of State, Washington D.C. 34 p.

Wood, E.M. and Rajasuriya, A. (1996). Handbook of Protected Marine Species in Sri Lanka. Marine Conservation Society and National Aquatic Resources Agency. 26 p.

Zahir, H. 1999. Marine Research Center, Ministry of Fisheries, Malé, Maldives. Personal communication.

Status report India

Dr M V M Wafar
National Institute of Oceanography, Dona Paula, Goa – 403 004, India

India has a coastline of 7,516 km, of which the mainland accounts for 5,422 km. The coastline of the Lakshadweep islands is 132 km and that of Andaman and Nicobar islands is 1,962 km. The Exclusive Economic Zone generated by taking into consideration the offshore islands is about 2 million km^2, which is about two thirds of the land area (2.9 million km^2).

The importance India's coastal resources is reflected in marine fish production which, at more than 2.5 million tons per annum, ranks India seventh among the maritime countries. In the order of decreasing importance, the catch consists of oil sardine, penaeid prawns, Bombay duck, croackers, lesser sardine, non-penaeid prawns, elasmobranchs, ribbon fish, silver bellies, cat fish, mackerel, anchovies, perches, pomfrets, carangids, seer fishes, tunnies, cephalopods and other miscellaneous groups. In 1994, the export of marine products fetched a record 6 billion US $, or 3.6% of India's total export earnings.

The last ever full-pledged census of the fishing industry – fishermen, fisherwomen, dependent family members, craft and gear employed by them, their socio-economic status etc – was made in the eighties. At the time, there were 2,132 fishing villages with 1,438 fish landing centers. The number of fishermen directly involved in fishing was 0.4 million and the number of people dependent on their income (children and other family members) was 1.9 million. More than 70% of them were illiterate. A total of 134,000 crafts were used, and less than 10% of them were mechanized. A large variety of gears (0.6 million units), from traps to trawls, were used. Considering the rapid progress of the fishing industry in the last 10–15 years, these numbers may have grown twofold by now.

The fishermen are only about 1% of the population dependent on coastal resources in one form or other (200 million people). The overall impact on the coastal zone can be judged from the following data: every year, Indian coastal seas receive 4 billion m^3 of domestic sewage, 0.4 billion m^3 of industrial sewage, 50 million m^3 of river-borne effluents, 33 million tons of solid waste, 5 million tons of fertilizer residues, and thousands of tons of pesticide and detergent residues.

THE CORAL REEFS OF INDIA

Coral reefs occur along the coast of Gulf of Mannar, Gulf of Kutch, Andaman, Nicobar and Lakshadweep (see maps, pages 12–13). In the first four areas, corals occur as fringing reefs around a chain of offshore islands (about 20 in Gulf of Mannar, 15 in Gulf of Kutch and 400 around Andaman and Nicobar islands). In Lakshadweep, the corals form about a dozen atolls. Besides these five areas, corals have been reported to occur in some submerged banks and intertidal areas along the west coast of India. The total area of various reef features (as deduced from satellite images) is about

Table 1. Diversity of scleractinian corals from Indian reefs.

Reef area	Reef type	Hermatypes		Ahermatypes	
		Genera	Species	Genera	Species
SE coast (Palk Bay and Gulf of Mannar)	Fringing	28	84	9	10
Gulf of Kutch	Fringing/patchy	20	34	3	3
Andaman and Nicobar islands	Fringing	47	100	12	35
Lakshadweep islands	Atolls	27	69	4	9
Submerged banks	Patchy	5	5	–	–
Central west coast	Patchy	8	8	–	–
Total		51	156	21	44

2,300 km^2, but the extent of coralline shelves below one optical length (detection limit of satellite-borne sensors) could be several times higher, especially the shelves of the Andaman and Nicobar reefs. In the Indian reefs, a total of 200 species of coral, belonging to 73 genera can be found (Table 1).

Today, resource harvest from Indian reefs – be it food fish, mining of coral blocks, collection of debris, or collection of seashells – is only for sustenance of the reef-dependent population. In the early eighties, reefs in the Gulf of Kutch were utilized for commercial mining of coral sand (up to 1 million tons per year). Though commercial mining has come to an end, clandestine removal of coral debris is still a practice in some reef areas in the Gulf of Mannar.

At present, tourism to reefs *per se* is not well-organized in India, and where it occurs it is usually carried out with other objectives, mostly religious. For example, some reef areas in Gulf of Mannar and Gulf of Kutch are located near shrines (Rameswaram temple, Pirotan Dharga). Only in the Lakshadweep islands, thanks to the access-on-permit policy, can the extent of tourism be judged correctly. The tourism industry there operates on a low volume, high value approach, and amounts to less than a thousand visitors per year.

THE BLEACHING EVENT

The 1998 bleaching event affected all Indian reef areas to varying degrees. The Andaman and Nicobar reefs appear to have suffered the most (up to 80% mortality), followed by the Lakshadweep (43–87%) and the Gulf of Mannar (an average of 60%) reefs. The reefs in the Gulf of Kutch seem to have fared well, with mortality levels much below 30%. Of all Indian reefs, these are the most northern and they occur in extreme, arid conditions. The area also experience a large seasonal temperature range (15–30°C) and quite often prolonged spells of desiccation due to high tidal amplitudes (several meters). Adaptation to these extreme conditions could have rendered the corals of the Gulf of Kutch more tolerant to bleaching and its associated effects (e.g. UV-impact) than corals of other reefs.

The effects on other reef organisms is unknown, since quantitative data on their condition prior to bleaching are scarce. Post-bleaching surveys did not, however, show any abnormal or substantial reduction in the abundance of any reef dwellers, including fish. Surprisingly, after the bleaching event, the 1998 tuna catch in the Lakshadweep islands was exceptionally high. The exceptional catch is difficult to relate to the bleaching event, but the increasing sea surface temperatures could have favoured migration of tuna; they are known to follow warm currents. The socio-economic effects of coral bleaching are difficult to evaluate, since neither reef fisheries nor tourism are organized industries. In fact, a large part of the local population has not even realized that bleaching is an ecological disaster.

Coral mortality in the Chagos Archipelago

Dr Charles Sheppard
Department of Biological Sciences, University of Warwick, UK

SUMMARY

Most of the corals and soft corals on the seaward reefs of all six Chagos atolls have recently died. The reefs of Chagos were previously known to be among the richest of the Indian Ocean, as well as the least affected by man. However, 1999 comparisons between the present situation and that found by earlier surveys, particularly during 1996, showed that only about 12% of the substrate on the seaward reefs is live coral today. Up to 40% was identified as dead coral, and 40% as unidentifiable dead substrate, much of which is almost certainly severely eroded, dead coral. In 1996, an average of about 75% of the substrate was living corals and soft corals. Some reefs have fared better than others, but on many of these once spectacular reefs, such as the seaward reef of Nelson Island, no living coral or soft coral (or any living coelenterate at all) was seen during a 20 minute snorkel in clear water. Lagoons contained greater amounts of living coral (about 28% living coral, with 67% of the substrate covered by dead colonies or bare).

Most corals are becoming heavily eroded, leaving extensive rubble. Rubble on reefs is highly erosive and tends to prevent recolonisation. Reef fish were not counted systematically, but on many reefs there were clearly less than 25% of the former abundance and diversity. The same applies to other invertebrate groups, such as starfish, urchins and molluscs, which appear to have become very uncommon in Chagos waters, at least above 20 m.

This situation represents unprecedented destruction and change of coral reef communities. Possible consequences are outlined below. It is clear, that the situation requires a substantial re-think of present approaches and research priorities in coral reef science and conservation.

INTRODUCTION

Following the rise in surface seawater temperature (SST) in 1998, there have been numerous reports of coral bleaching and mortality in tropical waters. It is a world-wide phenomenon, but of varying extent. In the Indian Ocean, the temperature rise occurred between April and June 1998, and reports of affected reefs have now been posted from many locations in East Africa, the Maldives, Sri Lanka and throughout South-East Asia.

This report documents the phenomenon in the reefs of the Chagos Archipelago, where effects have been severe. First, a brief background to the Chagos reefs is given.

REEFS OF THE CHAGOS ARCHIPELAGO

All atolls and submerged banks of Chagos appear to be actively growing reefs. Most reef flats dry out at low tide, especially those on the seaward side of the islands, and compared to many other reefs in the Indian Ocean they are depauperate, partly due to the occasional coincidence of low spring tides with solar noon. Areas lying close to shore which dry, have the poorest biota. Seaward of this is a boulder zone with storm tossed reef fragments colonised by the surge-resistant cup sponge *Phylospongia* and the alga *Turbinaria*. The boulder zone

Map of Chagos Archipelago, Indian Ocean. As well as islands, the map shows the contour of the shallow submerged banks.

is followed by an algal ridge at the extreme outer edge of the seaward reef flat. The algal ridges and associated spur and groove systems of the seaward reefs of the Chagos atolls appear to be the largest and best developed in the Indian Ocean. They occur on the seaward edges of most Chagos' seaward reef flats, and are devoid of significant coral cover.

Reef slopes, in contrast, have the highest biological diversity. The profiles of most seaward reef slopes show a descending slope from the algal ridge at an angle of between 5 and 20° to a depth of 10–20 m. On most reefs, this is followed by a "drop-off", at which the slope usually increases sharply to between 30 and 50°, and sometimes becomes vertical. A few reefs slopes descend more evenly throughout. The steep slope usually continues to a depth of more than 40 m, where a second shelf may be found. Lagoonal reef slopes are generally more uneven, with many irregularities provided by sandy patches. They normally support a less diverse benthic fauna than seaward slopes, even though coral cover may be high, particularly due to the coral genera *Acropora* and *Porites*.

METHODS

About 90 sites on 40 transects were examined. Each transect was divided into 1–3 sites, and the division was determined by the presence of markedly different coral zones (whether the corals were alive or not). At each site, estimates of percentage cover by each major reef component, species group or species were made by swimming from the shallowest zone (usually the spur and groove zone or from the tops of coral knolls) toward deeper water.

The initial intention was to measure the cover of each reef component and coral species using line transects, in the way it was done at these sites in 1996 and 1978. However, it soon became obvious that there was not enough live coral to justify line transects. With such a low cover, line transects may hinder assessment rather than help to quantify coral cover. In many of the sites, seeing what was still alive became the issue, rather than obtaining a accurate measure of the cover. Also, diving equipment was not available in 1999, which limited the study to depths attainable by snorkelling. Instead, visual estimates of cover and simple presence were made down to 12 m, and commonly to 20 m or more in the clear water of seaward slopes.

RESULTS

Corals and soft corals

Corals in the Chagos Archipelago have suffered very heavy mortality. The pie chart reflects the general impression of the reduction in corals.

The massive reduction in live coral is clear (Figure 1). Seaward reefs throughout Chagos used to have about 50–70% living corals, 10–20% soft and false corals, with only 10–20% of the substrate being "bare" (in fact covered with fine, filamentous algae) as seen in the pie chart for 1996. The large reduction in live coral and soft coral cover is obvious.

Seaward reefs 1996

Seaward reefs 1999

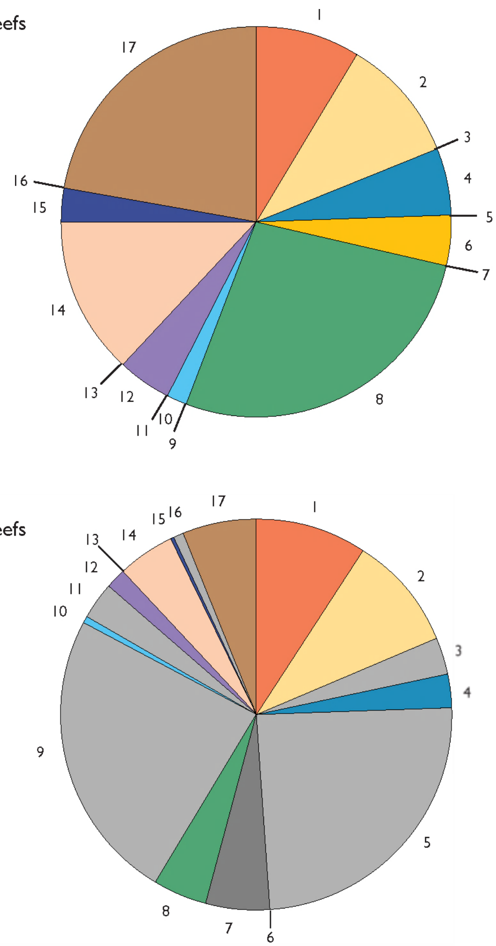


Figure 1. Reef cover values from before (top) and after (bottom) the 1998 bleaching event.
Key: 1: Red algae, 2: *Porites* live, 3: *Porites* dead, 4: digitate coral live, 5: digitate coral dead, 6: table coral live, 7: table coral dead, 8: other coral live, 9: other coral dead , 10: *A. palifera live*, 11: *A. palifera* dead, 12: *Heliopora* live, 13: *Heliopora* dead, 14: Soft coral, 15: *Millepora* live, 16: *Millepora* dead, 17: bare substrate.

The reduction in red algae may also be important. The snorkelling survey in 1999 visited the shallowest parts specifically and, if there was a possible bias towards recording red algae, might have yielded a higher value. Instead, the survey shows a reduction in red algae as well. The calcareous algal ridges and spur formations around all atolls, however, appear perfectly sound. Both soft corals and false corals (mainly fire coral *Millepora*, and blue coral *Heliopora*) were almost eliminated in 1999.

Overall, there was a substantial reduction in coral cover for most groups. Almost no table corals remained alive, and on seaward slopes almost no live digitate corals were found. In fact, the majority of all species were dead. An exception on seaward slopes were colonies of the large genus *Porites*, which seem to have been particularly resistant.

Table 1. Average changes in (%) cover of substrate in 1999, as compared with transects measured in 1996.

	Massive *Porites*	Digitate corals	*Acropora palifera*	*Acropora* tables	Other corals	Soft corals	Mean fall
Averages	–	-8	-17	-9	-11	-10	-55

Table 1 shows the average changes in cover for different species groups. In total, coral loss on seaward slopes was estimated to be 55%. Considering that total cover previously was 50–75% depending on the exact location, most of it has been eliminated.

Difference in lagoonal and seaward reefs

Lagoons heat up more than seaward facing reefs, and might be expected to have suffered more from the change in water temperature in 1998. The reverse was found to be true in 1999. The simplest explanation is that since lagoonal reefs frequently experience warming, corals in lagoons may be adapted to this. The following comparison shows that for several groups of corals, especially the massive *Porites* forms, survival was much higher in lagoons than on seaward reefs (Figure 2). The lagoons of Diego Garcia, Salomon and Peros Banhos are included in the comparison. The Egmont lagoon is not included, since it almost lacks live coral. It recently became more enclosed due to linking of the islands, and is presumably suffering a corresponding restriction in water exchange. It is also very shallow.

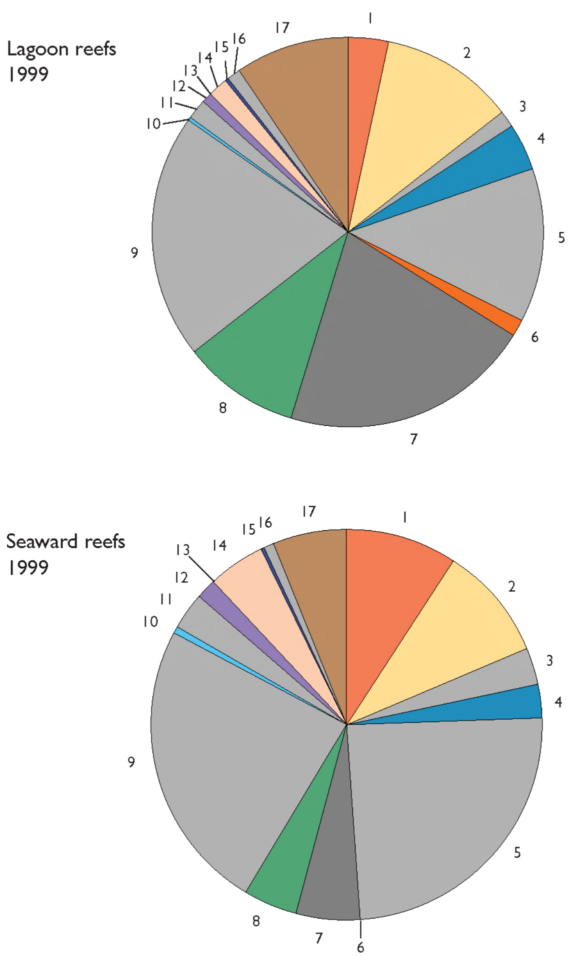


Figure 2. Pie charts showing reef cover values from lagoons (left) and seaward reef slopes (right).
Key: 1: Red algae, 2: *Porites* live, 3: *Porites* dead, 4: digitate coral live, 5: digitate coral dead, 6: table coral live, 7: table coral dead, 8: other coral live, 9: other coral dead , 10: *A. palifera* live, 11: *A. palifera* dead, 12: *Heliopora* live, 13: *Heliopora* dead, 14: Soft coral, 15: *Millepora* live, 16: *Millepora* dead, 17: bare substrate.

The lack of coral in the Egmont lagoon can probably not be attributed to the 1998 water temperature rise.

DISCUSSION

Several possible consequences of this mortality arise.

1. Direct reef erosion

Direct reef erosion if caused by a reduction of limestone-depositing species in shallow water. The most exposed reefs in Chagos are shallow water reefs dominated by corals which showed high mortality, commonly total. The reefs also have an extensive cover of calcareous red algae of the *Porolithon* group, which was reduced but not as greatly affected as the corals. This cover remained high on the wave-breaking spurs, commonly 10–50%, occasionally more.

2. Indirect reef erosion

Indirect reef erosion is probably going to be serious. Erosion of dead corals by waves and boring organisms is proceeding, and coral skeletons are reduced to rubble. The mobile fragments produced are extremely abrasive and damaging to marine life, and effectively prevent new larvae from attaching to the rock. Eventually the fragments will disappear, but the time required is not known. Even though most or all species have survived somewhere in the Chagos Archipelago and can produce larvae, they may show little reproductive success for many years.

3. Loss of diversity

Loss of biodiversity is another possible consequence of bleaching and coral death, but at present we have almost no idea what the consequences may be. There are examples from, for example, the Galapagos, where endemic fish species became extinct, following heavy bleaching during an earlier ocean warming event. The warming of the Indian Ocean occurred throughout most of the coral archipelagos, as well as in the rich East-African and Arabian regions, so local extinctions may have occurred in Chagos too, but this is not known at present. At best, the established reef assemblages have been severely disrupted.

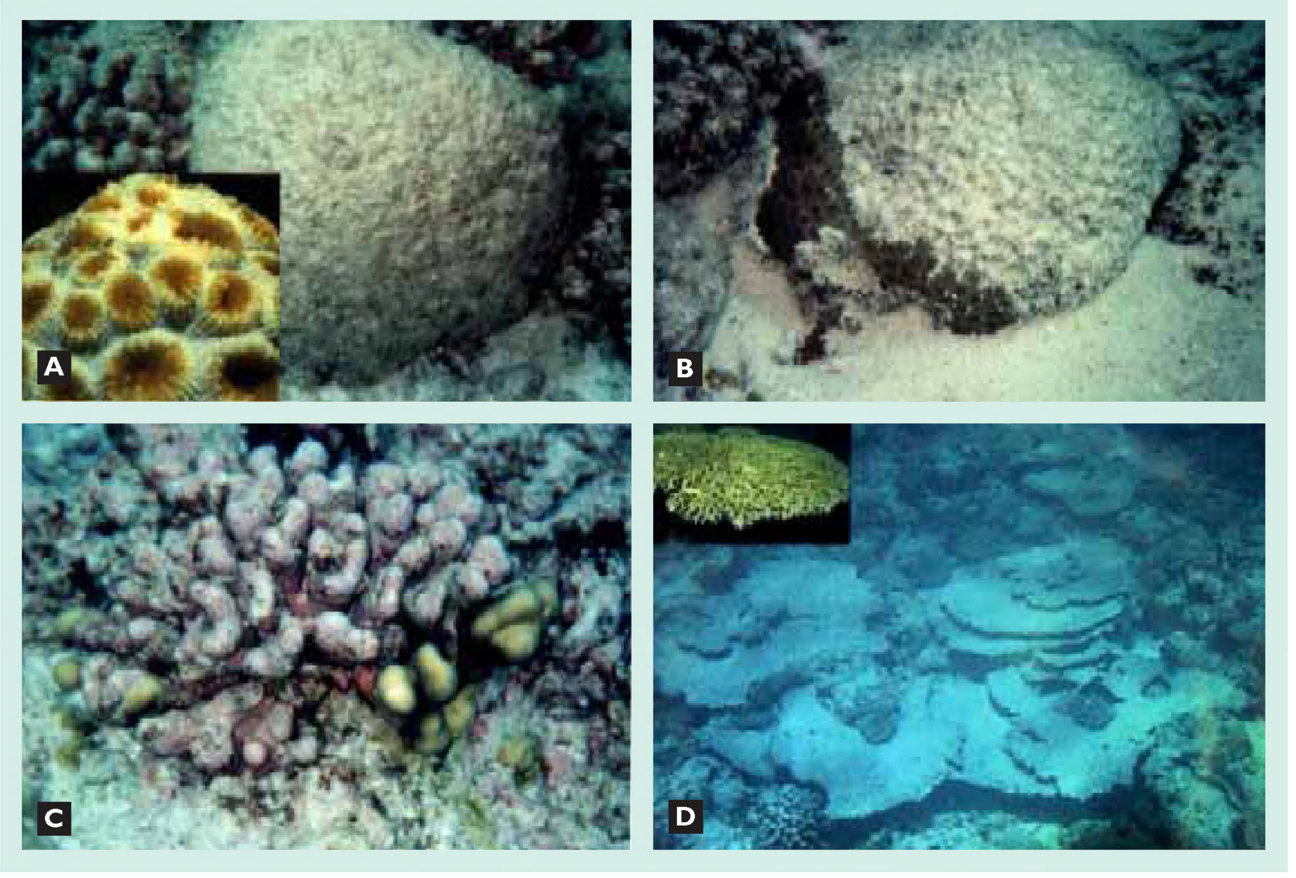
4. Sea levels

The possibility of increased erosion must be considered in conjunction with a possible rise in sea level, which multiplies its effects. Without coral growth, erosion will become increasingly evident.

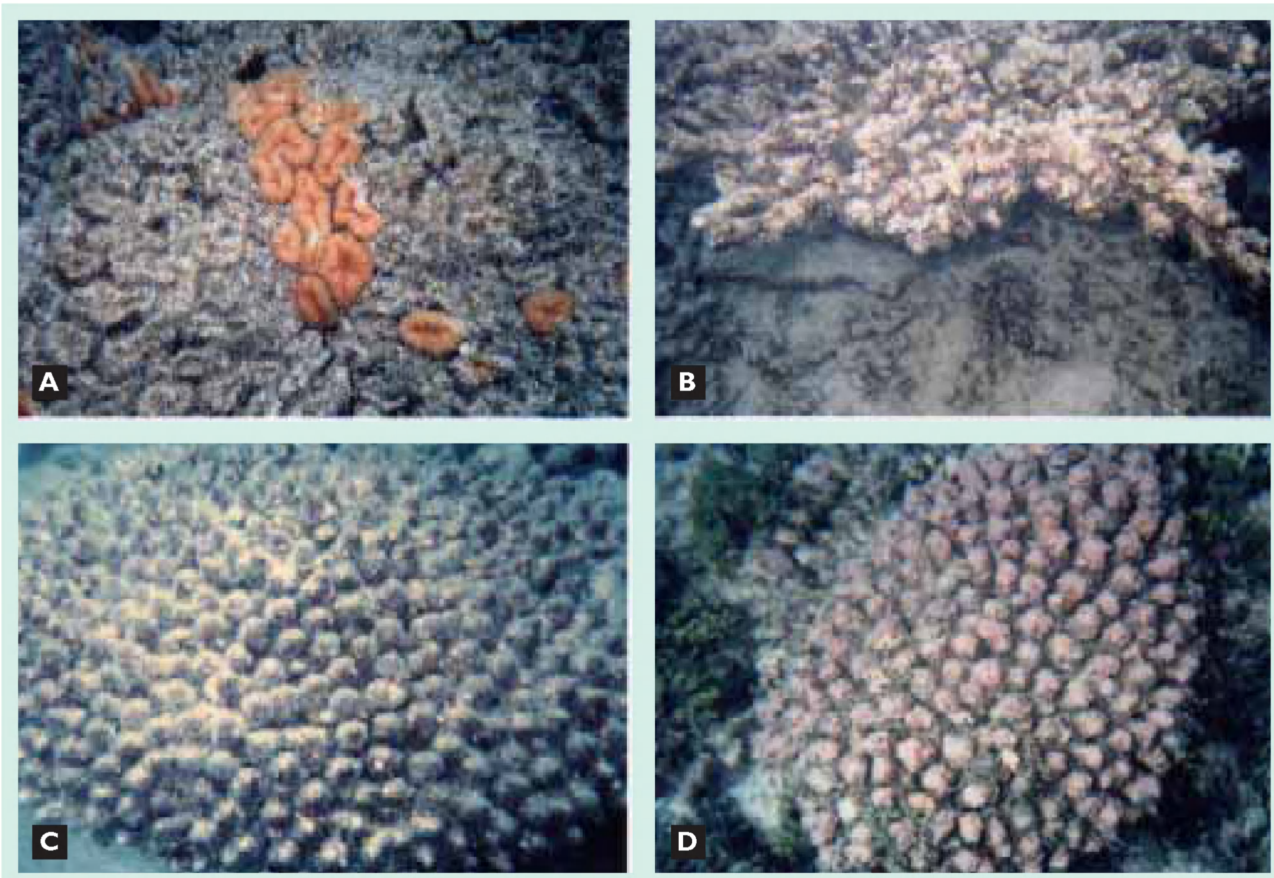
5. Fishing pressure

Over the next few years, fishing pressure from artisanal fisheries will increase in the Indian Ocean. As human populations increase and coastal fish stocks decline, the pressure is likely to increase substantially. Although it may be true that reef fish have declined, Chagos may retain its relative attraction to Indian Ocean fishermen.

Various dead corals in Chagos, 1999. **A:** A massive *Favia* coral (with inset of live example taken elsewhere). **B:** A massive *Favia* coral with part of base still living. Dead part has eroded about 1 cm. **C:** Close up of *Stylophora pistillata* with part of base still living, but mostly covered with calcareous red algae. **D:** Large expanse of *Acropora* table corals, probably a mix of *A. clathrata* and *A. cytherea*, all dead (inset is example of a living coral of this species). **Photos:** C. Sheppard.



Various corals in Chagos, 1999. **A:** A massive *Lobophyllia corymbosa* coral from Diego Garcia lagoon. Red disks are still-living polyps. **B:** A massive faviid coral, now unidentifiable. Dead part has eroded about 1 cm. **C:** Close up of edge of a table coral, showing eroding and crumbling tips. **D:** Large whorls of *Echinopora lamellosa*, mainly dead, but with some live tips to some of the leaves. **Photos:** C. Sheppard.



6. Recovery

There is little information on how long it may take for reefs to recover, but reef recovery on a much smaller scale clearly takes many years or centuries. The suggestion that this is a "natural event" merely dodges the issue, and may only provide a refuge in which to avoid finding a solution. It might be true that it has happened before – a century ago no reef monitoring took place anyway – but many of the coral colonies that were killed are around 200–300 years old. So clearly, this scale of mortality has not occurred within that time frame.

7. Alternative stable states

Several examples show that if a reef is stressed and changed, and the stress is removed, the reef may not necessarily revert to its original condition. In part, this appears to depend on the severity of the stress. Good examples of this exist in the Caribbean and Indian Ocean. When corals die, they form fragments which are abrasive and inhibit new coral settlement and growth, exacerbating the situation. The long-term prognosis of the 1998 coral mortality may therefore be very poor.

Status report Kenya

Dr David O Obura
CORDIO-East Africa, P.O. BOX 10135, Bamburi, Kenya

BACKGROUND

Kenya's coastal population is expected to exceed 2 million people by the year 2000, with an annual growth rate of 3.7%, of which a large proportion is due to migration of people from other parts of Kenya. Increasing economic activity, due to shipping, freight handling and tourism, provides a strong draw for migrant workers, as well as conditions for environmental degradation. Marine resource use is largely unregulated, and the predominant near-shore coral reef activities include subsistence and small-scale commercial fishing and tourism.

The Fisheries Department estimates fisheries statistics for the Kenya coast, though a lack of resources for comprehensive monitoring of the catch makes the estimates unreliable. Marine fish catch rates have been estimated at various levels, from 3 to 13 tons/km^2/yr, with estimated maximum sustainable yields for coral reefs varying between 5 and 10 tons/km^2/yr. The number of subsistence fishermen is currently about 5,000, with close to 35,000 dependents and perhaps another 1,000 people involved in fish distribution and processing. Numbers are continually increasing, even though many reefs are overexploited and severely degraded, and degradation due to fishing is likely to increase in the near future. Of the 750,000 tourists visiting Kenya during a normal year, 70% spend at least some of their time in coastal hotels, and close to 200,000 stay in hotels adjacent to, or visit, Marine Protected areas. Tourism is one of the principal sources of income for the coastal economy. Both fisheries and tourism depend on coral reefs and the associated ecosystems (seagrasses, mangroves). Any loss of productivity, diversity or integrity of coral reefs could have severe consequences for coastal people and the economy.

Kenya's coral reefs are divided between two main areas: the southern, almost-continuous fringing reef system from Malindi to Shimoni (a distance of approximately 200 km), and more broken up patch and fore reef slopes around the islands of the Bajuni Archipelago, from Lamu and northwards (a distance of approximately 100 km). In both areas, hard substrate patches with coral growth are interspersed between extensive seagrass and algal beds. Within these patches, coral cover is typically about 30%, with over 50 genera and up to 200 common species of coral recorded so far (Obura, unpublished data). Reef complexity and diversity is higher in the south and decreases northwards past Lamu due to increasing influence of the cold-water Somali current system. Fish abundance is typically 1,500–2,000 kg/hectare, though this varies greatly with back reef and fore reef location, the influence of sediment, and the intensity and type of fishing effort (Samoilys, 1988; McClanahan, 1994; 1998).

THE BLEACHING EVENT

The 1997–98 El-Niño Southern Oscillation had severe impacts on the climate of East Africa, with unprecedented rains starting in October 1997 and continuing to July 1998. Sea water temperatures in March and April 1998 rose to an average of 1.5°C above values measured during the same period in 1997, with daytime, low tide highs of over 32°C (Figure 1). Bleaching was first noticed in Kenya around March 15, 1998, and then rose to unprecedented levels of 50–90% of the corals along the entire Kenya coast. Mortality from bleaching appeared to peak about mid-May, and subsequently some bleached corals recovered, while others continued to die up until October.

Following the coral bleaching in 1998, living coral cover decreased significantly on all known reefs in Kenya. Table 1 illustrates the changes in various benthic cover categories on a reef in Malindi that had a stable coral community and normal cover characteristics from 1994–1998. Coral cover then decreased to 40% of pre-bleaching levels, while soft corals decreased to 10% of pre-bleaching levels. As a result of new available

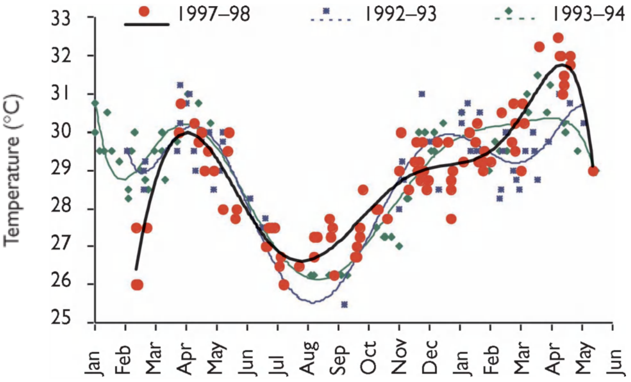
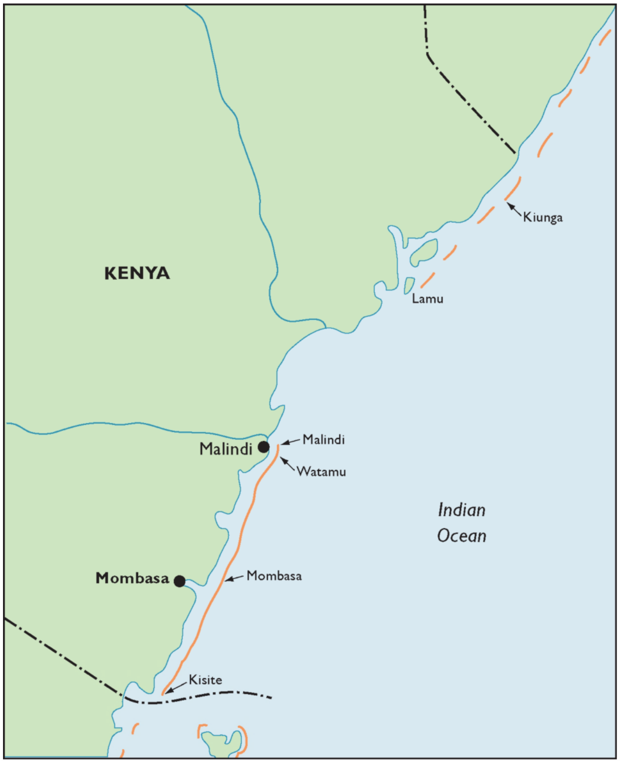


Figure 1. Seawater temperature in shallow coral patch reefs in Kenya, measured using a hand-held thermometer during field visits. Curves are 7th-power polynomials to illustrate seasonal cycling. Data shown for 18-months January–June periods for 1992–93, 1993–94 and 1997–98.



Kenya's coral reefs are divided between two main areas, a fringing reef system in the south (from Malindi to Kisite) and patch reefs and fore reef slopes in the north. After the 1998 bleaching event, the living coral reef cover has decreased on all known reefs in Kenya.

Table 1. Changes in benthic community structure as a result of bleaching (in% cover). Example of Malindi Marine National Park. M = mean, st. error = standard error of the mean.

Cover	Before (1994)		After (1999)	
	mean	*st. error*	*mean*	*st. error*
Coral	35.7	2.46	14.7	4.63
Soft coral	9.6	1.96	1.0	0.42
Other	1.4	0.70	0.1	0.06
Algae				
Turf	31.2	4.58	59.6	7.82
Halimeda	7.0	2.39	5.7	2.61
Macroalgae	1.6	1.24	0.5	0.21
Coralline algae	3.8	1.40	8.7	3.68
Seagrass	0.1	0.07	1.3	0.66
Coral variables				
# Colonies	112.6	12.64	37.0	2.08
# Genera	19.8	1.77	8.7	0.88

substrate, the cover of algal turf increased by 200%. The number and diversity of coral colonies along sample transects decreased by a factor 3 and 2 respectively, with many small colonies remaining compared to the more numerous, but larger colonies before bleaching. About ten other sites have been visited by experienced coral reef researchers (including Kiunga, Lamu, Watamu, Vipingo, Kanamai, Mombasa, Galu, and Kisite), all suffering a similar fate, with coral cover at 10–50% of pre-bleaching levels.

Bleaching was observed at all depths (to 20 m), with the highest impact and mortality at depths less than 2–3 m. Bleaching and mortality were highest in shallow habitats and pools, where water stagnation occurs, or where corals are regularly exposed to outflow of shallow (warm) lagoon waters and/or to mangrove and sediment influence. Bleaching and mortality were least in wave-exposed habitats and locations subject to upwelling of cooler deeper water.

Variability in space was a dominant feature observable, with different localized responses to a region-wide and ubiquitous threat. The impact of high temperature stress varied with habitat type and the suite of dominant species – wave zones and back-reef lagoons dominated by arborescent *Acropora* species were the most susceptible, and face loss of ecological function.

Species and higher taxon-specific variability in bleaching was also high, ranging from 0–100% bleaching and mortality. *Pocillopora, Stylophora* and arborescent *Acropora* spp. were among the most susceptible corals, with close to 100% bleaching and/or mortality at some sites, even where exposed to high water motion. Other genera exhibited variable levels of bleaching and mortality even within the same species, at some sites low and at others severe. In general, where mortality levels were 50% and greater, sites on a scale of 100–200 m^2 lost up to 50% of their species and genus diversity (Table 1), though at a larger scale of several kilometers the loss of species was lower. The number of coral colonies recorded in transects dramatically decreased by up to 90% (Table 1, Figure 2), showing that the survival of corals

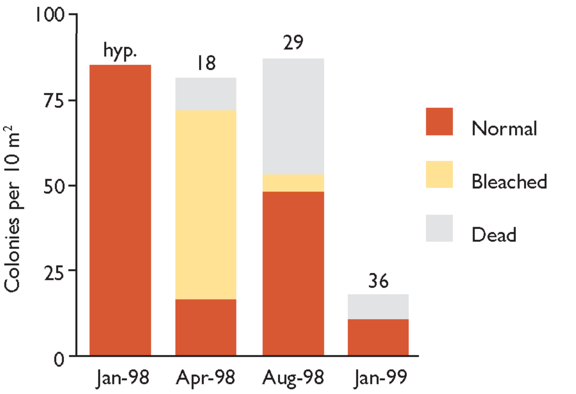


Figure 2. Number of coral colonies that were normal, bleached or dead at four sampling occasions in Malindi, from January 1998 to January 1999. The numbers above the columns indicate the number of 1 m^2 quadrats sampled each time. January data (# colonies) back-calculated from April and August.

following bleaching can be very low; the number of living colonies was lower in January 1999, than that recorded for unbleached corals in April 1998, at the height of bleaching (Figure 1).

OTHER IMPACTS OF BLEACHING

No data has been collected so far to determine the impact of bleaching on other marine organisms, though extensive historical data exists for gastropods, sea urchins and fish. Similarly, previous socio-economic studies will provide good baselines for assessing the impact of coral bleaching and mortality on coral reef resource users.

Coupled with the severe loss of coral cover and potentially reef vitality, the already high levels of subsistence fishing on many reefs in Kenya (at or above their maximum sustainable yields) suggest that fisheries may become increasingly unsustainable in the short term. The socio-economic impact of the bleaching on other sectors, such as tourism, is harder to predict, but the economic dependence on tourism in Kenya makes this an important sector for investigation. These two areas will comprise the principal focus of socio-economic investigations into the after-effects of the 1998 coral bleaching and mortality.

MONITORING AND RESEARCH RELEVANT TO BLEACHING

Kenya has a relatively well-developed marine research sector, with a number of subtidal and intertidal ecological studies extending from nutrient dynamics to ecological interactions. This summary is restricted to research areas related to corals and the impacts of bleaching.

1. Coral species diversity, abundance, and distribution (Obura, Coral Reef Conservation Project). Biogeographic distribution and ecological zonation of coral species to reveal species-specific variation susceptibility to differences in environmental stress.
2. Benthic community structure (Coral Reef Conservation Project). The effects of fishing (McClanahan) and sediments (Obura) on the benthic community structure of coral reefs, related to management and conservation of reef resources and biodiversity.
3. Coral stress resistance field studies (Obura, Coral Reef Conservation Project). Field surveys on coral condition to examine patterns of stress among coral species with respect to environmental changes. Before, during and after the 1998 bleaching event.
4. Coral genus surveys and levels of bleaching (McClanahan, Coral Reef Conservation Project). Timed surveys of the extent of bleaching during the 1998 bleaching event.
5. Zooxanthellae and chlorophyll concentrations in normal and bleached corals (Mdodo, Moi University/Kenya Marine and Fisheries Research Institute and Obura, CRCP). MSc study on the dynamics of zooxanthellae and chlorophyll in normal and bleached corals, with decreases of on average 80% of both factors in bleached corals compared to healthy ones.
6. Rapid assessment of coral reefs and training of personnel (Kenya Wildlife Service, supported by WWF, UNEP, FAO and IUCN). Training and monitoring programme conducted in the Kiunga Marine Reserve, for repetition at other sites. Recorded the first bleaching observation in Kenya and established baseline benthic and bleaching data for monitoring in northern Kenya.
7. Coral genus reference and display collection (Didham, Kenya Wildlife Service).

REFERENCES

Gubelman, E. and Kavu, B. 1996. Traditional utilization of natural resources within and around Kiunga Marine and Dodori National Reserves, Kenya: Results of Participatory Rural Appraisal and Recommendations for Integration of local communities into Management Planning for KM&DNRs. World Wide Fund for Nature-East Africa Regional Programme Office, Nairobi.

McClanahan, T.R. 1994. Kenyan coral reef lagoon fish: effects of fishing, substrate complexity, and sea urchins. *Coral Reefs* 13: 231–241.

McClanahan, T.R. 1997. Recovery of fish populations from heavy fishing – does time heal all? *Proceedings of the 8th Coral Reef Symposium* 2: 2033–2038.

McClanahan, T.R., Glaesel, H., Rubens, J. and Kiambo, R. 1997. The effects of traditional fisheries management on fisheries yields and the coral-reef ecosystems of southern Kenya. *Environ. Conserv.* 24: 1–16.

McClanahan, T.R. and Muthiga, N.A. 1988. Changes in Kenyan coral reef community structure due to exploitation. *Hydrobiologia* 166: 269–276.

McClanahan, T.R. and Obura, D. 1995. Status of Kenyan coral reefs. *Coast. Manag.* 23: 57–76.

McClanahan, T.R. and Obura, D. 1997. Sediment effects on shallow coral communities in Kenya. *J. Exp. Mar. Biol. Ecol*. 209: 103–122.

McClanahan, T.R. and Shafir, S.H. 1990. Causes and consequences of sea urchin abundance and diversity in Kenyan coral reef lagoons. *Oecologia* 83: 362–370.

Nzioka, R. 1990. Fish yield of Kilifi coral reef in Kenya. *Hydrobiologia* 208.

Obura, D. 1995. Environmental stress and life history strategies, a case study of corals and river sediment from Malindi, Kenya. PhD thesis, University of Miami.

Obura, D.O., Muthiga, N.A. and Watson, M. (in press). Kenya. In: *Coral Reefs of the Indian Ocean: Their Ecology and Conservation.* Eds: McClanahan, T.R., Sheppard, C.R.C. & Obura, D.O. Oxford University Press.

Samoilys, M. 1988. A survey of the coral, reef fish communities on the Kenyan Coast.

UNEP. 1998. East Africa Atlas of Coastal Resources. 1. Kenya. Nairobi: UNEP.

van Katwijk, M., Meier, N., van Loon, R., van Hove, E., Giesen, W., van der Velde, G. and den Hartog, D. 1993. Sabaki River sediment load and coral stress: correlation between sediments and condition of the Malindi-Watamu reefs in Kenya (Indian Ocean). *Marine Biology* 117: 675–683.

Watson, M., Ormond, R.F.G. and Holliday, L. 1996. The role of Kenya's marine protected areas in artisanal fisheries management. *Proc. 8th Int Coral Reef Symp.,* Panama.

Weru, S. 1991. An appraisal on the Kiunga Marine National Reserve. Kenya Wildlife Service.

A preliminary assessment of coral bleaching in Mozambique

Dr Michael Schleyer[1], **Dr David Obura**[2], **Helena Motta**[3] and **Maria-Joao Rodrigues**[4]

[1] *Oceanographic Research Institute, Marine Parade, Kwa-Zulu-Natal, South Africa*

[2] *CORDIO-East Africa, P.O. Box 10135, Bamburi, Mombasa, Kenya*

[3] *Special Adviser for Coastal Zone Management, Ministry for Co-ordination of Environmental Affairs (MICOA), Maputo, Mozambique*

[4] *Fisheries Institute, Maputo, Mozambique*

The 1997–1998 El Niño southern oscillation caused elevated sea temperatures that resulted in global coral bleaching. Coral reefs constitute an important biological resource in terms of their complex biodiversity and are the basis for tropical fisheries and marine ecotourism. They represent one of Mozambique's main coastal assets, and coastal communities and the growing tourism industry rely mainly on reef-based resources.

Today, about 6.6 million people live within Mozambique's 48 coastal administrative districts. This represents 42% of the current population (15.7 million), which is expected to grow at 3% p.a. (INE, 1998). In 1994, the population density in coastal districts was 28 persons/km^2. In 1996, much higher densities were recorded in the coastal cities: 1,525 persons/km^2 in Maputo, 625 persons/km^2 in Beira and 409 persons/km^2 in Nacala (Lopes).

Sea surface temperatures along the coast of Mozambique show a seasonal variation. In general, high surface water temperatures (26–30°C) are observed from November to May, while lower temperatures (21–26°C) occur from June to October (SADCO data, 1960–1997). Sea surface temperatures along the northern coast are normally 1–2 degrees higher than those along the southern coast.

The Mozambique Current, which transports the warm water, is part of the anti-cyclonic sub-tropical gyre that consists of the South Equatorial Current, the Agulhas Current system and the eastward flow to the north of the sub-tropical convergence. According to Saetre and da Silva (1984), the circulation of the Mozambican Current along the Mozambican coast includes three anti-cyclonic cells within the Beira, Inhambane and Maputo bights, as well as some smaller cyclonic eddies.

The reefs along the Mozambican coast consist of fossilized dune and beach rock colonized by corals to a varying degree. During the millennia, the shoreline has been successively exposed and submerged, forming a compound shoreline (Tinley, 1971) where coral reefs are distributed in three regions:

1. The northernmost section of the coast extends for 770 km from the Rovuma River in the north to Pebane in the south (17°20'S). It is characterized by numerous small islands that form the Primeiras, Segundas and Quirimba archipelagoes. Coral reefs form an almost continuous fringing reef on the eastern shores of the islands and the more exposed sections of the mainland coast.
2. The central section of the coast between Pebane

(17°20'S) and Bazaruto Island (21°10'S), a distance of about 950 km, is classified as swamp coast (Tinley, 1971). In this section, twenty-four rivers discharge into the Indian Ocean, each with an estuary supporting well-established mangrove stands. The coastal waters are shallow and this, together with sediments from the rivers, cause high turbidity levels. Coral reef formation in this area is therefore severely limited.

3. The southern section stretches for 850 km from Bazaruto Island southwards to Ponta do Ouro (26°50'S). The coastline is characterized by high dunes, north-facing bights and barrier lakes. The dune systems attain heights of 120 m and are considered to be the highest vegetated dunes in the world (Tinley, 1971). The distribution of reefs along the coast and nearshore islands is patchy and reefs are more sparsely inhabited by corals.

There are three types of fisheries in Mozambique, comprising industrial, semi-industrial and artisanal fisheries. These three sectors land about 90,000 tons/year from an estimated maximum sustainable yield (MSY) of about 300,000 tons/year (Chotard & Carvalho, 1995; Sanders, 1988; Silva & Sousa, 1988; Palha de Sousa, 1996). The industrial and semi-industrial fleets currently generate 40% of Mozambique's foreign revenue, gained largely from prawn fisheries dependent on mangroves and estuaries for their productivity.

The artisanal fishery, on the other hand, is responsible for about 70% of the total catch, with an average production of 4.6 tonnes/km^2 in the fishing grounds which extend up to 5 km offshore (Sanders, 1988). Very little information is available on artisanal fisheries, and resource assessments have only been undertaken in Maputo Bay. These fisheries are largely centered on the reefs.

Coral reefs are one of the main attractions for the tourists industry in Mozambique. Most tourism occurs along the coast, where the best infrastructure for tourism is established, especially near the coral reefs of Pemba, Mozambique Island, Bazaruto Archipelago, Inhaca Island and Ponta do Ouro.

The current survey was undertaken to assess the consequences of coral bleaching in Mozambique waters, as the extent of reef loss during the 1997–1998 El Niño phenomenon was unknown. A secondary objective was the training of Mozambican scientists to increase the scientific capacity in this specialized field. The survey was undertaken by MICOA staff and post-graduate students between 24 March and 9 April 1999, at the end of summer. The group was accompanied throughout by Dr Michael Schleyer of the Oceanographic Research

The coral reefs of Mozambique are distributed over three areas. The effects of bleaching were most extensive on exposed reefs in the north and around Inhaca Island. All of the monitoring sites listed in the table (pages 39–41) are numbered.

Locality	Reef	Description	Results
Pemba	1. Wimbi Beach	Patch reef of beach/dune rock at 3.5–7 m in sheltered bay; subject to eutrophication and sedimentation. Prominent species: *Porites rus, P. nigrescens, P. lutea* and *Diploastrea heliopora.* Fish community poor.	Reef cover 30–40%; coral cover 0–60%, mean ~30–40%. Mortality from bleaching ~30%. Also COTS and COTS scars.
	2. Quilalulia Channel	Sparse patch reef of coral rubble in a 1.5–2.5 m channel between Quilaluia and Sencar Islands. Corals consisted of a sparse mix of soft and hard corals. Fish community poor.	Reef cover 40–60%; coral cover < 1%. Heavy mortality from bleaching in 1998.
	3. Sencar	Fringing reef of excellent profile on seaward edge of island, depth ranging from 3–7.5 m onto sand. Near total mortality from bleaching. Previous coral population rich and diverse. Fish population poor, possibly heavily fished.	Solid reef cover; 1% coral survival after the 1997–1998 El Niño event.
	4. Pemba Bay	Excellent reef on beach rock in sheltered bay, dropping steeply from 3–8 m onto sand. Reef subject to eutrophication and turbidity from the bay, but little evidence of bleaching. Heavily colonized by *Porites rus* and *P. nigrescens;* also considerable *Stylophora pistillata* and plate *Montipora sp.* Large numbers of *Diadema.* Fish well represented.	Near solid reef and coral cover; mortality from bleaching < 30%.
Nacala	5. Fernao Veloso Bay	Patch reef developing into fringing reef, 2–7 m deep, in sheltered entrance to lagoon. Coral cover low in inshore region, improving offshore. Mixed community of *Porites* and *Acropora* and a diversity of other corals. Relatively little bleaching. Fish community poor.	Reef cover variable, with commensurate variability in coral cover. Coral cover 0–90%; mean cover on the fringing reef 50–70%. Bleaching of ~30% in 1998.
Angoche	6. Baixo St Antonio	Fringing reef at 3–7 m depth, subject to considerable surge and surf, with marked spur and groove formations manifesting the original dune rock structure. Evidence of bleaching in 1998 and the current year. Mixed, but not prolific fish community.	Substantial reef with 30–40% coral cover, whereof 25% soft corals. Mortality from bleaching ~20%; some evidence (< 2%) of current bleaching.
	7. Mafamede Island	Reef similar to above, but more consolidated. Evidence of bleaching in 1998 and the current year. Mixed, but not prolific fish community.	Hard and soft coral cover each ~20%. Mortality from 1998 bleaching ~20%; < 2% in current year.

Locality	Reef	Description	Results
Bazaruto Island	8. Inner Two-Mile Reef	Partially sheltered mixed coral community, 1–3.5 m deep, on the landward side of a fringing rock reef between Ilhas Benguerra and Bazaruto. A COTS outbreak commenced on this reef in 1995, 80% of which has been destroyed. The post-COTS deterioration of the reef has continued with reef collapse and erosion; largely rubble was found. Evidence of coral recruitment was only found at the inner periphery of the reef. Fish community poor.	Previously high coral cover, ~80%, and species diversity; the reef has suffered 80% mortality.
	9. Coral Garden	A coral garden protected within two northern projections of Two-mile Reef. Depth, surface to 8 m. Coral community rich and diverse, dominated largely by staghorn and tabular *Acropora* spp. Little evidence of current and past bleaching; some mortality from COTS, boat and diver damage. Fish community diverse and abundant.	Coral cover high, ~80–90% in parts of the reef. Mortality ~20% in parts due to the causes listed.
	10. Lighthouse Reef	Partially sheltered mixed coral community, 1–3.5 m deep, on the landward side of a fringing rock reef north of Bazaruto lighthouse. Coral cover and community structure variable according to degree of exposure and sedimentation on the reef. This ranged from monospecific outcrops of large staghorn corals to a sparse cover of sediment tolerant faviids and soft corals. Little present or past bleaching. Fish community rich and abundant.	Coral cover 5–90% depending on position on the reef. El Niño bleaching in tidal gullies 10–20%. Current bleaching ~1%.
Inhambane	11. Mike's Cupboard	Fossilized dune rock of substantial profile, at 16 m depth, with gullies and potholes. Coral cover low due to swell-generated turbulence, turbidity and sedimentation; mainly sediment tolerant soft corals and faviids with *Pocillopora* and *Stylophora*. No evidence of COTS or bleaching. Good fish community, but few coral fish.	Coral cover 2–10%.
	12. Coral Garden	A wave-cut beach rock platform exposed to surge and surf at 1–5 m. Dominated by tabular staghorn and soft corals. Some El Niño and current bleaching. Poor fish community.	Coral cover 5–60%; El Niño bleaching ~ 5–15%; current bleaching <1%.

Locality	Reef	Description	Results
	13. Anchor Bay	Small, low profile reef in the sea, at 9 m depth. Evidence of a previously rich coral community decimated by COTS. COTS and recent feeding scars were observed and a local report of the destruction of the reef over the last three years confirmed our finding. *Pocillopora* and a few *Acropora clathrata* are the main survivors. Little evidence of recent coral recruitment. Fish community surprisingly good; mainly snappers and herbivores.	Coral cover ~2–5%.
	14. Cabo das Correntes (Paindane)	Coral garden at 1–5 m on the landward side of a largely submerged rocky reef exposed to strong currents and surf. Coral community dominated by a diverse and extensive cover of soft corals. Scant evidence of bleaching. Fish community good in the deeper water, largely snappers and goatfish with very few chaetodons.	Coral cover 0–90%; mean ~60%; almost exclusively soft corals. Three colonies of digitate *Acropora* were bleached and encrusted with coralline algae.
Inhaca Island	15. Pta Torres Channel	Shallow reef of *Porites* bommies, faviids and a few *Acropora* spp. fringing a sand-bank channel. The reef top is exposed at low tide and the reef extends to a depth of 2 m. It is clearly subject to a tidal race, turbidity and eutrophication. Fish were sparse, mainly herbivores, half-beaks and sand-dwelling species.	Little evidence of bleaching in 1998 but ~40% of the corals were undergoing recent bleaching. A further 40% of the bommie tops were dead from (natural) tidal exposure.
	16. Pta Torres	A reef consisting of an emerging dune rock wall dropping to a depth of 6 m. Sparsely inhabited by corals tolerant of a tidal race, turbidity and sedimentation. *Stylophora pistillata,* faviids and *Pocillopora verrucosa* were most abundant, in that order. Recent bleaching has caused near total mortality; quantitative assessment was difficult due to turbidity. Fish were sparse.	Coral cover 2–5%. Mortality from recent bleaching ~90%. The only unaffected genera were *Pocillopora, Goniopora, Goniastrea, Astreopora, Pavona* and *Leptoseris.*
	17. Barreira Vermelha	Mixed *Acropora* community, 2–5 m deep, on flat bottom with a few small *Porites* bommies. Sheltered location inshore of Inhaca Island. Poor visibility (0.5 m) limited the quantitative assessment, but extensive beds of *Palythoa,* evidence of El Niño bleaching and current bleaching indicated that this was an affected reef. No fish were seen.	No assessments were possible.

Institute and from 24–30 March by Dr David Obura, the East African co-ordinator of Cordio.

Evidence of bleaching for the present and past year was sought in six localities, listed from north to south in the table. Dives were made on a total of 17 reefs (see map and table) and a visual assessment of reef type, faunistic cover and the extent of reef damage attributable to bleaching and crown-of-thorns starfish (COTS) was made. Quantitative measurements using transect techniques proved inappropriate due to sea conditions, nature and condition of the reefs, and the fact that most of the work was done using snorkel rather than SCUBA. However, it was possible to record random video-photo quadrats at ten of the stations for later analysis. An overview of the results is given in the table.

In Mozambique, the effects of El Niño bleaching were most extensive on exposed reefs in the north and decreased further south, except at Inhaca Island where serious recent bleaching was encountered. Extensive COTS damage was also found at Bazaruto and Inhambane. The COTS outbreaks commenced in 1995–1996 and, as sufficient time has elapsed for reef erosion and collapse to occur, the damage on these reefs was more pronounced. Consequences of the El Niño bleaching are going to be even more serious, since coral mortality on the northern reefs was as high as 90%; a similar progression in the collapse of reef structure on the seriously bleached reefs is anticipated. The biodiversity of these sites will be impaired, as coral recruitment was only observed at the Bazaruto COTS site and at a low level. Fish populations on damaged reefs, the basis of many of Mozambique's valuable artisanal fisheries, were also poor. Both the fisheries and the tourism value of these sites will thus be affected.

Assessment of the extent of damage, socio-economics effects, mitigation and recovery in Tanzania

CHRISTOPHER MUHANDO
Institute of Marine Science, University of Dar es Salaam, Zanzibar, Tanzania

INTRODUCTION

Coral reefs play a crucial role to the well-being of coastal communities in Tanzania. Coastal fisheries, ecotourism and coastal land protection are, to some extent, sustained by coral reefs. A variety of fish species, spiny lobsters, octopus, sea cucumbers, clams, oysters and turtles form the basis of harvestable reef resources. More than 30% of marine fish landings are harvested on or adjacent to coral reef environment. Coral reefs also support offshore fisheries by providing feeding and nursery grounds for some oceanic (pelagic) fish stocks. Tourism based on coral reef ecosystems is picking up, creating new opportunities for employment and substantial amounts of income for the people of Tanzania.

The coral reef environment is also an excellent laboratory for demonstrating biological and ecological complexity to students, as well as to the general public. Thus, it has a potential role to play in education and research. Extraction of natural products have shown that the reef environment accommodates organisms whose extracts have pharmaceutical potential.

Recent surveys, using SCUBA, suggest that there are more than 150 coral species in Tanzania (Johnstone *et al.,* 1998). Corals in the genera *Acropora, Porites, Galaxea, Montipora*, are the main reef builders. Other important organisms occurring in and among the coral reefs include fish, crustaceans, molluscs, sponges, algae, seagrasses, polychaetes, bryozoans, echinoderms and ascidians. In spite of several attempts (Horrill *et al.,* 1994; Richmond, 1997; Johnstone *et al.,* 1998), the species inventory of the coral reefs of Tanzania is far from complete.

Due to the narrowness of the continental shelf in Tanzania, coral reefs are close to land. Abundant reefs occur around islands and sand banks in the Mafia, Zanzibar and Pemba channels (see map). The healthier corals occur around the small islets and sand banks, rather than adjacent to mainland, e.g. around the Zanzibar channel islets and in the Songosongo archipelago. In general, as would be expected, coral reefs located far from urban centres have richer resources than nearby coral reefs (e.g. Songosongo archipelago, Mnazi Bay and Mafia islets). Furthermore, due to limited accessibility, fish are more abundant around relatively deeper and/or high current coral reefs than around shallow and protected reefs.

The main environmental factors affecting coral distribution include water depth, substrate type, turbidi-

Distribution of coral reefs in Tanzania. Due to the narrow continental shelf, reefs are close to land. The effects of coral bleaching varied; generally shallow-water reefs and reefs around Mafia suffered more. Proposed study sites are named.

ty, sedimentation, salinity, tides (emersion), water pollution, population explosion of predatory organisms (especially crown-of-thorns starfish) and ecological competition with algae and other non-reef building organisms. The main anthropogenic threats to coral reefs include over-exploitation, destructive activities (fishing and anchor damage), sedimentation (unplanned agriculture and deforestation) and pollution.

In order to prevent and eradicate overfishing and destructive fishing, laws and regulations aimed at preventing overfishing, destructive fishing and environmental pollution have been enacted. Zoning of coastal marine protected areas for reef conservation purposes is another positive step taken by the Government (e.g. the establishment of Mafia Island Marine Park).

Although useful, the current efforts to regulate exploitation of coral reef environments and resources are facing two serious obstacles. The first obstacle is lack of human and financial resources to facilitate proper enforcement of existing regulations, carry out research and monitor the coral reef environment. The second obstacle is that given the current trend in human population increase and the system of free entry to reef resources, efforts to reduce fishing efforts and destructive activities on coral reefs are unlikely to be realised unless new management strategies are instituted.

THE STATUS OF CORAL REEFS BEFORE 1998

Most reports suggest a widespread degradation of coral reef environments and their associated living resources in Tanzania (UNEP, 1989; Horrill *et al.,* 1994). While a decline in coral reef resources and environment near urban centres is obvious, reefs in remote areas seem to be in relatively "better condition", such as SongoSongo, Mafia, islets in the Zanzibar channel, Misali in Pemba, and off Mnazi bay in Mtwara (this may be incorrect, due to lack of initial or pristine reference conditions). However, after the recent coral bleaching event, the condition of the reefs in Tanzania needs to be assessed again.

CORAL BLEACHING EVENT IN TANZANIA

Coral bleaching in Tanzania probably occurred from February and continued through May 1998. In Zanzibar, coral bleaching started in the last week of March (pers. obs.). Coral bleaching was reported from all parts of the Tanzania coast. The extent of coral bleaching on a national level could not be accurately estimated, but individual reports seem to suggest that bleaching was not uniform. Corals in shallow water (reef flats) bleached more that those in deeper waters. Mafia coral reefs (Kitutia and Pange) seem to have suffered more than Zanzibar reefs. Similarly, corals on the western side of Pemba Island were more affected than corals on the eastern side.

The response differed considerably between coral species. In general, more than 60% of the scleractinian corals showed signs of bleaching (Table 1 and 2). The *Acropora* bleached most. Other coral species that bleached include *Echinopora, Montipora, Millepora, Pocillopora, Seriatopora, Galaxea, Astreopora, Lobophyllia* and *Porites*. A few corals, such as *Diploastrea* and *Pachyseris,* didn't show any signs of bleaching in Zanzibar.

Two factors seem to be associated with coral bleaching in Tanzania: water temperature and rainfall (salinity). The water temperature was 30.5°C (according to a temperature logger placed at 3 m on a coral branch at Bawe, Zanzibar), about 2°C higher than in the previous year (28.5°C) (Figure 1). Even casual swimmers in

Table 1: Bottom cover category summary in some of the monitored coral reef sites in Zanzibar in 1997.

Benthic category	Bawe (W-coast)	Changuu (W-coast)	Chapwani (W-coast)	Chumbe (SW-coast)	Kwale (SW-coast)	Mnemba (E-coast)
Hard coral	53.11	50.17	44.31	51.85	29.73	13.95
Softcoral	2.45	0.74	2.85	0.76	1.66	30.67
Rhodactis	0.97	6.65	2.37	0.49	0	0.1
Zoanthids	0.14	1.65	0.58	0.05	0.03	0.05
Sponges	0.85	0.09	0.17	0.36	0.18	0
Algae	2.94	10.97	3.88	8.87	28.06	2.44
Others	2.04	2.27	0.74	0.12	0.39	0.03
Substrate	37.5	27.46	45.1	37.5	39.95	52.76

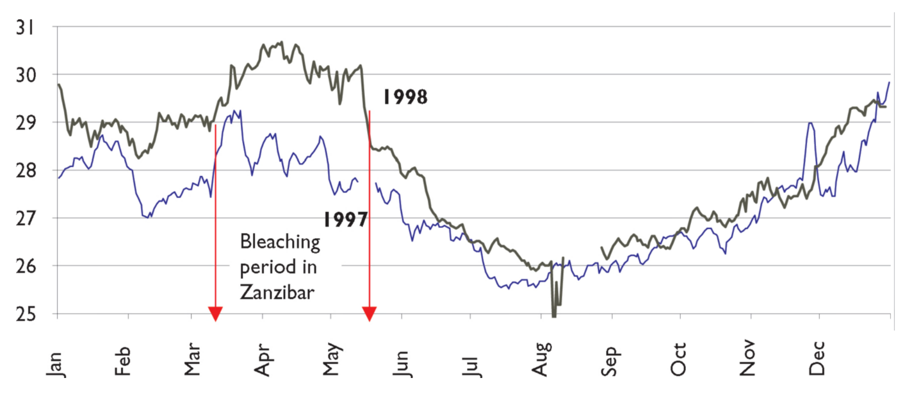
Source: IMS-LGL Coral reef monitoring programme, 1997.

Table 2: The extent of hard coral bleaching on monitored plots in Zanzibar

Coral category	Chapwani	Changuu	Bawe	Chumbe	Kwale
Hard coral before bleaching, October 1997	44.31	50.11	53.11	51.85	29.73
Hard coral after bleaching, November 1998	25	33	45	42	15
Normal coral	44.4	42.6	33.3	16.5	32.8
Bleached	12.7	14.8	11.8	49.4	36.4
Partly bleached	21.0	25.8	14.1	9.3	15.0
Dead coral	19.9	5.8	33.2	11.5	7.1
Partly dead coral	2.0	10.0	7.6	13.3	7.7

Source: IMS-LGL Coral reef monitoring programme, 1998

Figure 1. Seawater temperatur (°C) on Zanzibar coral reefs in 1997 and 1998.



Zanzibar noticed the rise in water temperature from the first week of April to the second week of May in 1998. During this period, Tanzania was also experiencing heavy El Niño-rains. The effects of dilution, especially in shallow waters, cannot be ignored, considering that the tidal range was about 4.5 m at spring tides during the bleaching period.

Different views have been expressed on the survival of corals after bleaching. In Zanzibar, survival after bleaching seems to differ between sites. Survival appears to have been high in some reefs, such as Bawe and Chumbe coral reefs (pers. obs.), while in other reefs, like Changuu and Chapwani, coral survival was very low, probably less than 40%. In some of the reefs in the Mafia Island Marine Park, coral death after bleaching was estimated to more than 70%. Due to the lack of a proper coral monitoring programme, the rates of coral survival after bleaching has remained largely unknown for most Tanzania reefs.

The coral death has triggered ecological disturbances likely to start a chain of ecological reactions. After bleaching and eventual death, the dead corals were colonised by filamentous algae. By November 1998, macroalgae and coralline algae had replaced the filamentous algae. Observations made in January 1999 show that small corals have started to recruit in some places, while in other places corallimorpharia and soft corals have established on the skeletons of dead coral. It is unclear how animals that depend on corals have reacted. Obvious, however, is an abundance of herbivorous (algae eating) fish. Although important, animal and plant succession on dead corals has not been given attention in Tanzania, yet.

The effects of coral death on reef fauna and flora have not been clearly established at a national level. However, Pemba dive operators have reported that Misali Island coral reefs may have lost their tourist potential after the bleaching event. There are no such complaints from other tourist diving locations, but the actual economic effects remain to be investigated.

SCIENTIFIC WORK ON TANZANIA CORAL REEFS

A number of national institutions, as well as Government institutions and NGOs are dealing with coastal zone environment and resource management in Tanzania. Among these, only the Institute of Marine Sciences, Frontier-Tanzania (NGO) and Tanga coastal zone program conduct research and monitoring of coral reefs on regular basis. Coral reef monitoring methodologies are not harmonised between the reef study groups, and there is no agreed procedure for exchanging results of research or monitoring. Some actions are required to unify coral reef monitoring activities in Tanzania, but how this should be attained is open for discussion.

At the Institute of Marine Sciences, there are a number of coral reef studies and programmes going on. The main activities on the Zanzibar coral reefs include coral reef monitoring, coral reef mapping, coral settlement and coral transplantation experiments. The coral reef monitoring programme was sponsored by CIDA, Canada, (1994–1998) and the main objective was training in coral reef monitoring techniques and establishment of baseline data for reefs located off Zanzibar town. The coral reef mapping project is a Sida-SAREC funded activity aiming to describe the distribution of coral reefs in Tanzania. This project is in its final stages.

Other reef programmes at IMS include coral settlement and reef environmental restoration by transplantation of coral fragments. The aim of these activities is to find out whether coral larvae availability and settlement form a problem, and whether coral transplantation is possible and useful or not in enhancing the coral replenishment process in Tanzanian reefs. After preliminary results (Franklin *et al.,* 1998; Lindahl, 1998), more detailed studies are now in progress in Mafia and Zanzibar reefs.

Visiting scientists, PhD and MSc students have been participating in the research on coral reefs. Some examples of these studies are nutrient dynamics on

Zanzibar reefs (Muhammed, submitted MSc thesis), coral reef settlement on Tanga reefs (Nzali *et al.,* 1998), distribution of corallimorpharia on Zanzibar reefs (Kuguru, MSc study), distribution pattern of scleractinians on the eastern and western coasts of Unguja Island (Mbije, MSc study) and effects of heavy metals on the growth of coralline algae (Kangwe, submitted MSc thesis).

According to Dr Jean-Luc Solandt of Frontier Tanzania, the current Frontier activities on coral reefs include baseline surveys, scientific research, rapid assessment and monitoring of coastal resources (including coral reefs) and a Marine Education and Training Program. Frontier Tanzania has surveyed and monitored the health of corals in the Mtwara area since 1997. Fish assemblages have also been investigated, from a biodiversity (species) and a commercial (family) perspective. Permanent monitoring plots were selected, and a reef check undertaken in Mnazi Bay in 1997 and 1998. Coral mining and fish landings in Mtwara harbour are being investigated now. Frontier is also currently carrying out a rapid assessment of marine reserves in Dar Es Salaam. At the moment, Frontier has five scientists that could collaborate with the IMS in assessing and monitoring the effects of coral bleaching in Mtwara.

As you may have noted, none of the programmes mentioned above plan to assess the extent of coral death, socio-economic effects or mitigation and recovery of coral after a bleaching event.

REFERENCES

English, S., Wilkinson, C. and Baker, C. (eds) 1994. Survey manual for tropical marine resources. Australian Institute of Marine Science. Townsville. 368 pp.

Franklin, H., Muhando, C. and Lindahl, U. 1998. Coral culturing and temporal recruitment patterns in Zanzibar, Tanzania. *Ambio* 27 (8): 651–655.

Horrill, J. C., Machano, H. and Omar, S. H. 1994b. Baseline monitoring survey of coral reefs and fisheries of the Fumba peninsula, Zanzibar. *Environmental Study Series,* No. 16.

Johnstone, R., Muhando, C. and Francis, J. 1998. The status of coral reef of Zanzibar: One example of a regional predicament. *Ambio* 27 (8): 700–707.

Lindahl, U. 1998. Low-tech rehabilitation of degraded coral reefs through transplantation of staghorn corals. *Ambio* 27 (8): 645–650.

Nzali, L. M., Johnstone, R. and Mgaya, Y. D. 1998. Factors affecting coral recruitment on a nearshore reef in Tanzania.

Richmond, M. (ed.) 1997. A guide to the seashores of Eastern Africa and the western Indian Ocean islands. 448 pp.

UNEP 1989. Coastal and marine environmental problems of the United Republic of Tanzania. *UNEP Regional Seas Report Stud.* No. 106. 33 pp + annex.

Influence of coral bleaching on the fauna of Tutia Reef, Tanzania

MARCUS C ÖHMAN[1], ULF LINDAHL[2], CHRISTIANE K SCHELTEN[3]
[1] *Dept of Zoology, Stockholm University, Sweden*
[2] *Kristineberg Marine Research Station, University of Gothenburg, Sweden*
[3] *Environmental Dept, University of York, UK*

ABSTRACT
In 1998, coral reefs of Tanzania were severely affected by bleaching. The coral mortality that followed caused a concern for coral reef degradation and overall resource depletion. In this study, we investigated coral bleaching effects on the coral reef fauna at Tutia Reef in Mafia Island Marine Park, Tanzania. Corals from adjacent reef patches of the species *Acropora formosa* were transplanted into plots, and reef structure and associated fish assemblages were examined before and after the bleaching event. Following the coral bleaching, 88% of all corals died. A year after the event, a large proportion of the dead corals was still standing. As surviving and dead corals were from different clones, results suggested that genetic variation might influence bleaching tolerance.

After the bleaching event, a change in fish community composition, with an increase in fish abundance, could be seen. Species diversity, however, was less affected. There was a correlation between structural complexity and fish densities after disturbance. This indicates that the reef may uphold an abundant fish population as long as the architectural structure is intact. The impact that the coral beaching event may have on fisheries is difficult to anticipate. The Tutia Reef supports a multi-species fishery and a variety of techniques are used. As a broad range of species are targeted, including smaller fishes, catches may not be reduced as long as the reef structure is sustained. If reef degradation follows, however, fish abundance is likely to decrease.

INTRODUCTION

Large areas with coral reefs are found along the coast of Tanzania, including Pemba, Zanzibar and Mafia islands. The reefs provide coastal populations with important resources, especially fisheries. In Zanzibar, for example, more than 23,000 fishermen are supported by reef fisheries alone (Johnstone *et al.,* 1998). Corals are also used as building material (Coughanowr *et al.,* 1996). In addition, tourism is a growing business, with reef diving being a major attraction (Anderson, 1998). However, the utilisation of coral reefs for subsistence or as a source of income is accompanied by resource depletion. Many coral reefs in Tanzania show signs of habitat degradation, one reason being the use of destructive fishing methods (Johnstone *et al.,* 1998), and as a consequence catches are decreasing (Shah *et al.,* 1997).

In 1998, the coral bleaching event added to ongoing human disturbances, and further increased coral degradation. Comparatively high bleaching impacts were reported from Tanzania, and in some areas subsequent coral mortality reached 90% (Wilkinson *et al.,* 1998; 1999). For example, Mafia Island, situated south of Zanzibar and 20 km east off the Rufiji River delta, was severely affected. The waters around Mafia Island comprise some of the richest marine habitats in East Africa (Horrill & Ngoile, 1991), and contains the Mafia Island Marine Park (MIMP). The people of Mafia Island depend on the coral reefs for their livelihoods, and there has been a concern for the resource impoverishment that may follow the bleaching event.

This paper presents preliminary data from a research project on the effects of coral bleaching on the reef fauna at Tutia Reef, Mafia Island, and discusses the socio-economic consequences the disturbance may have. More detailed results will be reported elsewhere (Lindahl *et al.,* in prep), and for further discussions on the influence of coral bleaching on reef fauna, see Lindahl (1999) and Öhman (1999) in this report.

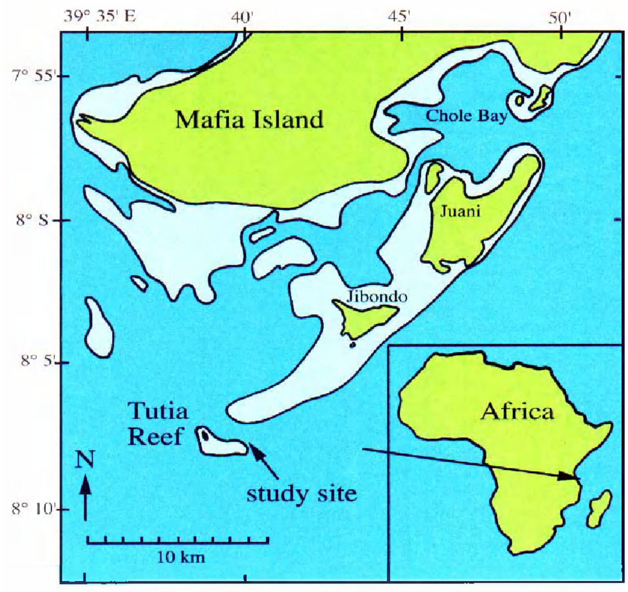


Figure 1. Map of Tutia Reef within the Mafia Island Marine Park, Tanzania.

METHODS

The study was carried out on Tutia Reef, Mafia Island, Tanzania (Figure 1). Thirty-two plots of staghorn corals, *Acropora formosa*, were transplanted from adjacent reef patches in 1995, two years before the first census (Lindahl 1998). In two separate sites within the reef area (200 m apart), plots measuring 2.5 x 2.5 m were prepared in a back reef area of 3 m depth, on a substrate with a mixture of coral rubble and sand.

Living coral cover of *A. formosa* was estimated through point sampling of randomly taken photographs of each plot. Structural complexity was estimated from 1998 measurements of the height of coral branches in five 10 cm sections of two parallel line transects laid out across the plots. The fish were identified to lowest identifiable taxa and counted by a stationary SCUBA diver spending 10 minutes on each plot. The timed counts were replicated three times on different days.

The changes in abundance and diversity of fish over time were analysed with a pairwise t-test, and related to structural complexity using Spearman Rank Correlations. The ANOSIM permutation test (analysis of similarities) was performed (5,000 permutations) to test for significant differences in fish community composition before and after bleaching (Clarke & Ainsworth, 1988). To quantify how much different fish taxa contributed to changes in fish community composition, the SIMPER procedure was used (Clarke, 1993).

RESULTS AND DISCUSSION

In 28 of the 32 plots all corals died after the bleaching event. The live coral cover in the remaining four plots was only marginally affected. Since the plots of living coral were transplanted with corals from what we believe is a distinct clone, the difference in survival after

Dead table-forming *Acropora* spp. after massive bleaching in April–May 1998, Tutia Reef, Mafia Island. The photos were taken in November 1998. Photos: Olof Lindén.

the disturbance can be an indication of within-species genetical variability in sensitivity to coral bleaching. Similar results were found in a study by Edmunds (1994) in the Caribbean.

In the 1998 census in this study, most of the corals that died after the bleaching event were standing intact, thus upholding the structural complexity of the reef. However, the relatively fragile, dead branches of staghorn coral will be more sensitive to erosion by physical and biological processes than live corals. A study of a coral reef destroyed by an *Acanthaster planci* infestation showed that the dead corals turned into rubble within a few years, resulting in a drastic decrease in fish abundance and diversity (Sano *et al.,* 1987). Such erosion of the coral reef may also expose lagoonal areas and the shoreline to increased wave-action, leading to the destruction of other important and productive habitats. In addition, the coral mortality may have a negative effect on the economically important coral mining for construction materials and lime production.

This industry, however, mainly targets massive corals such as various *Porites* spp, which were less affected by the bleaching event than *Acropora* (Wilkinson *et al.,* 1999).

In terms of fishery resources, the critical question is how bleaching and subsequent coral mortality will influence fish abundance and species composition. In this study, a 39% increase in fish numbers was seen between 1997 and 1998, while species diversity remained fairly constant. An analysis using the multivariate ANOSIM test showed that the fish community changed significantly between years ($p < 0.001$). According to the SIMPER test, various herbivorous fishes such as scarids, acanthurids and grazing pomacentrids made the most significant contribution to the shift in the fish community composition. The increasing abundance of herbivores may be an indirect effect of coral mortality, which often leads to an increase in algal growth. However, the relationship between food resources and fish densities is not straightforward, since fish populations may be limited by recruitment (Doherty & Fowler, 1994) or other factors. In a study carried out at the Great Barrier Reef, for example, herbivores did not respond to increased algae cover following a Crown-of-thorns starfish infestation (Hart *et al.,* 1996).

The consequences that a fish population shift may have on the future development of the fish community on Tutia Reef is difficult to anticipate, and it is difficult to foresee its implications for the fishery. A range of biotic and abiotic factors influences coral reef fish communities and, in addition, a reef fishery is typically multi-technique and multispecific (Öhman, 1999). Fishermen at Mafia Island commonly use small-meshed nets, indiscriminately targeting a range of fish species, including smaller reef fish (pers obs).

This study did not show any reduction in fish abundance as a result of the coral mortality following the coral bleaching event. Hence, the impact on fishery resources could be of minor importance. The crucial factor, however, is the fate of reef structure and complexity. As many reef-fish species are closely associated with the reef habitat, coral destruction is likely to affect the fish community (Jones & Syms, 1998).

Many habitat variables have been shown to relate to fish community parameters, and habitat degradation could alter fish numbers (Sano *et al.,* 1984; 1987; Munday *et al.,* 1997; Öhman *et al.,* 1997; 1998; Öhman & Rajasuriya, 1998). The results of this study suggest that reef structure is important for fish density and species diversity. There was a significant correlation (Spearman rank correlation) between structural complexity and fish abundance ($r = 0.86$, $p < 0.05$), as well as between structural complexity and the number of fish taxa ($r = 0.76$, $p < 0.05$) after the bleaching. Hence, if the corals break down and are turned into rubble, it could severely reduce fish numbers. For the same reason, a rich fish community could proliferate if the reef structure remains intact.

ACKNOWLEDGEMENTS

Comments on the manuscript were given by M. Bergenius.

REFERENCES

Anderson, J. 1998. The value of coral reefs for the current and potential tourism industry on Unguja Island, Zanzibar. In: *Coral reefs: values, threats and solutions.* Johnstone R, Francis J, Muhando CA (eds.). Proc. Natl. Conf. Coral Reefs, Zanzibar, Tanzania. Sida, UDSM, UNEP, Nairobi.

Clarke, K.R. 1993. Non-parametric multivariate analyses of changes in community structure. *Austr. J. Ecol.* 18: 117–143.

Clarke, K.R. & Ainsworth, M. 1988. A method of linking multivariate community structure to environmental variables. *Mar. Ecol. Prog. Ser.* 92: 205–219.

Coughanowr, C.A., Ngoile, M.A.K. & Lindén, O. 1996. Coastal zone management in eastern Africa including island states: a review of initiatives. *Ambio* 24: 448–457.

Doherty, P.J. & Fowler, A.J. 1994. An empirical test of recruitment limitation in a coral reef fish. *Science* 263: 935–939.

Edmunds, P.J. 1994. Evidence that reef-wide patterns of coral bleaching may be the result of the distribution of bleaching-susceptible clones. *Mar. Biol.* 121: 137–142.

Hart, A.M., Klumpp, D.W. & Russ, G.R. 1996. Respons of herbivorous fishes to crown-of-thorns starfish *Acanthaster planci* outbreaks. II. Density and biomass of selected species of herbivorous fish and fish-habitat correlations. *Mar. Ecol. Prog. Ser.* 132: 21–30.