CORAL REEF DEGRADATION IN THE INDIAN OCEAN

Status reports and project presentations 1999

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

ISBN 91-630-8329-9

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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.

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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.

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STATUS REPORTS FROM DIFFERENT REGIONS

Coral reef ecosystems in South Asia

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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.

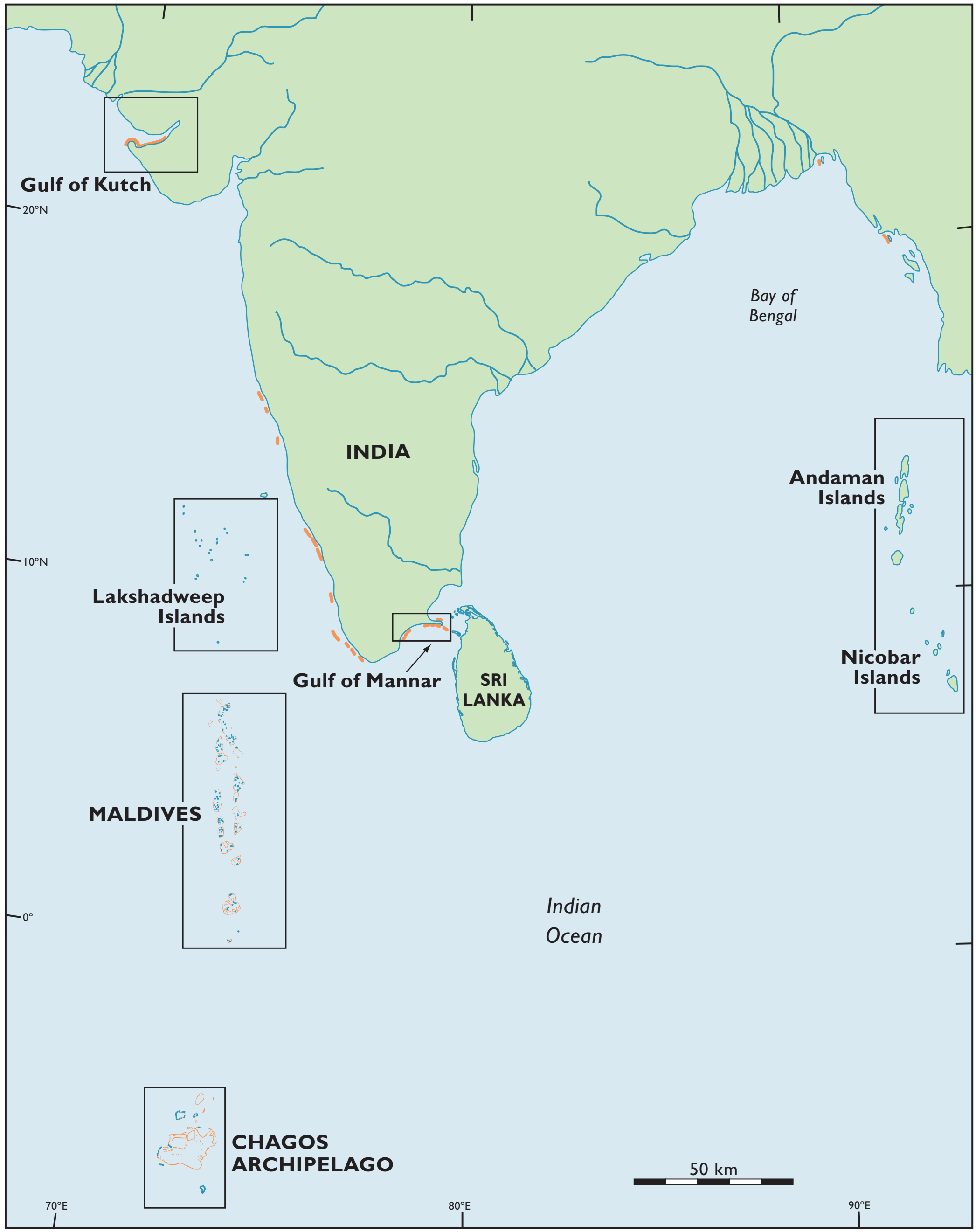
Nevertheless, active management of coral reefs and related resources remains at a relatively low level, mainly due to economic under-development of poor coastal communities, poor planning and co-ordination of development activities, and a lack of trained personnel and equipment. The inability to implement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

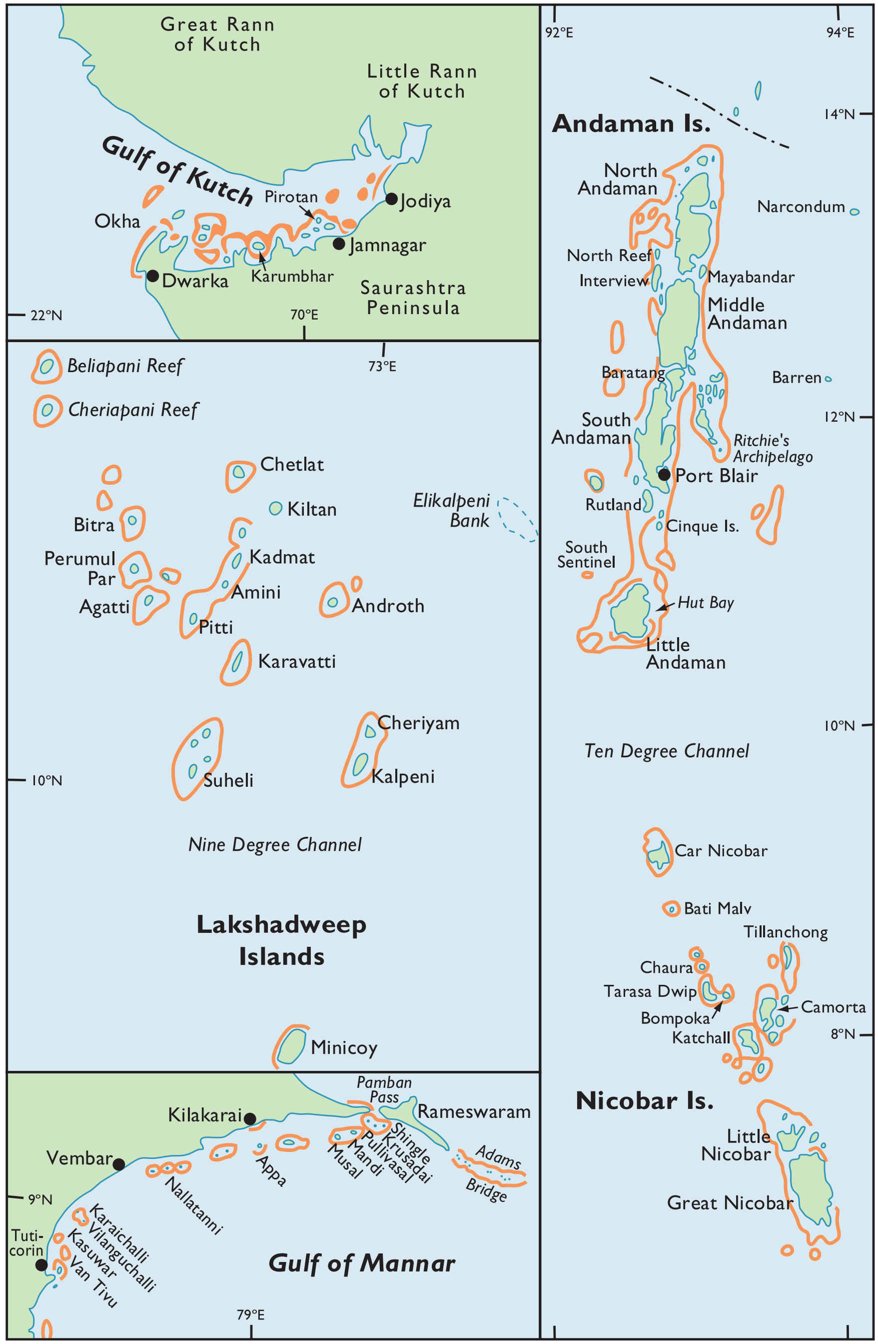
INTRODUCTION

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.

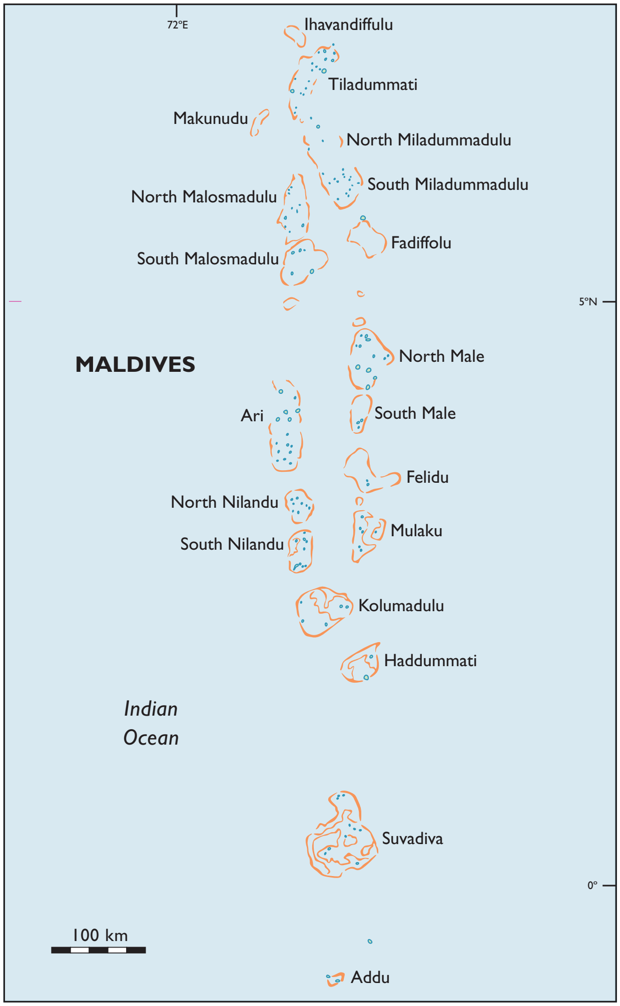
Coral reefs off the mainland coast continue to be exploited for extraction of lime, reef fisheries and collection of ornamental shells, sea fans, seaweed, sea cucumbers, spiny lobsters and sea horses (Hoon, 1997). Agricultural and industrial run-off, pesticides and oil pollution adds to the degradation 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.

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Status report India

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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

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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.

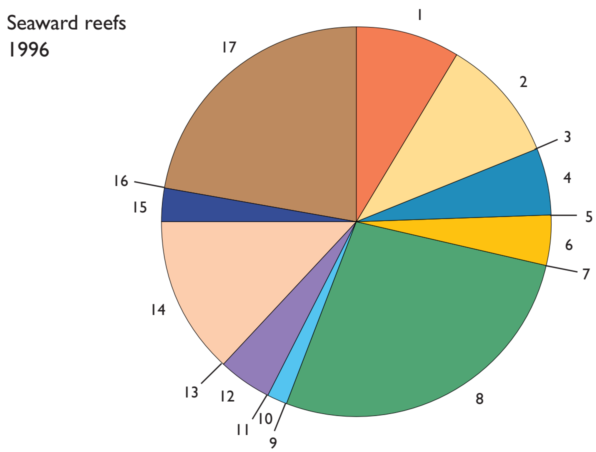
The initial intention was to measure the cover of each reef component and coral species using line transects, in the way it was done at these sites in 1996 and 1978. However, it soon became obvious that there was not enough live coral to justify line transects. With such a low cover, line transects may 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.



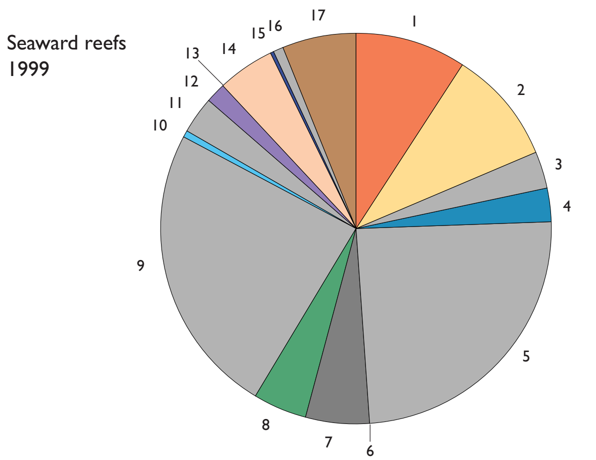


Figure 1. Reef cover values from before (top) and after (bottom) the 1998 bleaching event.
Key: 1: Red algae, 2: *Porites* live, 3: *Porites* dead, 4: digitate coral live, 5: digitate coral dead, 6: table coral live, 7: table coral dead, 8: other coral live, 9: other coral dead , 10: *A. palifera live*, 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.

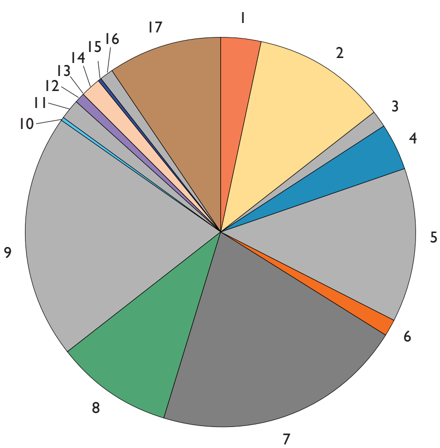
	Massive *Porites*	Digitate corals	*Acropora palifera*	*Acropora* tables	Other corals	Soft corals	Mean fall
Averages	–	-8	-17	-9	-11	-10	-55

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.

Lagoon reefs
1999



Seaward reefs
1999

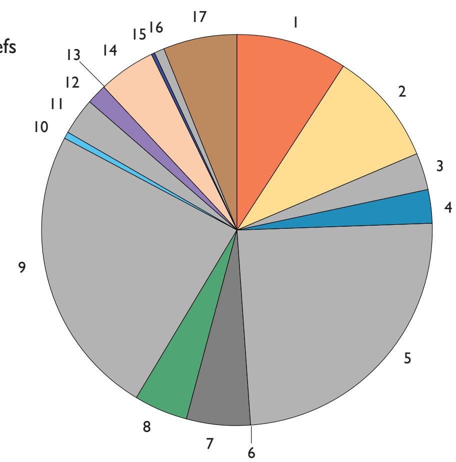


Figure 2. Pie charts showing reef cover values from lagoons (left) and seaward reef slopes (right).
Key: 1: Red algae, 2: *Porites* live, 3: *Porites* dead, 4: digitate coral live, 5: digitate coral dead, 6: table coral live, 7: table coral dead, 8: other coral live, 9: other coral dead , 10: *A. palifera* 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.

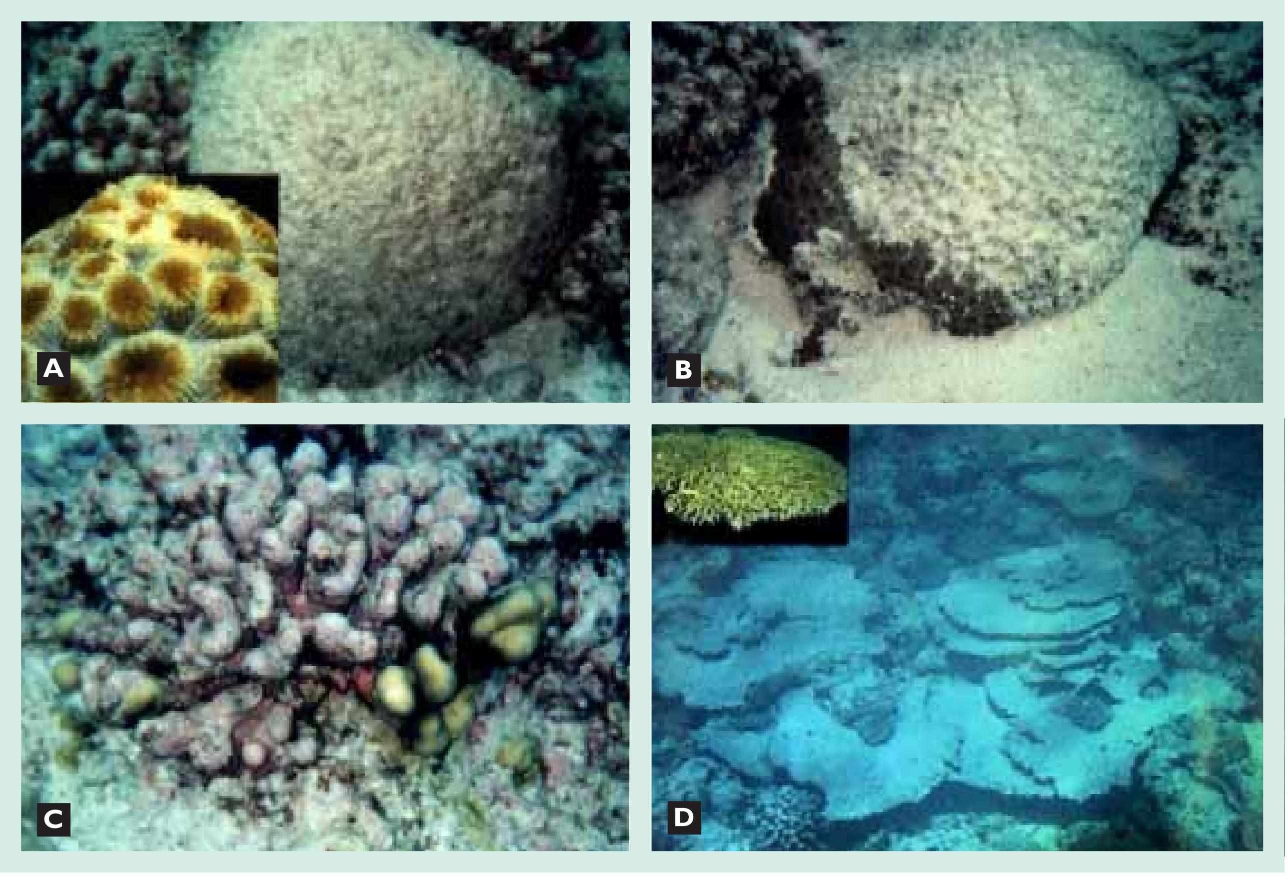
4. Sea levels

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.

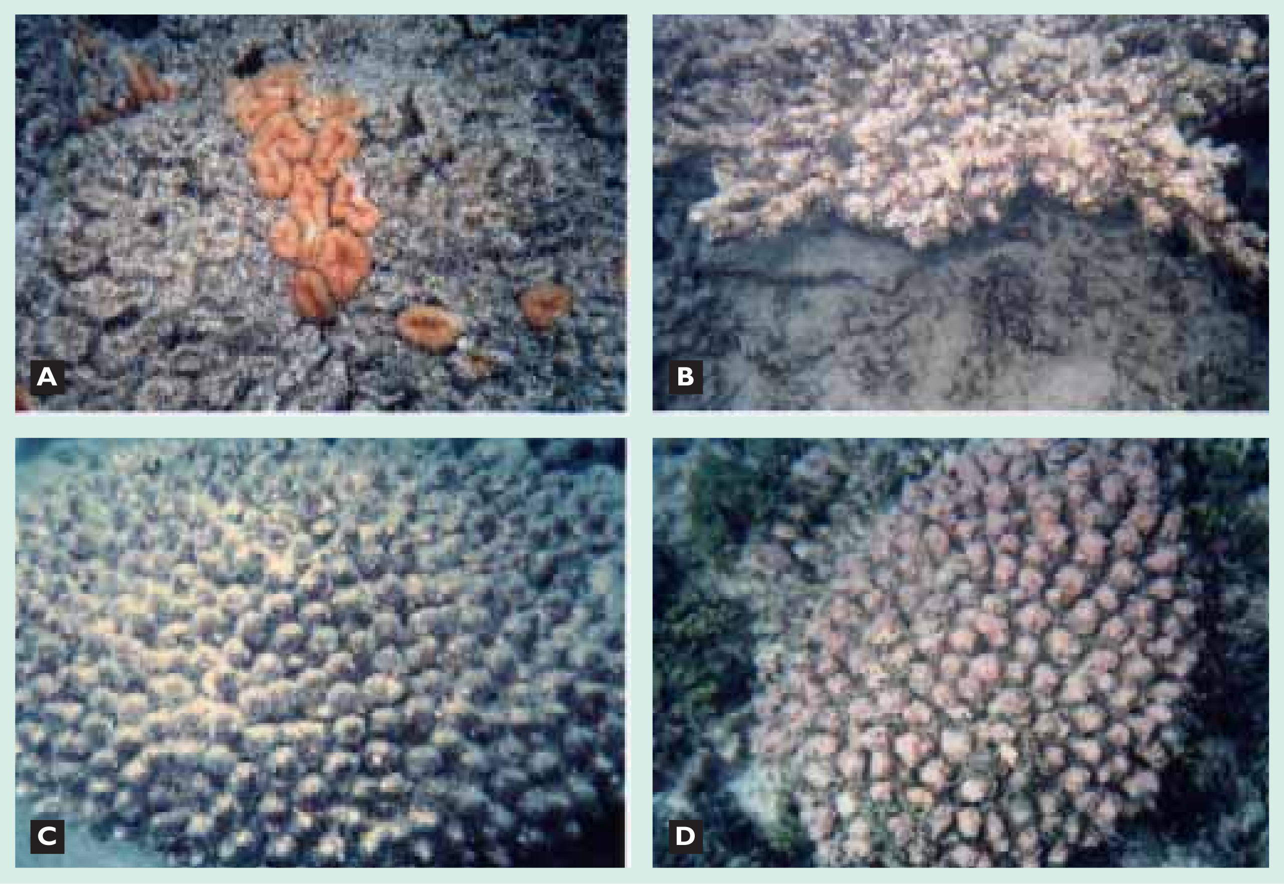
5. Fishing pressure

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

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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

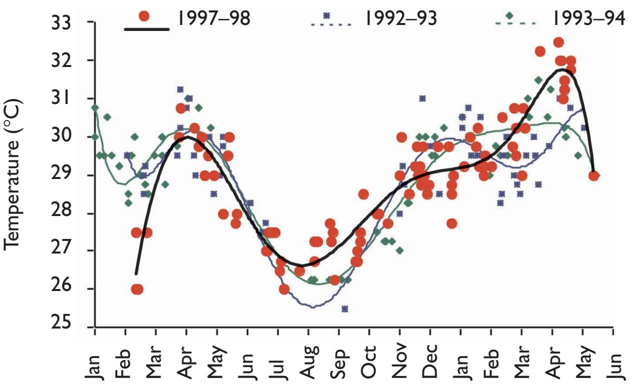
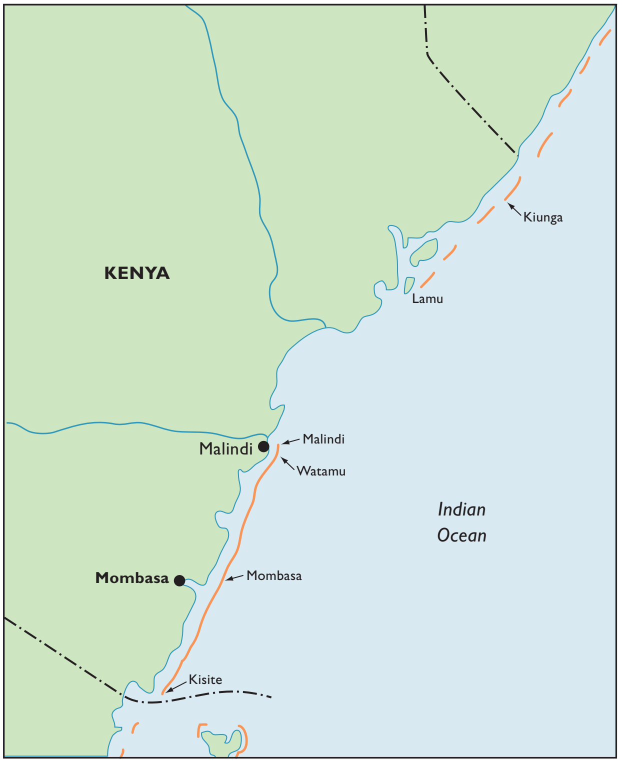


Figure 1. Seawater temperature in shallow coral patch reefs in Kenya, measured using a hand-held thermometer during field visits. Curves are 7th-power polynomials to illustrate seasonal cycling. Data shown for 18-months January–June periods for 1992–93, 1993–94 and 1997–98.

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



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.

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 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).

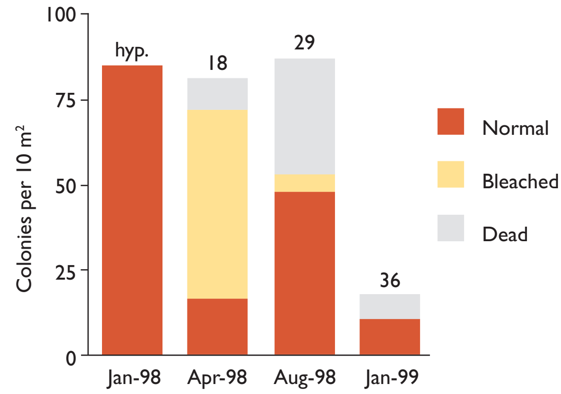


Figure 2. Number of coral colonies that were normal, bleached or dead at four sampling occasions in Malindi, from January 1998 to January 1999. The numbers above the columns indicate the number of 1 m^2 quadrats sampled each time. January data (# colonies) back-calculated from April and August.

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).

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A preliminary assessment of coral bleaching in Mozambique

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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

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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

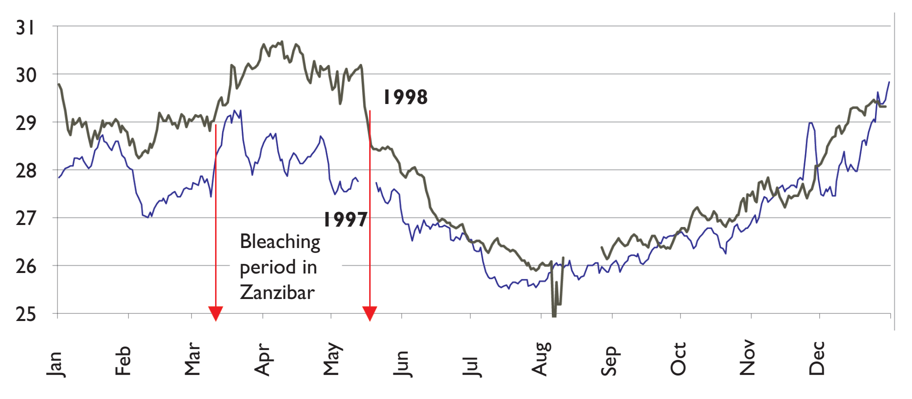
Source: IMS-LGL Coral reef monitoring programme, 1997.

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.

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

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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.

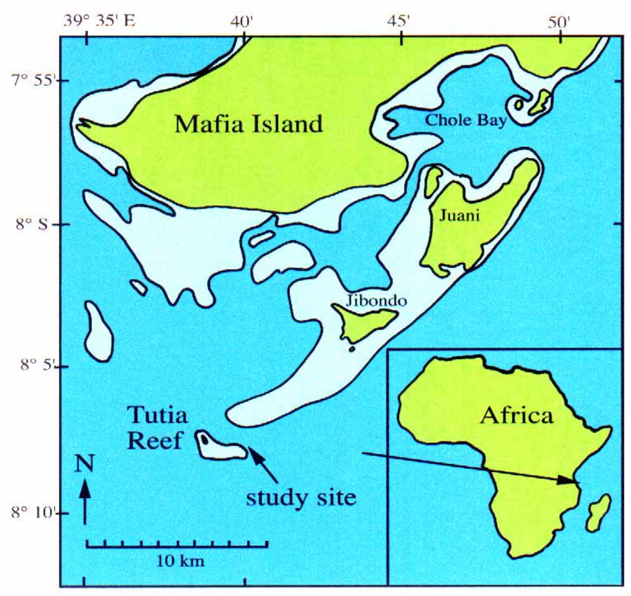

Figure 1. Map of Tutia Reef within the Mafia Island Marine Park, Tanzania.

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.

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Consequences of the 1998 coral bleaching event for the islands of the Western Indian Ocean

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CONTEXT

Coral reefs are vital for coastal populations and for human activities in general, as they provide people both with living resources and with "services" such as shore protection, sand accretion and coastal tourism.

The coral bleaching event of 1997–1998 summer is the most geographically wide spread and severe ever recorded. In the Indian Ocean, warm waters migrated from the South to the North during the first six months. As temperature stress was extreme and/or prolonged, mortality was catastrophically high in many areas (Kenya, Comoros, Seychelles, Tanzania, Maldives), the amount of dead corals ranging from 50–90%. Therefore, ITMEMS (International Tropical Marine Ecosystems Management Symposium) held in Townsville on 24 november 1998 recommended that a multi-disciplinary taskforce immediately be set up.

THE CORAL BLEACHING EVENT OF SUMMER 1997/1998.

Coral bleaching is a response to environmental stress, in particular high temperature, but it seems to be a multi-factorial response to a combination of temperature and other factors, such as irradiance and salinity changes.

According to the available data, Indian Ocean sea surface temperatures (SST) in the summer of 1997/1998 have been higher than previous years, and in some Seychelles reef flats 37°C was recorded (Robert, pers comm). SST data (IRD courtesy) indicate that hot spots affected the Mozambique Channel from December 97 to May 98.

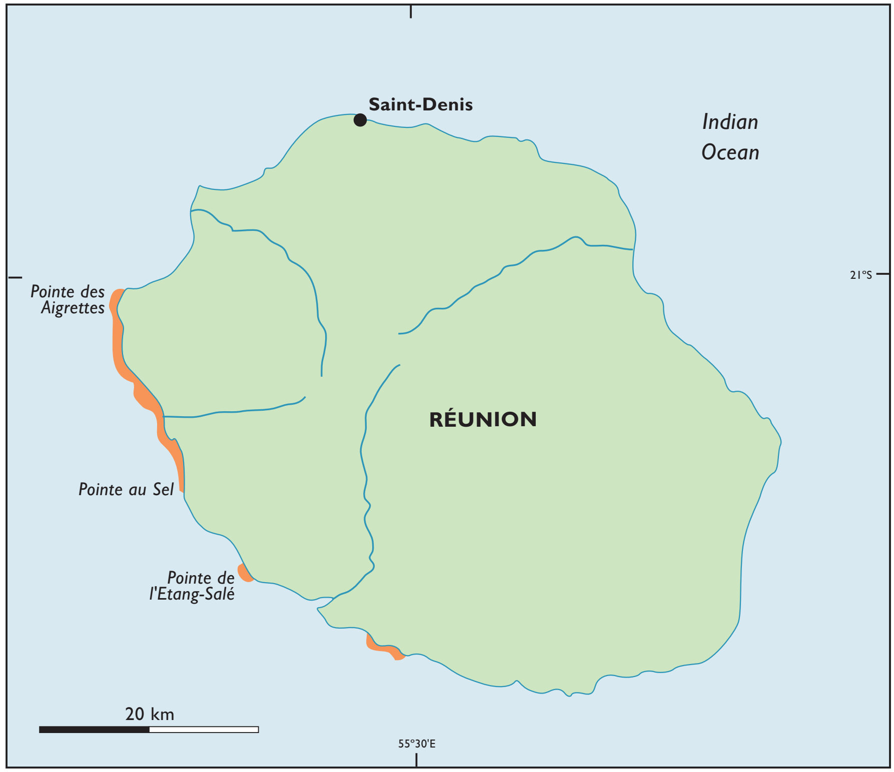
Coral bleaching, affecting both hard corals and other symbiotic organisms, periodically occurs in the Western Indian Ocean region. Frequency and intensity of the precedent episodes have varied from place to place, but are generally underreported: 1983/84 summer, 1987, 1997/98 summer. For the Western Indian Ocean islands, the peak event occurred during March and April 1998.

CORAL BLEACHING IN FRENCH ISLANDS OF THE INDIAN OCEAN

Réunion

Coral reefs are only fringing ones (12 km^2), lying exclusively on the leeward (west) coast, but in the south-

The fringing reefs of Reunion are all located on the western side of the island. Bleaching was moderate, and in many areas the reefs have now, May 1999, recovered.



east region, corals may significantly cover volcanic substrates (see map). The lagoonal areas are very shallow and few, but of great importance to tourism and recreational activities. Tourism is now the main source of income on the island.

Most of the inhabitants of Réunion live in the coastal zone (80% of 720,000 people). Overfishing of demersal fish (350 tonnes/year) has made the island dependent on seafood supply from external sources. Reefs have another important function: they protect the only white sandy beaches from cyclones waves.

Coral communities in Réunion have been studied for 20 year now, and are well-known. The reefs include 55 genera and 149 species. The state of coral reefs is also well-known. Today, 28% of the reef flats are considered to be severely degraded by human activities (sewage pollution, destructive fishing practices, etc).

After a week of heavy rainfall, the 1998 bleaching and mortality event was noticed in late February at the Planch'alizé reef flat station (Milleporidae, Acroporidae, Pocilloporidae, Poritidae families). No bleaching was observed in the nearby station of Trois Chameaux, but bleaching was also noticed in the Saint Leu lagoon and on the outer slope, and in Sainte Rose (in the south-east).

The extent of the bleaching in Réunion was moderate, affecting only pre-stressed colonies. Recovery was good, except in Planch'alizé and Sainte Rose. Dead colonies are now covered by algal turfs with associated damselfish (*Stegastes* sp.).

Mayotte

Mayotte is a high volcanic island with a barrier reef (1,500 km^2 wide) with a deep lagoon (depth 70 m) – it's one of the known double-barrier reefs in the world.

Fish associated with the coral reefs supply a major part of the animal protein, and is caught by nearly 3,600 fishermen. Fishing is reported as the second largest economic sector of Mayotte. The lagoon (*le Grand Lagon*) is a vital centre for tourism (9,000 visitors/year) and the potential for eco-tourism is great.

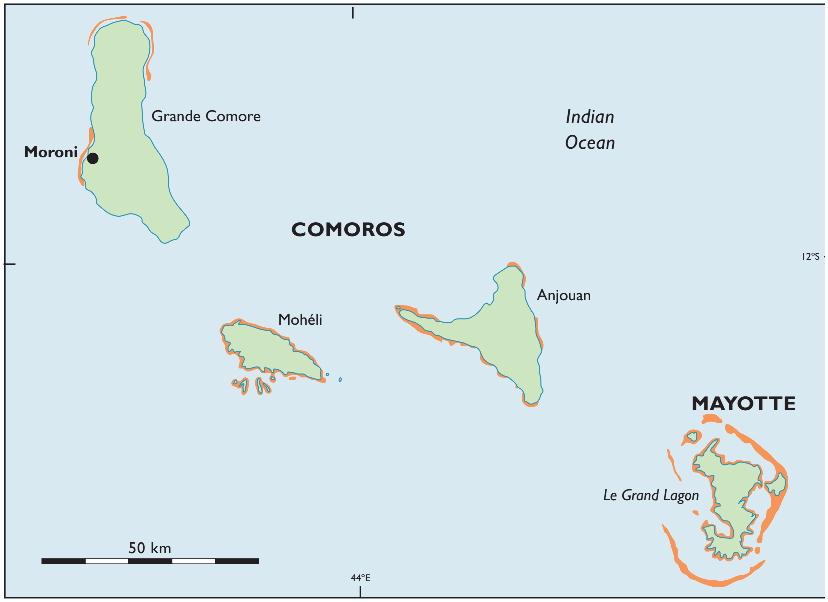
Around Mayotte, more than 200 species of coral have been identified, and the biodiversity of sponges, fish and other organisms is high (239 species has been counted in one place). The state of the fringing reefs is well-known: 50% are in good condition and 36% were degraded or dead before the 1998 bleaching event because of a strong, but less extensive, bleaching event in 1982/1983.

The 1998 bleaching and mortality event was intense and severe. All coral communities in the 0–10m range seem to have experienced moderate or severe bleaching. From April to August, local divers and scientists reported death as widespread, both in the lagoon and on the outer slopes. Up to 80% of the tabulate *Acropora* on the outer slope are now dead and covered by algal turfs and sediment. In August, bleaching of *Fungia* and soft corals was noticed in deep lagoonal places (15 m) by the local Fisheries and Marine Environment Service (SPEM).

One of the monitored side-effects of the bleaching was the massive contamination of dead colonies by the potentially toxic and epiphytic dinoflagellate *Gambierdiscus toxicus*. Samples collected by SPEM show that densities of this bioindicator exploded from 300 cells/g algae (average in 1993–1997) to 60,000 cells/g algae (October 1998). The environmental conditions are still suitable for contamination, and dinoflagellate density in December 1998 was 20,000 cells/g algae. Local authorities are now worried about the socio-economic consequences; this potential increase in the toxin production of the coral ecosystems of Mayotte could enter the food web and cause poisoning effects in humans.

Scattered islands

A number of scattered islands are located in the Mozambique Channel (Glorieuses, Juan de Nova, Bassas de India, Europa) and north of Réunion (Tromelin). Reef formations around these islands are either coral atolls or



The Comoros islands are surrounded by fringing reefs. After the 1998 bleaching event, 55% of the corals were reported dead. Mayotte has got one of the known double-barrier reefs in the world. It was severely affected by bleaching and subsequent mortality, and the dead colonies have been contaminated by potentially toxic dinoflagellates.

platforms (21 km^2). As human activities in the area are few and restricted to meteorological stations, these reefs are some of the last examples of undisturbed coral reefs in the Indian Ocean region.

Very few studies have been conducted in the area in the past 20 years (except on marine turtles), and coral biodiversity remains unknown.

The extension and gravity of the 1998 bleaching and mortality event is only known as anecdotal reports from military scuba divers. Around the islands in the Mozambique Channel, bleaching seems to have been massive.

CORAL BLEACHING IN OTHER COI ISLAND STATES

Comoros

Comoros consists of an archipelago of three islands, Grande Comore, Mohéli and Anjouan, surrounded by fringing reefs (see map, page 55). In 1995, the Comoros population was 0.6 million.

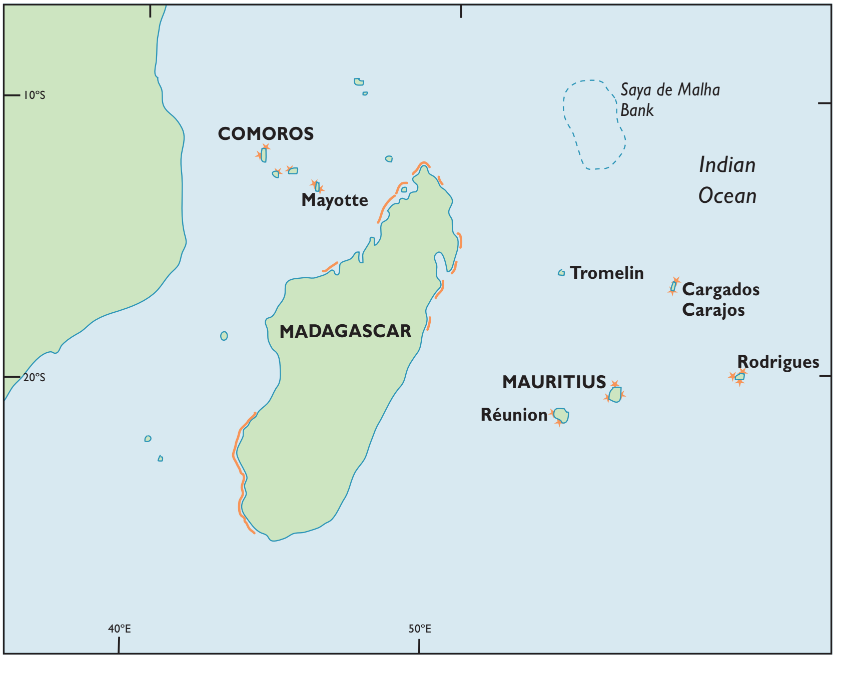
In May 1998, bleaching was observed around Grande Comore and Mohéli islands. Local scientists involved in the COI-Reef Monitoring Programme reported that roughly 55% of the corals had died during the 1997/98 bleaching event. On the reef slopes of Grande Comore, bleaching was observed as 50 m round patches, probably linked to underground freshwater runoff.

Madagascar

With a coastline of 4,800 km, Madagascar has well-developed reefs, including barrier reefs on the East coast (Masoala area, Tamatave) and mainly on the West coast (from south to north). Reef formations cover more than 1,000 km around the island. The reefs of Tuléar (south-west) are scientifically well-known and are surveyed by IHSM (Institut Halieutique et des Sciences Marines).

In 1995, the Madagascar population was 14.9 million and in 1996, tourism arrivals were 85,000.

Bleaching was first reported in March 1998, by diving clubs in Belomer (south-west). A scientific expedition showed that 30% of the hard corals were



Coral reefs around the western Indian Ocean islands (marked with red). Some of the areas are also depicted in greater detail (see pages 54, 55 and 57). Madagascar has well-developed reefs, including barrier reefs. Some areas experienced 30% bleaching during 1998.

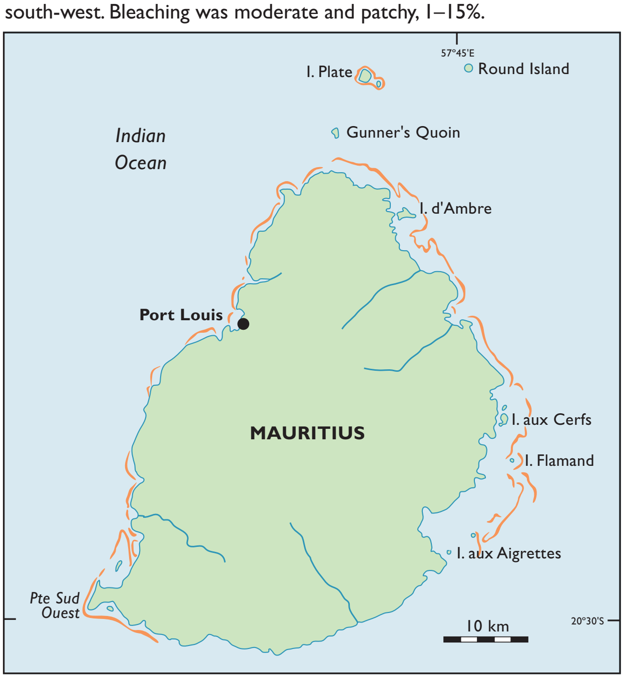
bleached (Maharavo, 1998). In February and March, temperatures were 32–33°C. Discolouration of photosynthetic, non-symbiotic marine organisms such as macroalgae was also noticed. Other locations around the island subject to bleaching were: Masoala, Mananara-Nord, Mitsio archipelago, Tuléar, Nosy Bé and Sainte Marie.

Mauritius

In 1995, the Mauritius population was 1.2 million. In Mauritius, tourism is particularly well-developed, with about 487,000 arrivals in 1996. As lagoons, which offer sheltered waters and sandy beaches, are very attractive for tourism and recreational activities, preservation of coral reefs is important.

Around Mauritius, the extension of coral reefs is 300 km² of fringing reefs and a barrier reef in the south-west. In the large lagoon of Rodrigues, the lagoon cover 200 km², and on the Cargados Carajos shoals 190 km² (Salm, 1996).

Mauritius has got extensive fringing reefs and a barrier reef in the south-west. Bleaching was moderate and patchy, 1–15%.

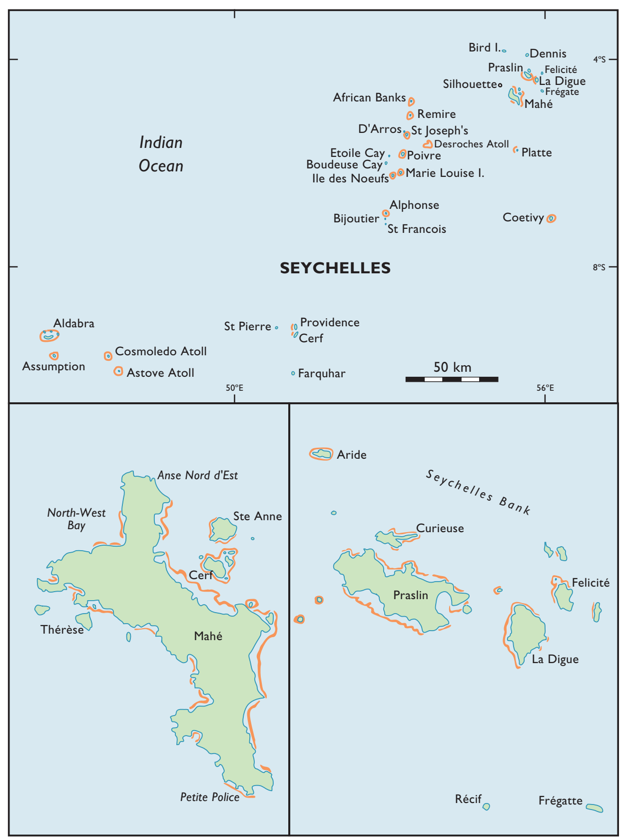


There was a minor bleaching event in Mauritius in 1998, with moderate and patchy occurence in localised areas. Surveys showed 1–15% bleaching in many locations (see also Status report Mauritius, page 60). Temperatures were about 3°C above the normal 27°C (Wilkinson, 1998). No data are available for the islands of Rodrigues and Cargados Carajos (also known as St Brandon Islands).

Seychelles

The Seychelles, made up of 115 scattered islands, also covers 1,374,000 km² of ocean. Fringing reefs are found

In Seychelles, visitors find fringing reefs, patch reefs and coral islands. They are of great importance to the tourism industry. In 1998, Seychelles Marine Park Authority found extensive bleaching and mortality at 14 different locations. Subsequent coral death ranges from 50–90%.



Bleached and partly bleached *Acropora sp.* and *Pocillopora sp.* at 15–18 m depth at St Pierre, Farquhar Group, Seychelles, in April 1998. The temperature in the water was 31–34°C. Photos: A Maslennikov

around the granitic islands of the Mahé group, and coral islands and patch reefs are the main reef formations around the other islands.

In 1995, Seychelles population was 0.1 million. Through tourism and fishing, coastal and marine resources contribute the most to the national economy. International tourism (130,900 visitors in 1996) contribute greatly to the economy of Seychelles. Fish is the main source of protein in the Seychellois diet (75 kg/ person a year), and in 1997 a fleet of approximately 400 boats landed around 4,000 tonnes of fish. Both tourism and fisheries are dependent on the quality of the marine environment.

In May 1998, Goreau's team assessed the bleaching event in 14 locations around the Seychelles islands, as part of a monitoring programme run by the Seychelles Marine Park Authority (MPA). Baseline data on the locations were available on videotapes, recorded in mid-1997. The extent of recent coral death was ranging from 50% to more than 90%. From March to May, extensive bleaching down to 23 m was reported for Aldabra, Providence and Alphonse groups. Temperatures recorded *in situ* were high, from 29–34°C, with the exceptional 37°C in some lagoons. *Acropora* spp. and other shallow water branching species were most affected. Bleaching of other marine organisms was also recorded, for example soft corals, sea anemones and giant clams. Since then, some signs of recruitment has been seen on the outer atolls.

In January 1999, dead corals around the main island of Mahé were covered by numerous filamentous algae. The density of potentially toxic dinoflagellates living on the dead colonies was assessed through the COI/REP programme VIGITOX.

CAPACITY OF THE ISLANDS COUNTRIES IN TERMS OF EXPERTISE AND PHYSICAL RESOURCES

At a regional level, the Environmental Programme of the Indian Ocean Commission (COI/REP) has focused its activities on two areas:

1. The Reef Programme

A functional network was established in 1997, with national focal points (sub-nodes). A coral reef methodology monitoring handbook has been approved by the countries and is now available. The Indian Ocean Commission Reef Action Plan (PAR/COI) includes monitoring of coral reefs as an important activity.

In 1998, GCRMN-COI surveys were carried out in the five countries before and during the bleaching event, in March and in July/December. Twenty-four stations were monitored according to the adapted manual, using parameters such as coral cover, algae, abiotic substrate and ichtyologic population. One addition to the English *et al*. (1994) manual was the assessment of reef flats, which are directly affected by human-based activities.

In April/May 1999, PAR/COI will conduct a new survey which will include more monitoring stations and a post-bleaching assessment. These activities are partly founded by the European Union and partly through national resources. Reef network stakeholders will meet in June to exchange collected data, including bleaching impacts.

The Reef network connects all the relevant focal institutions from the five member countries. The activities are considered as national components of the global GCRMN, and COI is a sub-node for ICRI-GCRMN. For the period 2000–2004, funding from the World Bank should be available for implementation of the GCRMN programme, but only for the four ACP countries (Comoros, Madagascar, Mauritius and Seychelles). Réunion, as part of the European Community, cannot be supported by these funding agencies.

2. The Ecotoxicology Programme

The Ecotoxicology Programme was created in 1998 and the action plan for 1999 will focus on a VIGITOX programme and a field-guide handbook on collection and treatment of microalgal and fish material . A VIGITOX assessment is already underway, a quick response to investigate the eventual links between coral bleaching and the risk for human poisoning through consumption of reef fishes, through contamination of dead corals by toxinogenic microalgae. Pilot reefs affected by coral bleaching have been selected for data collection, and the levels of toxicity in fish bioindicators will be evaluated.

Status report Mauritius

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INTRODUCTION

Mauritius is located in the western Indian Ocean, its main island approximately 800 km east of Madagascar (see maps, pages 56–57). The main island is volcanic with a high, humid central plateau. It is surrounded by fringing (and one barrier) coral reefs, except for short stretches of rock cliffs on the west and south-east coasts. The republic also include five unpopulated offshore islands on the northern shelf, plus the populated volcanic island of Rodrigues at 63°20E, 19°45'S, a fisheries station on sand cays of St Brandon Islands (also known as Cargados Carajos) at 59°30'E, 16°30'S and a cocoa plantation on Agalega sand cay much further north (estimate 56°E, 14°S).

Mauritius has a mixed population of more than 1.2 million people. They make their living on sugar cane agriculture, light industry and textiles, tourism (mostly high quality beach resorts, with over 250,000 guests per year), fishing (reef fishing and offshore bank fishing) and offshore banking. Rodrigues has a population of 30,000 people of African origin, who make their living on subsistence fishing, octopus fishing, cattle grazing and very small scale tourism.

CORAL REEF BIOTOPES

Fringing reefs protect extensive shallow lagoons nearly all way around the islands of Mauritius and Rodrigues. Most are well-established spur and groove reefs with an algal ridge. The lagoons have large beds of branching and tabular corals (*Acropora formosa*, *A. cytherea*, *A.hyacinthus*) and patches of *Pavona, Porites, Platygyra, Galaxea, Montipora* are common. There is extensive seagrass in lagoons, and sparse *Rhizophora* mangrove on the south-east coast of Mauritius, which recently was introduced to Rodrigues.

The marine ecosystems of the main islands are heavily degraded. On Mauritius, degradation is caused by pollution, eutrophication and fishing above sustainable yield. On Rodrigues, soil erosion and sedimentation are the main problems. On St Brandon, there is some fishing impact, but Agalega is probably pristine.

BLEACHING EVENT

Coral bleaching is characterised by the expulsion of symbiotic algae (zooxanthellae) is an increasing problem worldwide. Global warming has been implicated as one cause, but the phenomenon cannot be fully comprehended without an understanding of the variability of zooxanthellae populations in field conditions (Fagoonee *et al.*, 1999). Results from a 6-year field study provide evidence of density regulation, but also of a large variability in the zooxanthellae population, with regular episodes of very low densities. These bleaching events are likely to be part of a constant variability in zooxanthellae density caused by environmental fluctuations superimposed on a strong seasonal cycle in abundance.

SST anomaly data indicates that Mauritius, Rodrigues, and probably St Brandon and Agalega were affected by increasing temperatures from 10/1/98 until 7/3/98. A warm water mass, stretching from the northern tip of Madagascar to the western Australian coast, expanded into a massive warm water area, >1.5°C warmer than normal, covering mid-, south and western Indian Ocean; eventually moving north of Mauritius around 7/3/98, right across the central Indian Ocean.

EFFECTS ON CORAL REEFS

Mauritius and Rodrigues do not appear to have suffered mass bleaching events, although bleached coral colonies were evident on reefs and in lagoons.

During February 1998, Goorah, D., Rathacharen, B.D. and Kulputeea, D. of the Albion Fisheries Research Centre, Mauritius, surveyed for coral bleaching at two unregulated marine parks within lagoons (Balaclava on the west coast and Blue Bay on the south-east coast). They concluded that bleaching affected 39% and 31% of live corals in Balaclava and Blue Bay marine parks respectively, with total bleaching being 12% and 4% of live cover, and partial bleaching 27%.

In April, Turner concluded from observations at Trou D'Eau Douce on the east coast that many (up to 25% in some areas) *Acropora formosa* thickets in lagoons were partially bleached, but in most cases alive. Some *Acropora cytherea* was bleached. The few dead colonies had begun to be colonised by filamentous algae. Bleached colonies were often adjacent to unbleached colonies. Some *Porites* and small faviids on the reef and in the lagoon were bleached, some completely, most partially. Anemones were bleached, but soft corals and *Millepora* seemed to be unaffected. Similar observations have been reported since April from around the island by other workers.

In April 1999, Turner, Klaus, Hardman, Baghooli, Persand, Daby and Fagoonee surveyed 34 sites, both inside lagoons and outside the reef to 20 m depth around the entire coast of mainland Mauritius. Up to 50% of the *Acropora formosa* was partially bleached, usually on the upper surfaces of horizontal branches only. Of the *Acropora cytherea* tables, 30–50% were bleached. Some massive corals (especially *Galaxea, Goniastrea, Porites* in water less than 10 m deep) showed partial bleaching on their upper surfaces only. There were no large areas of dead, standing coral that could be attributed to the bleaching event of 1998, other than possibly the tabular corals on the reef flat of the barrier reef at Mahebourg. Tabular corals (mostly *Acropora cytherea*) at some sites (e.g. Balaclava, Trou aux Biches and Flat Island) were clearly overturned by a recent cyclone and storms (January/February, 1999).

SOCIO-ECONOMIC EFFECTS

Lagoons and reefs are already overfished and heavily degraded due to light industry, fertiliser, pesticide run-off and sewage. While bleaching has not caused major additional degradation this year, the weakened reefs are extremely vulnerable to future events, threatening fishing and tourism industries. Long term data of Fagoonee, Baghooli and Turner (unpublished) indicates an overall trend (independent of season): zooxanthellae densities within *Acopora formosa* have decreased over nine years, potentially making them vulnerable to future impacts.

WHY HAS MAURITIUS BEEN SO LITTLE AFFECTED?

1. Weather conditions in March/April were windy and often overcast, and hence calm conditions and low tides during the hottest parts of the day may not have occurred. Meterological Office data have been requested to analyse solar radiation, rainfall, wind and cloud cover since January 1997.
2. Mauritius' lagoons receive much freshwater run-off percolating through the lagoon floor and reef and from rivers, and are often cooler than the sea outside the reef (Daby, 1994).
3. Coral reef organisms in Mauritius are regularly exposed to widely fluctuating conditions (Fagoonee *et al.*, 1999).
4. Unknown, localised oceanographic conditions.

OTHER RELEVANT WORK IN THE REGION

The reef structure of Mauritius and Rodrigues was described in the 1980s by Pichon, Montaggioni and Faure. Degradation of reefs around Mauritius was described in the early 1990s by Muller *et al.*. An EC report to the Government of Mauritius includes percentage incidences of bleached corals in 30 minute swims at numerous sites in two lagoons. Other reports on the status of coral reefs are: Charpy, up to October 1998; Fagoonee, November 1998; and Watt, December 1998.

Several surveys of the coral reefs around Mauritius were carried out during 1998. Albion Fisheries Research Centre, Mauritius, have monitoring sites at locations around Mauritius, and conducted a coral reef bleaching survey at Balaclava and Blue Bay in February 1998. There are no observations for St Brandon or Agalega. Shoals of Capricorn Programme will begin work around Rodrigues, the Mauritius shelf, the outer islands and St Brandon in 1999, including a bleaching monitoring project.

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Status report Socotra Archipelago

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INTRODUCTION

The Socotra Archipelago is located in the north-western Indian Ocean, on the boundary of the Arabian Sea, 225 km east of Horn Africa, at 53–54°E, 12°30'N. It is a part of the Democratic Peoples Republic of Yemen. Four islands make up the archipelago, main Socotra and the Brothers: Abd el Kuri, Semha and Darsha. They are exposed, high and arid granitic islands with limestone plateaus and fluvial plains. The coastline consists of exposed, rocky coasts with cliffs, rocky headlines, cobble shores, and some sand beaches and dunes. Mangrove only occur behind sand berms or in sheltered wadis/ quorhs.

The size of the human population on Socotra is not known – estimates range from 30,000 to 80,000. (Mountain communities are probably uncensored.) Most of them are goat herders, fishermen and date palm grove growers. People on the islands live in extreme poverty, with poor health and low life expectancy. No development.

FISHING AND TOURISM

Fishing communities are scattered all around the islands. They fish lobster, reef fish and sharks for their fins. Fishing techniques most commonly used are catch nets, throw nets, line and a few cages. A cold store has been built, but is not yet operating. Thus, there is no market for fish unless Omani, UAE or Taiwan buyer boats are in the area. Fishing is probably well below sustainable yield, although small sharks (< 50 cm) may be overfished.

The islands have not been accessible for foreigners, and there is no tourism.

CORAL REEF BIOTOPES

The south coasts of the islands are rock/boulder dominated by macroalgae. There are also small (< 25 cm) faviids, small massives and encrusting corals and soft corals subordinate to the algal meadows. North and eastern coasts support low profile spur and groove coral structures and coral on limestone platform down to 8–9 m. They are mostly made up of *Acropora formosa*, *Acropora clathrata* (up to 2 m on Socotra, better developed up to 3 m on Semha), *Acropora valida* with *Stylophora pistillata* and *Turbinaria frondens*, *Goniastrea*, *Platygyra daedala* and *Porites*. Massives are generally < 0.5 m, except at one site where they are > 3 m. Small faviids and encrusting corals subordinate everywhere, also in deeper water.

The environment of Socotra is pristine, except immediately adjacent to the two small towns and the fishing villages.

BLEACHING EVENT

SST anomaly data indicate that Socotra was affected by increasing temperatures from 12/5/98 to 30/5/98. A 0.5°C rise off Somalia 14/4/98 reached the western tip of Socotra 17/4/98, and surrounded Socotra by 28/4/98. Warmer waters (1°C rise) developed off the South Yemen coast around 2/5/98 and a large warm water mass (+ 1–2°C) developed off the north coast of Socotra from 12/5/98. This mass enveloped Socotra and the south coast of Yemen and Oman by 19/5/98. From 23/5/98 to 26/5/98, it spread from the bottom of the Red Sea to the Gulf, bordering the north coast of Socotra. Cooling began 30/5/98, to less than 1°C, and no anomaly occured after 9/6/98.

EFFECTS ON CORAL REEFS

Corals were reported to be alive in March 1996 (Kemp, M.E.P.). Bleaching was first observed in mid to late May 1998 by De Vantier. Post-bleaching, dead coral was observed in November 1998 (Turner, Klaus, Simoes & De Vantier). By March/April 1999, coral, especially branching *Acropora* washed up on beaches as high berms after storms (Simoes). In April 1999, unbleached live coral was found around the Brothers (Abd el Kuri) (Krupp, 1999), and in deeper water off the north coast of Socotra (> 10 m) (Zajonz, 1999).

In November 1998, Turner, Klaus, Simoes and De Vantier found that 99% of the tabular, branching and massive corals surrounding Socotra were dead. Small faviids, at > 7 m depth, were mostly unaffected. Many soft corals, especially *Sinularia*, were bleached but alive. The coral structure was still standing in most places, and was still used as habitat by fish, though covered in filamentous algae. Areas of mobile coral rubble were developing. Of the Brothers, only Darsha and Semha were surveyed. Surprisingly, they were barely affected by bleaching.

In March to April 1999, another survey was carried out by Simoes, Krupp and Zajonz. They found that storms had caused breakage of branched corals, which were then swept up onto the beaches.

SOCIO-ECONOMIC EFFECTS

In November 1998, it was suggested that storms during the monsoon would probably cause break-up of the coral structure. This had happened by March 1999.

Fisheries will be severely effected – the lobster fishery may decline, and the fishermen may need to turn to deep-sea fishing. A decline in fisheries could cause poor protein diet and even greater poverty.

No further erosion effects are expected, due to the already severe exposure.

ARTICLES ON THE SCOPE OF CORDIO

Remote sensing as a tool for assessing reef damage

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INTRODUCTION

This paper is a written version of an oral presentation of the planned subproject *Remote sensing as a tool for assessing reef damage* within CORDIO, *Coral Reef Degradation in the Indian Ocean,* held at the CORDIO planning meeting in Colombo, Sri Lanka 26–28 January 1999. It is mainly based on the report *Possibilities of observing coral bleaching using satellite data* by Katinka Lindquist and Bertil Håkansson at the Swedish Meteorological and Hydrological Institute (Report 1999 No 5). Dr Bertil Håkansson is responsible for the Marine project within the Swedish remote sensing program RESE (*Remote Sensing for the Environment*). The report was prepared after a request from the author of this paper and two of the promotors of CORDIO, MISTRA (*The Swedish Fundation for Strategical Environmental Research*) and FRN (*The Swedish Council for Coordination of Research)*.

BACKGROUND

The approach is to take advantage of the research that is done within the Swedish remote sensing program. RESE is a Swedish user-adapted environmental remote sensing research program, funded by MISTRA, involving 60 researchers based at eight institutions at four different universities. The main goal of the research programme is "*to improve environmental management and research, by developing methods where information from remote sensing satellites is used operationally*". This fits in with the ambitions of CORDIO:

"*The proposed program will focus on the ecological and socio-economic effects of coral mortality in the coastal areas of eight participating countries. In addition, the program will investigate the possibilities of introducing mitigation or rehabilitation measures and study the natural patterns of recovery of coral reef communities. Furthermore, the program will establish a long-term, regional monitoring program for assessment of the status of coral reefs in the central and western Indian Ocean. The program also aims at identifying and initiating pilot activities to provide alternative livelihood activities to affected communities.*"

The RESE-program is organised in a matrix with five thematic projects in vertical columns and three, more technical, supporting projects in horizontal rows. One of the thematic projects deals with marine ecosystems, and among the technical projects one deals with sensor and atmospheric corrections and another with image analysis. Where these projects cross, the COR-

DIO-question: *Is it possible to detect the health of coral reefs in satellite images?* will be evaluated.

WHICH SATELLITE SENSOR CAN BE USED?

A satellite sensor is the "camera" on board a satellite that transmits the digital registrations received at Earth, transferred to images or data sets. One can choose an image resolution in the range of 4,000–6,000 m, depending on the type of application. The greater the resolution, the more detail is provided. However, this comes at the expense of image width and thus also the time interval at which images of a specific area are recorded. Table 1 shows image resolution for a number of sensors, as well as the number of pixels each sensor uses to describe coral reef areas of different sizes. If a coral reef area has a diameter of at least 100 m (approx 7,850 m^2) and the area is measured with SPOT XS, where a pixel covers 400 m^2, the area will be represented by 20 pixels. If the same sensor is used for a coral reef area with a diameter of 200 m, the area will be represented by just over 100 pixels. For coral reefs that are even larger, for example a diameter of 500 m, the number of pixels increases considerably. In order to describe a coral reef, an image resolution that provides 100 pixels is required (see Table 1).

THE USE OF SATELLITES TODAY

For a methodological study of coral bleaching based on satellite images, one would have to avoid areas that are very close to the coast. It is important to avoid land-based influences, for example in the form of sediments, as much as possible. Remote islands are the most suitable. When chosing a method, it is also important to pay regard to the type of reef. To control for human impact, it is also necessary to use validation and correction methods.

Today, information from satellites is used by, among others, the US Coral Reef Initiative (USCRI). With information provided by the NOAA-AVHRR sensor, hot spot-charts of sea surface temperature anomalies of +1°C or more are published more or less daily on the World Wide Web: http://psbsgi1.nesdis.noaa.gov:8080/PSB/EPS/SST/climohot.html.

WHAT DOES THE SATELLITE RECORD?

The optical sensors on board a satellite register the reflectance of objects. The registration doesn't always show the truth. Disturbances are caused by the contents of different particles in the atmosphere, the influence of the water column and the amount of seaweed on the coral structure. It is necessary to control for those

Table 1. Image resolution and number of pixels for describing reefs of different size.

Satellite and sensor	Image resolution (m)	Number of pixels describing a coral reef with a diameter of at least 100 m	Number of pixels describing a coral reef with a diameter of at least 250 m	Number of pixels describing a coral reef with a diameter of at least 500 m
SeaWiFS	1,130	0.01	0.04	0.2
NOAA AVHRR	1,100	0.01	0.04	0.2
MODIS-AM*	1,000	0.01	0.05	0.2
IRS-P3 MOS	500	0.03	0.2	1
Envisat MERIS*	300	0.1	1	2
Landsat MSS	80	1	8	31
Landsat TM	30	9	55	218
SPOT (XS)	20	20	123	491
Quick Bird*	4	491	3,068	12,272
Ikonos-2*	4	491	3,068	12,272

*Planned sensors, not yet in operation.

parameters and apply correction and validation methods to the data.

HOW DOES BLEACHING OCCUR AND WHAT CAUSES THE CHANGE IN COLOUR?

Bleaching of coral reefs occurs when the photosynthetic microalgae (zooxanthellae) and/or their pigment desert the coral temporarily or permanently. This is caused by some sort of stress, anthropogenetic or natural. Local bleaching is caused by, for example, high temperature, solar radiation, exposure to air, sediments, addition of fresh water (e.g. rain) and inorganic nutrients. The causes of large scale coral reef bleaching, i.e. involving more than 100–1,000 km^2, are increased sea surface temperatures and high solar radiation (particularly UV-radiation), which often occur together.

Bleaching occurs when the density of zooxanthellae and/or the concentration of photosynthetic pigment in the zooxanthellae is reduced. Most corals normally contain between one and five million zooxanthellae per cm^2, depending on the species, and 2–10 pg of chlorophyll per zooxanthella. When corals are bleached, they usually lose 60–90% of their zooxanthellae, and each zooxanthella can lose 50–80% of its photosynthetic pigment. The bleaching process is rapid, it may be over in a couple of days.

When the coral is bleached, its colour changes from a shade of yellow, brown or olive to more or less white. This causes reflectance to increase at all wavelengths. In a reflectance spectrum, the curve for an area with bleached corals will be displaced upwards compared to one with healthy corals.

AREAS FOR COMPLEMENTARY RESEARCH

To get a good picture of the spectral signature of healthy corals and of bleached corals in different stages, airborne hyperspectral technology can be used. For big areas it is a very expensive technique, but the most important wavelengths can be identified through pilot studies. For correct interpretation, it is also important to do ground surveys (ground-truthing) and compare field data with satellite registrations. During 1999, a launch of satellites with very high geometric resolution is planned, and those could provide very good data for this type of detection/monitoring.

LITERATURE SEARCH

Various databases were searched. The word coral bleaching produced quite a few hits. Glynn (1996) reported facts on coral bleaching in detail and others also often quote him. There is also a good article on coral bleaching in Scientific American (1994). Wilkinson described global distribution of bleaching in 1997–1998 in detail in a report published by AIMS (Australian Institute of Marine Science). However, a more specific search for remote sensing in combination with coral, yields only the occasional hit. In a new article, Mumby *et al.* (1997) discuss the possibility of mapping coral reefs with SPOT and Landsat data. Remote sensing also includes airborne observation techniques, and this gives a number of hits.

A combination of coral bleaching and remote sensing produces almost only hits from a group of collaborating researchers: Holden, LeDrew and others. Together, they have published five to ten articles, primarily in connection with conferences. The research of Holden *et al.* (1997; 1998) involves surveillance of coral health, and their articles deal with things such as identification of coral health based on their spectrum as measured with a handheld measuring instrument. They also use hyperspectral analysis, i.e. measurements are taken at very small wavelength intervals (1.4 nm). In order to determine which wavelength intervals to use to distinguish between healthy and bleached corals, these measurements are then subjected to so called “principal component analysis”. Magnitude of the reflectance is a significant factor.

In an article from 1997, Holden *et al.* discuss the possibility of using SPOT-images. The problem with seeing coral bleaching from a distance is that the coral spectrum is difficult to separate from other substrata, and that the water column above the coral causes optic fade-out of the spectrum. On a "normal" SPOT-image, where corals can barely be discerned as light-blue shadows, a type of transformation is applied so that they appear clearly. The next step is to convert digital data to reflectance spectra. This is done by correcting for fade-out in the column of water. Their analysis shows that reflectance spectra can be distinguished to a depth of 10 metres. They conclude: "these results lend confidence to the development of procedures that will use satellite or airborne digital imagery to detect and map coral ecosystem stress".

Holden *et al.* also suggest an area in need of further research – development of radiative transfer algorithms and general model development to correct the image for effects of a water column of varying depth. The problem is that brightness of the substrate substantially contributes to the radiation sensed at the sensor. So the three main variables are: water depth, water quality (attenuation coefficient) and bottom brightness. If you know two of these, then simple algorithms are available for correction of the digital image, but what if you don't know the depth for each pixel (which is often the case)? (pers comm).

Image data from SPOT and Landsat are "geocoded" with aid of the method "Ordnance Survey Maps" and are corrected radiometrically for sensor calibration, time of year and atmospheric conditions. The variation in ocean depth is one of the most cited difficulties with remote sensing of submarine environments. For example, the spectral signature of sand at 20 m can be similar to that of seaweed at 3 m. In order to get around this problem, Mumby *et al.* use a special model for correction for ocean depth. Their objective is not to look at coral bleaching specifically but, in the first stage, to distinguish between four types of seabed substrata (coral, algae, sand and seaweed) and, in the second stage, to determine the species of the seabed flora. Various satellite sensors are compared to airborne remote sensing equipment. Results show that distinguishing coral from the other three seabed substrata on satellite images is no problem.

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Coral bleaching effects on reef fish communities and fisheries

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ABSTRACT

Large proportions of the world's coral reefs were affected by the 1997 and 1998 coral bleaching event. This may have a profound impact on coral reef fauna, especially when the coral bleaching leads to coral mortality. Reef fishes are influenced by the structure of the reef habitat, and as habitat degradation through coral mortality will affect a large variety of interactions within the coral reef system, the composition and size of fish stocks may be altered. This, in turn, could imperil resources for a large number of people depending on fish for subsistence purposes or as a source of income. Due to the variety of factors that regulate reef fish numbers it is difficult to anticipate how coral reef fish assemblages are affected by coral mortality, and only a few studies have considered this issue. The effects of coral mortality could vary from one reef to another, depending on the fish community composition and habitat interactions before the impact, recruitment dynamics, and habitat structure before and after the disturbance. When the dominant coral fauna is affected and there are close interactions between corals and the existing fish populations, a shift in community composition can be expected. If large-scale habitat destruction follows coral mortality (i.e. the corals are broken into coral rubble), fish abundance and species diversity may decrease. In addition, coral mortality could decrease fish catches, which may have profound socio-economic effects. The impact of coral mortality on reef fisheries is likely to depend on aspects such as the nature of the fish community, target species and their habitat requirements, as well as the fishing techniques used.

INTRODUCTION

In 1997 and 1998, large proportions of coral reefs around the world were affected by coral bleaching. Corals are susceptible to variations in temperature (Drollet *et al.*, 1994; Kobluk & Lysenko, 1994; Fang *et al.*, 1997; Jones, 1997; Kushmaro *et al.*, 1997; Lesser, 1997; Podesta & Glynn, 1997) and the bleaching event is believed to be related to increasing water temperatures due to the 1997–1998 El Niño (Wilkinson *et al.*, 1998; 1999). Temperature stress can cause corals to expel their symbiotic algae (zooxanthellae). As a consequence, they appear white and if the stress is prolonged it will lead to coral death. During 1997–1998, coral bleaching and subsequent coral mortality was reported from reef areas in East Africa, the central Indian Ocean, the Middle East, the Indian sub-continent, South-East Asia, East Asia, large parts of the Pacific, as well as the Caribbean and the Atlantic (Baird & Marshall, 1998; Huppert & Stone, 1998; Winter *et al.*, 1998; Wilkinson *et al.*, 1998; 1999).

Profound effects on the coral reef ecosystem are to be expected in areas of coral bleaching, especially where bleaching leads to coral mortality (Glynn, 1984; Brown & Suharsono, 1990; Szmant & Gassman, 1990; Meesters & Bak, 1993; Fagerstrom & Rougerie, 1994; Ware *et al.*, 1996; Davies *et al.*, 1997). How coral bleaching and subsequent coral mortality may affect the reef-associated fish fauna is of specific interest. The fish community is a conspicuous part of the coral reef ecosystem with more than 4,000 species recorded world wide (Sale, 1980). Reef fishes are affected by the structure of the reef habitat and the resources it may offer in terms of food and shelter (Williams, 1991; Jones, 1991). As habitat degradation through coral mortality will influence the large variety of interactions within the coral reef system, the standing stock of fish may be altered (Jones & Syms, 1998). This, in turn, could jeopardize resources for a large number of people depending on fish for subsistence purposes or as a source of income.

The purpose of this paper is to consider the effects that coral bleaching and subsequent coral mortality may have on coral reef fish communities and reef fisheries.

FISH – HABITAT ASSOCIATION

Fishes that proliferate on coral reefs typically interact with corals and other reef structures. Variable preferences among fish populations and the patchiness characterising the reef environment allow for among-habitat distribution patterns at various scales (Williams, 1991; Syms, 1995; Ault & Johnson, 1998; Tolimieri, 1998). At the scale of microhabitats, a type of coral colony, for example, will attract a unique fish community (Ormond *et al.*, 1996; Munday *et al.*, 1997; Öhman *et al.*, 1998 a). Similarly, in patches at the size of tens of metres, such as monospecific stands of coral beds or areas of coral rubble, unique fish assemblages may aggregate (Meekan *et al.*, 1995). However, the most visible patterns, even for a casual observer, are large-scale habitats or zones (10s to 100s of m) (Green, 1996; Letourneur, 1996; Öhman *et al.*, 1997; 1998 b). Beyond differences within reefs are differences among reefs; one reef may hold a fish community observably different from another, due to a distinctive combination of habitat characteristics (Williams, 1991).

In addition to assemblage-specific habitat preferences, general habitat features may influence various fish population measures such as abundance and diversity. Of specific interest in terms of coral bleaching effects, is the relationship between fish and live coral. Positive correlations between fish densities and live coral cover have been reported in a number of studies (Bell & Galzin, 1984; Bouchon-Navaro & Bouchon, 1989;

Coral reef fishes associate with the reef habitat. If reef structure changes it may have profound effects on the fish community. Photo: Marcus C. Öhman.

Chabanet *et al.*, 1997; Öhman & Rajasuriya, 1998). Coral growth also contributes to overall reef structure and influences habitat complexity, and fish species diversity has been reported to increase with structural complexity of the habitat (Luckhurst & Luckhurst, 1978; McClanahan, 1994; McCormick, 1994). However, some studies show little or no correlations between fish and coral growth (McManus *et al.*, 1981; Bell *et al.*, 1985).

CORAL BLEACHING EFFECTS ON REEF FISH COMMUNITIES

Because of the close relationship between fish assemblages and reef structure, any alteration in habitat composition, such as coral bleaching, could influence the associated fish fauna. However, there are difficulties involved in predicting the outcome of a coral bleaching event. Bleaching may influence different habitats in different ways and sensitivity to bleaching may even vary among clones within the same species (Edmunds, 1994; Öhman *et al.*, 1999), hence general principles are difficult to anticipate. In addition, partial or total recovery has been noted in various areas (pers obs), which further complicates the issue.

A given reef fish assemblage is rarely structured by a single factor (Jones, 1991; Caley *et al.*, 1996; Jones & Syms, 1998) and a single event such as coral bleaching may have little or no effect, as other processes may be more important. For example, a fish population within a coral reef may be limited by recruitment and not by resource availability (Doherty & Fowler, 1994).

A few studies have considered the effects of coral bleaching on reef fish communities. Wellington & Victor (1985) investigated the effects of coral bleaching on a damselfish population. Even though the species in focus (*Stegastes acapulcoensis*) proliferate in close association with the substratum, the bleaching caused no alteration in fish numbers. Coral feeders should be expected to be more sensitive to a coral bleaching event and subsequent coral death than fish in other feeding categories. However, population densities of a corallivorous pufferfish (*Arothron meleagris*) were not affected in a consistent manner by coral mortality in the eastern Pacific following the 1982–1983 El Niño (Glynn, 1985; Guzman & Robertson, 1989). Apparently its feeding preferences were more general than first anticipated, since it changed its diet. Öhman *et al.* (1999) conducted a study on how coral bleaching had influenced reef fishes at Tutia reef, Tanzania. The disturbance (which caused large-scale coral mortality) resulted in a shift in fish community composition, while total numbers were less affected. After the bleaching event, Öhman *et al.* (1999) also detected an increase in the numbers of several herbivores.

The 1997/1998 coral bleaching event mainly affected fast-growing branching corals. Such corals are easily broken and a bare coral skeleton is more sensitive to disturbance than a living coral colony. Photo: Marcus C. Öhman.

Coral bleaching effects could be anticipated by considering the effects of other factors of disturbance. A number of natural disturbances frequently modify the

If corals are broken into rubble, fish abundance and species diversity will decrease and an overall shift in fish community composition will follow. Other species, such as the neon damsel (*Pomacentrus coelestis*), that prefer rubble habitats will dominate over species that depend on living corals for food and shelter.
Photo: Marcus C. Öhman.

reef habitat. Storms, for example, may cause large-scale destruction to a reef and have been reported to influence fish fauna through habitat alteration (Kaufman, 1983; Lassig, 1983; Letourneur *et al.*, 1993). However, what is more relevant for comparison is an impact that bears similarities to coral bleaching. The crown-of-thorns starfish (COTS) feeds on coral polyps and may devastate whole reefs when occurring in large enough numbers (Cameron *et al.*, 1991). Although one difference between coral bleaching and COTS infestations is that the latter will not leave any dead polyp tissue, there are similarities in that the coral colony is standing and the structure of the reefs is more or less intact. Munday *et al.* (1997) reported a reduction in coral-dwelling gobies that directly corresponded with the decline of live corals following a COTS outbreak on the Great Barrier Reef. Also, when COTS caused a decrease in live coral cover in Tahiti, the number of butterflyfishes declined with almost 50% (Bouchon-Navaro *et al.*, 1985). In another study on COTS effects, Sano *et al.* (1984; 1987) detected that coral mortality led to a decrease in both fish species diversity and abundance. However, Williams (1986) and Hart *et al.* (1996) showed that coral death had little impact on the associated fish community.

The severity of coral mortality caused by increased temperatures, COTS or any other type of disturbance is largely dependent on the subsequent developments of the reef structure. A coral skeleton still holds architectural complexity and far from all reef fishes are dependent on a coral substrate that is alive (Godwin & Kosaki, 1989; Jennings *et al.*, 1996; Öhman *et al.*, 1997; 1998 b). Hence, as long as there is a structure for reef fishes to associate with there may be an abundant fish community. However, an exposed coral skeleton is more susceptible to bioeroders and other degrading factors, which may break corals into rubble at a faster rate. This has been shown to decrease fish abundance and species diversity and to change community composition (Lewis, 1997; Öhman *et al.*, 1997). Öhman *et al.* (1999) found that there was a clear positive correlation between structural complexity of the reef and fish abundance and a negative relationship to the proportion broken corals.

CORAL BLEACHING EFFECTS ON REEF FISHERIES

Coral reefs are utilised as natural resources for a large proportion of the human populations (Cesar *et al.*, 1997; Berg *et al.*, 1998). Dive tourism is a significant part of the tourist industry and coral reefs are attractive dive sites (Hawkins & Roberts, 1994; Davis & Tisdell, 1995; Wilhelmsson *et al.*, 1998). Considering that reef fishes often are the main attraction for a diver (Milon, 1993), the status of the reef fish community is of utmost importance to this industry. Another considerable industry depending on the status of the reef fish fauna is the aquarium trade, which is selling live caught fish for ornamental purposes (Wood, 1985).

The most important industry on coral reefs, however, is the fishery (Russ, 1991; Munro, 1996). If coral mortality, following a coral bleaching event, decreases fish catches it is likely to have profound socio-economic effects. Most reef fisheries are carried out for subsistence purposes or as small-scale businesses (Ruddle, 1996). Hence, coral bleaching could directly influence food availability for a large number of people. It is difficult to predict coral bleaching effects on reef fisheries due to the complex nature of reef fish communities. Furthermore, reef fishing is multi-specific: a range of species is targeted and a variety of fishing techniques is used (Russ, 1991). In addition, potential fishing yields per unit area may vary from one reef to another (Bellwood, 1988; Dalzell, 1996). In fact, Arias-Gonzales *et al.* (1994) listed 48 yield estimates from around the world and catches ranged from 0.1 to 36.9 t/km^2/year. Hence, generalisations on coral bleaching effects on reef fishing will be difficult.

Another important aspect of coral bleaching effects on reef fisheries is the kind of fish species targeted and how these species may interact with coral bleaching. The 1997/1998 coral bleaching event had severe impact on fast growing corals in shallow waters, especially *Acropora* (Wilkinson *et al.*, 1999). Such shallow reef areas, with fast-growing branching or foliaceous species, are typically dominated by smaller fishes such as various damselfishes, wrasses and butterflyfishes (e.g. Öhman *et al.*, 1997), which are more likely to be affected by coral mortality. Smaller fishes are caught in the fishery in some areas (e.g. in Jamaica, Tanzania and Seychelles; pers obs) but the main target is larger species (Russ, 1991) such as groupers, snappers and grunts that dominate deeper waters (Williams, 1991). Hence, if coral bleaching is limited to certain habitats, only a part (if any) of the fishery will be affected.

CONCLUSIONS

Coral bleaching that leads to coral death will alter the reef structure. In general, coral reef fishes are closely associated with the reef habitat. Hence, coral bleaching would be expected to influence the fish fauna. However, because of the complexity characterising these fish populations and due to the variety of factors that regulate their numbers, it is difficult to determine what the consequences of coral bleaching might be. The effects may vary from one reef to another, all depending on the fish community composition, habitat interactions before the impact, recruitment dynamics, and habitat structure before and after the disturbance. If the dominant coral fauna is affected and there are close interactions between corals and the existing fish populations, then a shift in community composition is likely to occur. If large-scale habitat destruction follows coral bleaching, i.e. the corals are broken into coral rubble, chances are that there will be a major decrease in fish abundance and species diversity.

Coral mortality due to a bleaching event could have a major impact on the fishing yield. The extent of the impact will depend on aspects such as the nature of the fish community, target species and their habitat requirements and the type of fishing techniques used.

As a consequence of the coral bleaching event decreased fish catches may follow. It depends on the nature of the fish community and the kind of species targetted, as well as the kind of fishing techniques used. If the architectural structure of the reef is intact (i.e. the coral skeleton does not break) the reef could still hold large fish densities.
Photo: Marcus C. Öhman.

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Rehabilitation of degraded coral reefs

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DESTRUCTION AND RECOVERY OF CORAL REEFS

The mass mortality of corals during El Niño has accentuated the need for coral reef conservation and rehabilitation. The intact reef framework made up by dead corals may provide suitable conditions for coral recruitment, but the capacity for coral recolonization is often reduced by chronic disturbances. Several factors related to anthropogenic influences can prevent the recovery of coral reefs. Eutrophication leads to increased growth of algae, which compete for space with the corals and inhibit the recruitment of larvae (Wittenberg, 1992). Likewise, sedimentation caused by terrestrial run-off or dredging smother corals and prevent settlement of coral larvae (Maida, 1994; Babcock, 1991; 1996; Bak, 1979; Hodgson, 1990; Yap, 1990). In addition, recruiting coral larvae may be scarce as a result of the widespread coral mortality. Thus, it appears that colonization by coral larvae in many cases may be a bottle-neck for the recovery of degraded coral reefs.

Fragmentation is probably the predominant mode of reproduction among many of the major reef-building corals, and therefore important for the growth of coral reefs and for the recovery of coral communities after disturbances (Highsmith, 1982). Hence, rehabilitation of coral reefs through transplantation of corals could be seen as a way to bypass the critical stages of larval recruitment and early coral growth by using the coral's inherent ability to reproduce through fragmentation.

REHABILITATION OF CORAL REEFS

So far, rehabilitation of coral reefs has not been widely applied as a management option, but several studies have been undertaken in order to develop suitable methods. Most of the previous experiments on coral reef rehabilitation have aimed at either (1) improving the conditions for natural colonization by placing artificial substrates on the seabed (Clark, 1995; Harriott, 1988; Schumacher, 1994; Fitzhardinge, 1989; Thongtham, 1998) or by clearing or consolidating loose sediment (Hudson, 1988; Miller, 1993) or (2) transplanting corals to the degraded areas (Kaly, 1995; Guzmán, 1991; Auberson, 1982; Bowden-Kerby, 1996; Harriott, 1988; Maragos, 1974; Birkeland, 1979; Yap, 1992). These two methods have been combined, by transplanting corals to artificial substrates (Clark, 1995). Corals have also been transplanted in order to move populations away from threatened habitats, such as areas affected by effluent from a thermal power-plant (Plucer-Rosario, 1977) or by land reclamation (Newman, 1994). In order to improve fisheries or provide sites for recreation, coral reefs could also be created in areas previously devoid of corals (Oren, 1997; Schumacher, 1994; Bouchon, 1981; Bowden-Kerby, 1996).

The usefulness of coral transplantation and other methods for reef rehabilitation has been questioned since most of the suggested methods are very expensive (Clark, 1995; Hatcher, 1989; Harriott, 1988). Corals transplanted to benign environments often survive and grow, but damage and loss of transplanted corals due to wave action is common (Birkeland, 1979; Bowden-Kerby, 1996; Clark, 1995; Harriott, 1988). Some of the methods applied so far to fix corals on the seabed involve the use of underwater epoxy glue (Kaly, 1995; Yap, 1992), terracotta tiles (Plucer-Rosario, 1977; Birkeland, 1979), steel bars hammered into the substrate (Guzmán, 1991) or large concrete structures placed on the seabed (Clark, 1995). These methods are labour-intensive and require SCUBA diving and expensive materials and equipment, and therefore their application may be restricted to the reefs with the highest economic value, such as sites for dive tourism and recreation. However, most of the countries that are most seriously affected by coral reef degradation have limited resources for natural conservation, and it is clear that large-scale coral reef restoration can never be a realistic option in developing countries unless simpler methods are developed, methods that can be applied by the local community of reef-users without specialist skills and without great investments in materials.

The need for more cost-effective methods for reef rehabilitation has led to the suggestion that corals should be transplanted to low-energy environments without being attached (Woodley, 1989; Yap, 1990; Kojis, 1981). Studies on transplantation of unattached corals performed so far (Birkeland, 1979; Bouchon, 1981; Bowden-Kerby, 1996; Lindahl, 1998; Harriott, 1988; Plucer-Rosario, 1977) have yielded variable results, possibly due to the different species, methods and habitats that have been used.

Staghorn corals and other branching corals in the genus *Acropora* generally show good survival and rapid growth after transplantation, and the most promising results stem from studies of unattached staghorn corals placed in shallow habitats protected from strong wave action (Bowden-Kerby, 1996). However, this growth form has often been dislodged and killed by strong wave action after transplantation (Bowden-Kerby, 1996; Harriott, 1988). Likewise, Clark and Edwards (1995) found higher mortality of branching acroporids transplanted to a high-energy environment compared to species with massive growth forms. The branching growth form and small area of attachment of staghorn corals makes them vulnerable to strong water movement even if the corals are firmly attached to a stable substrate, whereas in a protected or moderately exposed environment this growth form has the ability to survive and attain stability even on loose substrate (Gilmore, 1976; Bowden-Kerby, 1996; Tunnicliffe, 1981).

In a recent two-year study, aimed at developing simple and cost-effective methods for reef rehabilitation, transplanted staghorn corals showed good survival and growth on unconsolidated substrate in a moderately exposed environment (Lindahl, 1998). The method of tying the corals together on strings before placing them on the seabed was shown to significantly increase their ability to colonize the target area.

Staghorn corals are common in shallow waters on many reefs worldwide; they grow rapidly and have a natural ability to reproduce through fragmentation and to colonise unstable substrate. Connell (1985) noted that small patches and clearings within existing coral populations are invaded quicker by branching and fragmenting species than by massive growth forms. Therefore, staghorn corals are especially suitable for rehabilitation purposes, not only because of their capacity to populate a specific target area, but also for the possibility of rapid regeneration of clearings and other damages on the source populations. This may not be the case with most of the slow-growing massive corals, and that should make them less suitable for transplantation. However, the usefulness of staghorn corals may be restricted to habitats with ”sufficient” shelter from wave action.

IDEAS FOR FUTURE RESEARCH

Experimental data is needed on the suitability for transplantation of a wide range of coral species in different habitats (i.e. depth, wave-exposure, water quality and sediment structure), and on the effects of interspecific competition among transplanted corals. A wider selection of donor species would reduce the risk of over-harvesting local populations, and a more diverse community of transplanted corals would also increase habitat complexity and resistance to diseases. The effects of transplanting corals between different habitats are poorly known. Intraspecific variability and adaptations to different environments may occur either through phenotypic plasticity or through genetic differentiation (Veron, 1995; Oliver, 1983).

Ecologically sound management of coral transplantation projects will not be possible without realistic estimations of the effects of coral collection on donor populations. Such estimations have been made on some coral species with distinct colonial growth forms based on data on abundance, recruitment, growth and survival (Oliver, 1985; Ross, 1983; Grigg, 1983). However, pruning and re-growth of dense thickets of branching corals, and the effects of coral collection on intraspecific competition have not been studied. Furthermore, culturing of corals may be an alternative to harvesting natural populations (Franklin, 1998).

The transport of corals for transplantation is critical, since it is impractical to store large quantities of corals submerged in water. Previous studies have indicated that staghorn corals can survive up to two hours of emersion if shaded (Harriott, 1988), and unpublished data show that this time could be more than doubled if some simple precautions are taken. Further studies of methods to alleviate desiccation stress on corals in different climates would be useful.

The economic incentives for reef rehabilitation vary greatly, e.g. between areas exploited for dive-tourism and reefs used by artisanal fishermen. The value of a coral reef may be difficult to estimate in economic terms (Berg, 1998; Spurgeon, 1992), but nevertheless, cost-benefit analyses of coral reef rehabilitation are needed for effective management. Previous estimations of the costs of coral reef rehabilitation have been based on more complicated methods, using SCUBA and/or expensive materials for attachment. For estimation of the benefit of reef rehabilitation, we also need more information on the capacity for long-term natural recovery of degraded coral reefs.

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Socio-economic aspects of the 1998 coral bleaching event in the Indian Ocean

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INTRODUCTION

Coral reefs are often referred to as the rainforests of the sea, with amazing beauty and incredible biodiversity. They are also the life support system for millions of coastal inhabitants who derive their livelihoods from them and benefit from the multiple services that reefs provide, such as shoreline protection, nutrient cycling, recreation, tourism and fisheries. Increased pressures on reefs brought about by demographic growth in the coastal zone, expanding tourism, changes in agricultural practices, destructive fishing and the influence of climate change all contribute to threaten the coral reefs.

During the period February to June 1998, a significant rise in the surface water temperature in the Indian Ocean and elsewhere was observed. This temperature anomaly, reported to be around 4–6 degrees above normal over an extended period of time, resulted in extensive coral bleaching and widespread mortality. Hard hit were large areas of coral reef, from Sri Lanka and the Maldives in South Asia to the East African coastal line stretching from Kenya and Tanzania to Madagascar and the Seychelles.

Such widespread bleaching has not been observed in recorded history. In certain areas, such as around the central granite islands of the Seychelles, only a few percent of the reefs are reported to have survived. The start of bleaching in February 1998 coincided with a large El Niño event, and bleaching stopped just as the Asia-Pacific climate switched over to a strong La Niña in June. The massive coral bleaching and mortality of 1998 should be considered against the backdrop of decades of rapidly deteriorating coral reefs all over the world, mainly due to human activities. What was alarming about the 1998 bleaching event, was the widespread occurrence and that many reefs previously regarded as near-pristine were seriously affected.

The bleaching and subsequent mortality may result in serious socio-economic impacts, particularly for those nations whose economies are heavily dependent on the revenues generated by reef-based tourism and reef-based fisheries. The situation raises several important questions such as: (a) whether the bleaching event is merely a one time occurrence, or whether such phenomena will be more frequent as the world's atmosphere and waters warm up; (b) Is there evidence that the reefs may recover? If so, what is the rate of recovery and what, if any, measures can be put in place to enhance recovery; and (c) socio-economic implications and the definition of remedial measures for mitigation of these impacts.

SOCIO-ECONOMIC CONSEQUENCES

With 135 persons per km^2, the Indian Ocean region is the most densely populated coastal region in the world (WRI, 1998). The majority of the population is poor and dependence on fisheries for income and animal protein intake is high. In the Southern Indian Biosphere Reserve in the Gulf of Mannar, nearly 200,000 people earn their livelihoods directly from the sea (one-third of the population) and 90% of fisherfolk are artisanal relying on harvesting nearshore reef-related fisheries and seaweed resources. Overfishing is already a major threat and the coral bleaching effect could worsen this. For instance, along the reef coastline of Eastern Africa, around 50% of the estimated 100,000 full-time fishers and several hundred thousand part-time fishers risk losing their livelihood if the overfishing trend is allowed to continue (Moffat *et al.*, 1998). Besides, some of the fish available may even become toxic, as levels of ciguatera poisoning in the French territories of the Indian Ocean have increased in recent months, linked to the coral bleaching event[2].

In other areas, diving and other coastal tourism activities are the main income generators. In the Maldives, for example, 45% of GNP stems directly and indirectly from tourism revenues. Coastal tourism is already under pressure in places like Kenya, where 90,000 out of 150,000 employees have lost their jobs in recent years (Moffat *et al.*, 1998).

Furthermore, the land area around the Indian Ocean is prone to seasonal cyclones and coral reefs form natural barriers to protect the coastline from erosion. In Sri Lanka, severe coastline erosion has already occurred in areas where the reef substrate has been heavily mined and further damage to the reef structure from bio-eroded dead coral could carry a heavy financial cost. Revetments, groynes and breakwater schemes to prevent further erosion are already costing the Sri Lankan government around US$ 30 million (Berg *et al.*, 1998).

Given this dependency on functions and services that the coral reef ecosystem provides, the impacts of massive coral bleaching on people in this region are likely to be severe. However, a precise estimate of the human impacts is difficult to make at this stage. This is due to the uncertainty surrounding many of the relationships between coral bleaching and mortality on the one hand and ecosystem services, such as fisheries, tourism and coastal protection on the other hand. Besides, the recovery rate of reef areas after wide-spread mortality is difficult to predict. The following two extreme scenarios, as well as many intermediate pathways, are conceivable: (1) damage to the reef is not too bad and recovery is relatively quick; (2) damage is severe and recovery is very slow or non-existent, in which case the long-term impacts will be severe.

In the optimistic first scenario discussed above, the likely socio-economic effects are:

- a possibly slight decrease in tourism-generated income and employment, as some dive tourists may stay at home or go elsewhere. Most tourists will not alter their behaviour.
- some change in fish species composition, both in the water and in fishery landings. Initially, total fish productivity may increase with larger populations of herbivores, though catches of certain target fish for niche markets, such as the ornamental fish trade, may be reduced.
- no major change in the coastal protection function, as bio-erosion of dead reefs and coral growth of new recruits might even each other out.

In the pessimistic second scenario described before, the socio-economic effects could be very severe:

- there may be major direct losses in tourism income and employment as the word gets out in the diving community through dive magazines and the Internet. This is especially likely when charismatic marine fauna disappears as a result of the bleaching and subsequent mortality.
- fish productivity may drop considerably as the reef structure disintegrates, resulting in reduced catches for fishermen, less protein in the diet, particularly for coastal communities, lower health status and possible starvation, particularly among the poorer segments of the community. Fishermen could

experience a major loss of income and reduced ability to purchase other food.

- a possible collapse of the protective barrier function of the reef, which could result in greater coastal erosion. This might be exacerbated by sea level rise.
- a major outbreak of ciguatera with significant human mortality can't be excluded.

VALUATION OF ECONOMIC DAMAGE

A very preliminary attempt to estimate the economic value of these two possible scenarios is presented in Table 1. This estimation is based on the valuation per square km of coral reef by Costanza *et al.* (1997) and data presented in Cesar (1997). These values are multiplied by the area of reefs in the Indian Ocean (i.e. 36,100 km^2; WCMC data-set as quoted in Bryant *et al.*, 1998). These economic estimates should really be seen as first back-of-the-envelope calculations, based on very rough incomplete impressions of the actual damage to the reef ecosystem functions, as well as large uncertainty about each of the relationships discussed above[3]. Further research, both bio-physical and socio-economic, is needed to get a better grip on the truth.

Table 1 gives a very preliminary idea about the possible damage involved. In the pessimistic scenario, the total damage over a 20-year time period could be over US$ 8 billion, primarily from coastal erosion (US$ 2.2 billion), tourism loss (US$ 3.5 billion) and fishery loss (1.4 billion US$). In the optimistic scenario described above, the losses are still considerable but an order of magnitude less than in the pessimistic scenario, stemming mainly from loss in tourism (US$ 0.3 billion) and fisheries (US$ 0.3 billion). However, the full human suffering as a result of the coral bleaching and mortality event, due to possible malnutrition and increasing poverty, as well as unemployment is more than dollar values can express.

CONCLUSIONS AND DISCUSSION

The coral bleaching event of 1998 has already led to severe ecological consequences. Much less is known about the socio-economic impacts. It can be expected, given the severity of the coral mortality following bleaching, that the overall socio-economic consequences are considerable and perhaps disastrous, especially for countries largely dependent on coral reefs for their income, such as the Maldives. The valuation of these impacts is preliminarily estimated at ranging from US$ 706 million to US$ 8,190 million.

However, large uncertainties exist with respect to these socio-economic consequences. Therefore, more applied research and field work is needed to assess the damage to the peoples and the economies around the Indian Ocean.

Table 1: Estimates of the economic damage due to 1998 Indian Ocean coral bleaching (Net Present Value in million US$ over a 20 year time horizon with a 10% discount rate)

Coral reef ecosystem services	Optimistic scenario	Pessimistic scenario
Food production (e.g. fisheries)	260	1,361
Tourism and recreation	332	3,477
Disturbance regulation (coastal protection)	0	2,152
Other services	114	1,200
Total	**706**	**8,190**

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ENDNOTES

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2. J.-P. Quod (pers. comm.) reports that there has been an increase in ciguatera in Reunion and other French territories in the Indian Ocean, apparently as a result of the bleaching disturbance.
3. Values per km^2 for food production (US$ 220/ha/yr) and other services (US$ 97/ha/yr) are taken from Costanza *et al.* (1997). Calculated values for tourism and recreation (US$281/ha/yr), as well as disturbance regulation (US$174/ha/yr) are based on values given in Cesar, H.S.J.1996. Economic Analysis of Indonesian Coral Reefs. Environment Department, Series 'Work in Progress', World Bank, Washington DC, USA. The calculations for tourism and coastal protection were based on the assumption that in the Indian Ocean, around 25% of reef areas have medium to high value infrastructure and 75% low value infrastructure and that around 50% of the reef areas have high tourism potential and 50% have low tourism potential. For this calculation, the present value data of Cesar (1996) were annualized based on a 10% discount rate per year. Note that these data are considerably lower and more realistic than in Costanza *et al.* (1997), which has high estimates for tourism and coastal protection: US$ 3,008/ha/year and US$ 2,750/ha/year respectively. In the pessimistic scenario, it is assumed that the bleaching and mortality witnessed in the Indian Ocean leads to a loss of 25% of reef-related fisheries from year 5 until year 20. In the first five years, this percentage grows linearly from 0% to 25%. All the other services are assumed to decline 50%, starting from year 5, with a linear growth from 0% to 50% in the first five years. These percentage losses in services are multiplied by the annual value of the services, and summed up across the services to give total annual losses per ha per year. This number is multiplied by the 3.61 million ha (36,100 km^2) of reefs in the Indian Ocean. Finally, the net present value over a 20-year period is taken with a 10% discount rate.

Sustainable energy and wastewater treatment as alternative/sustainable livelihood for costal communities

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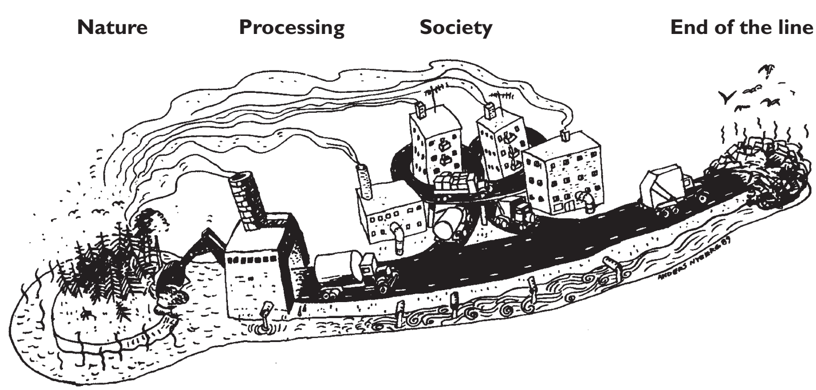
Energy is the basic resource for development and economic growth, but its use affects regional ecosystems, the global environment and the human condition.

Two billion people world-wide depend primarily on wood for their energy needs, while biomass burning removes the forest cover and contributes up to 40 percent of global emissions of carbon dioxide and other greenhouse gases. The energy situation has started to cause serious concern in many regions, especially the dependence on and the increasing scarcity of fuel-wood.

To avert the crisis, suitable programmes for introducing alternative energy should be developed. Renewable energy technologies, such as solar cells and windmills, can promote energy self-sufficiency in developing nations, preserve the environment and reduce the threat of global warming.

Over the past 40 years, the world's agricultural, health and energy problems have largely been addressed from a technological standpoint. As populations increase and global energy demand doubles over the next 20 years, a new strategy will be needed.

Appropriate technology and renewable energy seem to be the obvious solutions, particularly in developing nations. However, many believe that renewable energy



Most societies have a straight flow of raw materials, energy and waste. This has to be changed in order to achieve a sustainable society.

is an enigma. Everyone is in favour of it, but few take it seriously.

Twenty years of research and innovation, however, have made energy technologies more robust and far less expensive. The price of photovoltaics, for example, has dropped as rapidly as that of computers, or more than 90% since 1980. Energy security and environmental protection for developing nations will depend on developing and disseminating such new technologies.

Rapid advances in energy technologies will create great opportunities for developing countries in the next two decades. If they can avoid investing heavily in antiquated coal and oil technologies and choose alternative energy sources, such as wind power, solar cells and biogas instead, they could even move ahead of their industrial country counterparts.

Nearly unnoticed by governments and industry, the world energy economy has entered a period of rapid change that may be as far-reaching as the computer and telecommunications revolutions. Oil and coal-fired power plants may soon be relics of the industrial revolution. In Europe and United States, wind power is now often less expensive than coal, and more than 200,000 homes in developing countries already get their electricity from solar cells. Major corporations such as Shell, BP, Mitsubishi, Westinghouse, Siemens and Enron have announced investments in advanced fuel cells and solar cells. International oil and energy companies are now buying land areas in deserts to install solar cell plants in the future.

WIND ENERGY

Wind power is the world's fastest growing power source. The world's wind power capacity has doubled in three years. Wind turbines generate roughly 21 billion kWh — enough for 3.5 million suburban homes. Denmark is the leader in global wind power industry. Over 8% of the country's electricity is generated from wind power. It is the third largest export industry in Denmark, generating thousands of jobs. Danish companies have also formed successful joint venture manufacturing companies in for instance India, which has led to a rapid transfer of wind energy technology. The nations that could benefit most from further growth of the wind industry are in the developing world, where power demand is growing rapidly and most countries lack adequate indigenous supplies of fossil fuels. India is the leader so far, with more than 900 MW in place.

As the technology continues to improve , further cost declines can be expected. This could make wind power the most economical new source of electricity in many

In India, there is a continuous development of renewable energy sources, such as wind power and solar cells. At Tamil Nadu Agricultural University in Coimbatore, the Department of Bio Energy is developing small-scale units suitable for rural areas. They also have a "Technology dissemination" programme to spread new technology in the region. Photo: Niki Sporrong.

countries in the next decade. Wind energy is a domestic source of energy and can improve a nations degree of self-sufficiency. Wind power plants of, for example, 50 MW can be in operation in less than a year from signing the contract.

Wind turbines can be used competitively as a dispersed energy production technology in areas with dispersed electricity consumption.

Wind power has proved to be a reliable technology. It is modular, more power can be added quickly as the demand increases and it is a cost effective technology in many developing areas and nations. The most common ownership of wind turbines are through a co-operative or community.

Besides the classical applications, electricity producing wind turbines are used in hybrid systems, together with for example solar cells and a backup diesel-driven generator system. These integrated systems are very suitable in thinly populated areas or areas where electrification is not yet fully implemented. The advantage is that the investment in the wind turbine and solar cells can be paid for by the fuel saved for the diesel generator.

Example:
The Mexican village of Xcalac (pronounced Sca-Lac) is a fishing and tourist village of 250 people. It has some of the best fishing and skin-diving in Mexico, but is relatively undeveloped.

The closest power lines are 110 km away and the cost to extend the grid to Xcalac has been estimated to $3.2 million. The village has been powered by diesel generators, but reliability of the diesels has been very poor.

In 1992, Xcalac was re-electrified, at a cost of ~$450,000, with a wind and solar hybrid system. Until mid-1995, the system did not have a working backup diesel, so the electricity came solely from wind and sun. Even now, the backup generator is used infrequently due to high operating costs.

SOLAR ENERGY

The first solar cells were developed at Bells Laboratories in the 1950s. The cost of the electricity delivered by these cells were a thousand times higher than the normal price of electricity. Today, the price is much closer to the price of a traditional system. The price of

This solar power unit suitable for export to the developing world was developed by the University of Sydney. It consists of a combination of solar cells for electricity and sun panels for heating of water. Photo: Bull/Greenpeace.

solar cells is estimated to decrease by 20% each time the production doubles. The cost of producing solar cells are twenty times lower today than in the 1970s.

Around two billion people in the world have no electricity at all. In many cases, it is already cheaper to install locally electrified systems based on solar cells than to build large power stations or grid systems.

The development of more efficient and cheaper cells is very rapid. In Arizona, USA, a solar plant is producing electricity for 5,5 cents/kWh. In the US, the average price for electricity is 6–7 cents/kWh.

Several international companies are now marketing solar shingles that can replace existing roofing materials and produce electricity. This will decrease the cost even more.

Solar panels carry on through rain, dust and snow and work for at least 30–40 years. The systems are designed to be consumer friendly, although the battery needs periodical maintenance. This maintenance can be carried out by a local villager who is specially trained for the job.

BIOGAS

Biogas is an environmentally friendly and economically viable source of energy in rural areas.

Biogas has been used in China, India and Pakistan for more than a thousand years. In China, for instance, there are more than seven million biogas plants.

Denmark is seen as a technical leader in biogas production. The technique is sophisticated and the Danish government has decided to double the biogas production by the year 2000 and is aiming for a ten times increase by year 2020. The potential is calculated to 8,33 TWh/y (30 PJ).

The possibilities of biogas are enormous. The gas can be used for production of heat, electricity or as fuel for cars. The most modern biogas plants prove that the technique is safe and tested, and the development of standardised plants shows that safe and stabile plants can be established to a decent price.

The economic attractiveness of an installation is based on the significant fuel cost savings that it generates. The fuel cost savings can pay back the capital costs of the system within a couple of years.

Animal dung is the most commonly used input, mainly because of its availability, but any biodegradable organic material can be used for processing. Plant materials like wood chips, palm nut shells, stalks of cotton, rice hulls, maize cobs, soy husks or coconut shells can all be used.

In India, Pakistan and China, biogas has been used for more than a thousand years. In this village, Islamnagar, outside Bhopal in India, 36 biogas plants have been installed. Animal dung is collected and mixed with water (left). The mix is poured into a concrete tank with a steel drum (right), often directly connected to a gas stove in the kitchen. Afterwards, the dung is used as fertiliser in the fields. Photos: Niki Sporrong.

WASTEWATER

Wastewater problems are becoming acute in many parts of the world and, for the future of cities, wastewater treatment is one of the most critical areas of development.

The discharge of sewage into coastal waters can have a destructive impact on coral reefs and coastal ecosystems. The population in coastal areas grows rapidly, and the use of freshwater and discharge of sewage will increase. As this has destructive effects on coastal environments, in particular coral reefs, it is essential that especially cities and tourist resorts aim to reduce the amount of freshwater used and discharged as sewage. This can be achieved by implementing alternative ways of use, and treatment of the sewage.

Biological treatment of organic wastes has been used for centuries. Composting, for example, is a natural way to enhance nutrient cycling. Nature sees sewage as a resource, while modern society sees sewage as a problem, and often thinks the solution is to transport it to rivers or directly to the sea.

We need to seriously change our way of thinking. Instead of discharging treated or untreated sewage into the sea, it should be kept inland for some productive uses. Several demonstration projects shows that complete use of wastewater for aquaculture and agriculture is possible.

The Chinese developed aquaculture systems several thousand years ago. These systems use the sewage/nutrients and produce fish. Today China is the world's leading producer of farmed fish (Figure 1).

Another way of doing it is to separate the sewage at source. Today, most sanitation systems mix faeces and urine. In the human body, urine is separated from faeces. If we keep it that way, we will get two valuable resources. The faeces can be composted to produce biogas, which in turn can be used for cooking or to generate electricity. The urine can be used as fertiliser on farmland or in greenhouses.

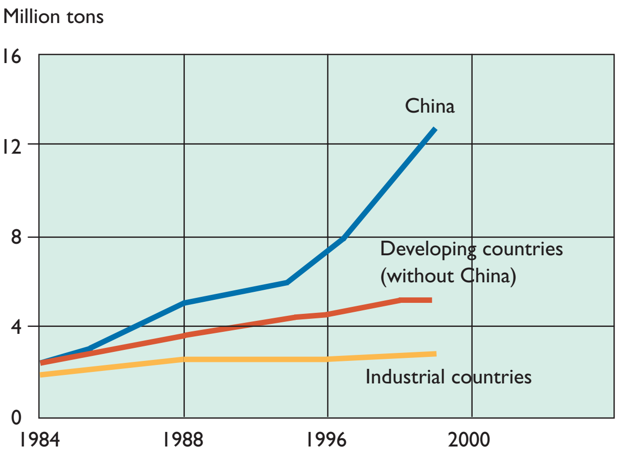


Figure 1. Aquaculture production by region 1984–1995.
Source: FAO

Table 1. Toilet water content

	Urine	Faeces
Nitrogen (N)	5,6 kg	0,09 kg
Phosphorus (P)	0,4 kg	0,19 kg
Potassium (K)	1,0 kg	0,17 kg

By implementing modern technology, a community can be self-sufficient on energy and by using existing resources, pollution of coastal waters can be avoided and instead sewage can be used to supply the community with food products. This will strengthen the economy of the community, as well as increase the quality of life. A better environment will also strengthen the tourism. By re-using the nutrients for food production and fertilising plants, communities can support the tourist resorts and thereby create a source of income.

LIST OF CORDIO PROJECTS 1999

East African Region

Regional co-ordinator: Dr David Obura
Institute: CORDIO East Africa

KENYA

Country co-ordinator: Dr N. H. Muthiga
Institute: Kenya Wildlife Service, Mombasa

1. Annual monitoring of the impacts of the 1998 El Niño on coral reef community structure in Kenya

This activity will extend existing annual monitoring of coral reefs in Kenya to deeper reefs, through training and supporting protected area rangers in the Kenya Wildlife Service. The Kiunga Marine Reserve was completed in March 1999, with five other sites to be surveyed later in the year. Monitoring of shallow lagoonal patch reefs has been undertaken for over 15 years by the Coral Reef Conservation Project (T. McClanahan), and of some deeper reefs for 6 years (D. Obura). This information will be summarized as baseline data for CORDIO.
Co-ordinator: Dr N. H. Muthiga
Institute: Kenya Wildlife Service

2. Investigation of the effects of the 1998 El Niño-related coral bleaching on bio-physical and fisheries aspects of Kenyan coral reefs

Four projects have been proposed by KMFRI scientists for funding by CORDIO, focusing on various aspects of the coral reef physical and biological environment. The projects have been organized as a group proposal to a) provide a comprehensive description of physical, biological and resource use dynamics of a typical Kenyan coral reef lagoon and fringing reef (Mombasa), and b) build on past group projects conducted by KMFRI in Mombasa, Watamu and Gazi-Shirazi.
Co-ordinator: Mr David Kirugara
Institute: Kenya Marine and Fisheries Research Institute (KMFRI)

Project 1. Physical – Ultraviolet and temperature interactions
This study will investigate annual patterns of UV-radiation and temperature as they change with water transport over the fore reef and lagoon areas of a typical fringing reef in Kenya.
Researcher: D. Kirugara

Project 2. Biological – Zooxanthellae and chlorophyll dynamics
The objective of this study is to improve knowledge of zooxanthellae and chlorophyll concentrations and how they change with bleaching. This projected is also intended to develop an indicator for assessing bleaching status and coral health.
Researchers: R. Mdodo & P. Wawiye

Project 3. Biological – Bioerosion and algal succession
Algal succession patterns and bioerosion of coral reef

lagoons will be studied to determine the degree of coral reef degradation resulting from the 1998 bleaching event.
Researchers: S. Mwachireya, J. Uku & P. Wawiye

Project 4. Fisheries – Coral reef fisheries
Artisanal fisheries catch statistics and socio-economic surveys of fishermen will be conducted to investigate nay long-term effects of coral mortality on fisheries, and of the awareness of fishermen of potential impacts. The project will be linked with similar CORDIO projects in South Asian and the Indian Ocean Islands.
Researchers: D. Obura & G. Mwatha

TANZANIA

Country co-ordinator: Christopher Muhando
Institute: Institute of Marine Science, University of Dar es Salaam

1. Extent of coral mortality at selected sites in Tanzania

The extent of coral mortality is to be determined and permanent monitoring stations established at several sites along the coast of Tanzania. As much as possible, monitoring will be conducted in collaboration with local research, mangement and/or conservation instutitions.
Co-ordinator: Christopher Muhando
Institute: Institute of Marine Science
Collaborating institutions: Fisheries Department, Tanga Coastal Zone Management Project, Mafia Island Marine Park, Frontier Tanzania

2. Determining the socio-economic impact of coral bleaching and mortality in Tanzania

The impact of the 1998 coral mortality on coral reef resource users will be investigated using informal and formal survey methods, focusing on the fisheries and tourism industries. Socio-economic survey tools developed for South Asia through other CORDIO activities will be incorporated for comparison around the region.
Co-ordinator: Narriman Jiddawi
Institute: Institute of Marine Science

3. Individual study projects – Changes in the competition between hard corls and sea anemones (corallimorpharia) following the 1998 coral mortality.

Past studies have shown that on degraded reefs, sea anemones (especially *Rhodactis* spp.) can outcompete corals to dominate reef surfaces. This study will investigate if reefs degraded due to the 1998 bleaching will become dominated by sea anemones and how this may relate to past findings.
Researchers: B. Kuguru, E. Mbije & C. Muhando
Institute: Institute of Marine Science

MOZAMBIQUE

Country co-ordinator: Helena Motta
Institute: Ministry for Co-ordination of Environmental Affairs (MICOA)

1. Preliminary assessment of coral bleaching in Mozambique

Rapid assessment surveys were conducted along the entire coast of Mozambique in March/April 1999 to determine the impacts of the 1998 El Niño on coral bleaching and mortality. Coral bleaching and mortality were significant, on average 30–80% of the corals at any single site. Suitable permanent monioring sites and training needs were identified for further CORDIO-related activities.
Co-ordinator: Helena Motta
Institute: Ministry for Co-ordination of Environmental Affairs (MICOA)

2. Training and establishment of permanent coral reef monitoring sites in Mozambique

The training of research officers and graduate students in coral reef monitoring techniques was identified in (1) as a priority activity to build national capacity for

monitoring and establish a human resource base for development of research activities on coral reef issues. The training course is scheduled for September 1999, followed by establishment of monitoring sites by course attendees.
Funding: These activities will be covered by MICOA, with support from CORDIO through participation of the East Africa Co-ordinator and generalization of course structure and materials for use elsewhere in the region.
Co-ordinator: Helena Motta
Institute: MICOA
Collaborating institutions: CORDIO and Dr Michael Schleyer, Oceanographic Research Institute, South Africa

South Asia Region

Regional co-ordinator: Dan Wilhelmsson
Institute: CORDIO South Asia/SACEP

REGIONAL

1. Socio-economic impacts of the 1998 coral bleaching event in the Indian Ocean

In this regional project, impacts of the 1998 coral mortality on tourism and fisheries will be investigated. The study will especially focus on the effects on tourism in Maldives and on ornamental fisheries in Sri Lanka (see Sri Lanka 2).
Co-ordinator: Herman Cesar, researcher/consultant
Institute: Institute of Environmental Studies, Free University, Amsterdam

SRI LANKA

Country co-ordinator: Arjan Rajasuriya
Institute: National Aquatic Resources Research and Development Agency (NARA)

1. Impact of coral bleaching on reef communities

The impact of the 1998 coral bleaching and mortality will be investigated through monitoring of the loss of coral cover, coral recovery, abundance of reef fish, invertebrates and algal communities. Reef productivity, reef ecology and coral diseases will also be studied, as well as the impact of bioeroders and changes in their populations. At Hikkaduwa Marine Sanctuary, experimental reef restoration will be tested by transplanting corals.

2. Monitoring and assessment of socio-economic aspects of coral bleaching and degradation in Sri Lanka

The broad objective of the study is to identify and assess the socio-economic implications of coral bleaching in selected sites of Sri Lanka, focusing on ornamental fisheries, coastal demersal fisheries and tourism. The ornamental fisheries study will be carried out together with Herman Cesar (see Regional project above).

3. Develop alternative livelihoods for people dependent on coral reef resources

The aim of this project is to attempt to develop various alternatives to fishing in coastal areas. One example is to introduce young fishermen to ornamental fish cultivation as an alternative livelihood.

MALDIVES

Country co-ordinator: Dr H. Maniku
Institute: Marine Research Centre (MRC), Ministry of Fishery

1. Reef recovery processes: Evaluation of succession and coral recruitment in the Maldives

In this project, the spatial and temporal patterns of coral recruitment will be investigated, using permanent quadrats and experimental settlement plate studies to determine natural distribution and abundance of juvenile corals in different zones on the reef.

2. Assessing bioerosion and its effects on reef structure following a bleaching event in the Maldives

The objective of this project is to provide valuable information about the magnitude and direction of change in the reef framework and topographical complexity of shallow reef-flats, and finally to be able to predict the time-scales of reef recovery with greater accuracy.

3. Building a data base on the economics of coral reef deterioration with special reference to bleaching

The objective of the study is to determine the fishing communities socio-economic situation for the pre- and post-bleaching scenario. The aim is to integrate the socio-economic findings with the biophysical results of the national reef monitoring program, which would lead to more effective planning and policy making at the national level. Data will be entered and analyzed using a Geographic Information System (GIS).

INDIA

Country co-ordinator: Dr M. V. M. Wafar
Institute: National Institute of Oceanography

1. Recovery and monitoring of coral reefs

Through environmental monitoring of coral reefs, assessments of changes in live coral cover and coral biodiversity over time, and rates of recruitment will be made. Studies will be carried out in four different areas: Gulf of Kutch, Lakshadweep Islands, Gulf of Mannar and Andaman Islands.

2. Assessment of the effects of coral mortality on reef communities

Changes in community composition over time, regarding macro- and microalgae and bioeroders, will be studied and compared with historical records.

3. Socio-economic effects of bleaching on local populations and tourism

This study aims to identify and assess the socio-economic implications of coral bleaching on tourism and on local populations directly dependent on reef resources for sustenance.

Central Indian Ocean islands

Regional co-ordinators: Susie Westmacott & Dr Jean Pascal Quod
Institutes: CORDIO and ARVAM (Agence pour la Recherche et la Valorisation Marines)

Island Focal Points
Comoros: Fouad Abdou Rabi, AIDE
Madagascar: Edouard Mara, Inst Halieutique et Sc Mar (IHSM)
Mauritius: Dav Daby, University of Mauritius
Mayotte: Bertrand Wendlling, Direction de l'Agriculture/SPEM
Reunion: Jean Pascal Quod, ARVAM
Rodrigues: Iain Watt, Shoals of Capricorn
Seychelles: John Collie, Marine Parks Authority (MPA)

1. To establish a simple and effective identification scale for bleached coral reef organisms

The underwater identification guide will be aimed at the non-specialist diver on how to detect a bleached coral organism, and how to assess the amount of bleaching. In addition, it will include assessments for algal growth, coral diseases and lesions. It will also provide data on basic spatial assessments.
Co-ordinators: Dr Jean Pascal Quod and Dr John Turner
Institutes: ARVAM (Agence pour la Recherche et la Valorisation Marines) and the University of Wales

2. To establish a rapid assessment and identification methodology of Ciguatera risk by contamination level on bleached reefs

A rapid methodology will be developed for both sample collection and analysis. Initially, analysis of the samples will be done in Reunion at ARVAM, but eventually the technique could be taught to other interested CORDIO countries. With continuous sample collection and monitoring, the risk map may show spatial and intensity changes in the toxic dinoflagellate, which may be connected to increased algal cover after the bleaching event. Recommendations will enable health authorities to deal with any potential outbreaks of Ciguatera.
Co-ordinator: Dr Jean Pascal Quod
Institute: ARVAM (Agence pour la Recherche et la Valorisation Marines)

3. Assessment of post-bleaching status of coral reefs around island states

This activity aims at providing an immediate, accurate and rapid status report of the biological impact of the bleaching around the island states. In addition to the biological data, a general socio-economic description of

each site will be conducted. This will be based on a simple checklist. The rapid assessment of reef condition will utilise simple techniques such as manta tows at as many sites as possible. Representative or unsurveyed sites will be chosen. Existing, available data will be compiled into the reporting process when possible. The rapid socio-economic assessment of reef uses and users will be carried out at each monitoring site, utilising simple forms developed specifically for CORDIO. Collection, analysis and reporting of data will be facilitated and organised by island focal points with external expertise where necessary and assistance from CORDIO co-ordinators.
Co-ordinators: Dr Jean Pascal Quod and Susie Westmacott
Institutes: ARVAM (Agence pour la Recherche et la Valorisation Marines) and CORDIO

4. Long-term monitoring of biophysical and socio-economic factors

This project will compile and assess monitoring activities currently undertaken and other relevant programmes and projects implemented throughout the islands. This will result in an overview status report on which suggestions for database requirements, additional monitoring parameters and stations can be based. This assessment can also help to expand the current monitoring efforts.
Co-ordinator: Dr Jean Pascal Quod and Susie Westmacott
Institute: ARVAM (Agence pour la Recherche et la Valorisation Marines) and CORDIO

5. Development of a database of pictures and videos of marked colonies at CORDIO monitoring sites

This project will provide a photographic database at colony level for lagoonal and outer reef sites. This will enable assessment of long-term changes and comparisons to other sites. Data collection will be facilitated by island focal points.
Co-ordinator: Dr Jean Pascal Quod
Institute: ARVAM (Agence pour la Recherche et la Valorisation Marines)

APPENDIX

Coral Reef Degradation in the Indian Ocean
Planning meeting, Colombo Hilton, Sri Lanka
January 26–28 1999

AGENDA

Tuesday 26
9.00 a.m.–10.00 a.m.
Introduction: background, project structure
Sida
World Bank
Global Coral Reef Monitoring Network
Presentation of participants

10.00 a.m.–3.00 p.m.
Presentations from the different groups in following order:

10.00 a.m.–10.20 a.m.
Sri Lanka (Mr Arjan Rajasuriya)

10.20 a.m.–10.40 a.m.
India (Mr Ramachandran, Mr Wafar)

10.40 a.m.–11.00 a.m.
Maldives (Mr Hassan Maniku)

11.00 a.m.–11.20 a.m.
Kenya (Mr David Obura)

11.20 a.m.–11.40 a.m.
Tanzania (Mr Christopher Muhando)

11.40 a.m.–12.00
Mozambique

12.00–1.00 p.m.
Lunch

1.00 p.m.–1.20 p.m.
Madagascar, Reunion, Comores (Mr Jean-Pascal Quod)

1.20 p.m.–1.40 p.m.
Mauritius, Socotra (Mr John Turner)

1.40 p.m.–2.00 p.m.
Seychelles (Mr David Rowat)

2.00 p.m.–2.20 p.m.
British Indian Ocean Territories (Mr Charles Sheppard)

2.20 p.m.–2.40 p.m.
Australia (Mr Chris Simpson)

2.40 p.m.–3.00 p.m.
Space Agency (Mr Ulf von Sydow)

3.00 p.m.–3.30 p.m.
Coffee break

3.30 p.m.–5.00 p.m.
Conclusion of information and background data in perspective of the project.

Dinner

Wednesday 27
08.00 a.m.–08.30 a.m.
The economics of coral reef deterioration with special reference to bleaching (Mr Herman Cesar)

08.30 a.m.–09.00 a.m.
Coral transplantation for recovery (Mr Ulf Lindahl)

09.00 a.m.–09.30 a.m.
Fish communities and bleached reefs (Mr Marcus Öhman)

09.30 a.m.–10.00 a.m.
Sustainable energy and wastewater treatment as alternative livelihood for coastal communities (Mr Rune Leithe-Eriksen)

10.00 a.m.–10.30 a.m.
Coffee break

10.30 a.m.–12.00
Plan the activities of the project on basis of the reviews of the previous day.
Discussion

12.00–1.00 p.m.
Lunch

1.00 p.m.–5.00 p.m.
Continued discussion

Thursday 28
08.00 a.m.–12.00
Development of an action plan.

12.00–1.00 p.m.
Lunch

1.00 p.m.–5.00 p.m.
Afternoon session

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