# CORAL REEF DEGRADATION IN THE INDIAN OCEAN

Status Report 2005

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The World Conservation Union

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Finland

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ISBN 91-973959-4-3

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| *Published by* | CORDIO<br>Department of Biology and Environmental Science<br>University of Kalmar<br>SE-391 80 KALMAR<br>Sweden |
| *Maps* | Tommy Holmberg |
| *Production* | Bo Heurling AB |
| *Printed in Italy 2005 by* | Eurolitho, Milan, through Italgraf, Stockholm, Sweden |

# Foreword

Coastal ecosystems in tropical regions are rich in biodiversity and highly productive. They form the basis for the marine food web that ultimately results in fish catches that support the coastal human population. Coral reefs together with sea grass beds and mangrove forests are some of the most productive ecosystems in the Indian Ocean Region. The productivity of these systems is staggering, often yearly production figures in the range of 20 tones of fish per $km^2$ have been found. However, if the environment is abused the productivity is likely to drop dramatically.

Unfortunately decreasing productivity of coastal waters is now the norm throughout much of the Indian Ocean. The catch per effort is steadily going down affecting the livelihoods of coastal communities. The reasons for the decreasing productivity can be attributed both to local and regional/global phenomena. The coastal zones over most of the planet are becoming overpopulated – often the population density is in the range of several thousand people per $km^2$ – also in rural areas. As a consequence, during the past decades the coastal zone has become urbanized in many countries surrounding the Indian Ocean. As a result pollution, sedimentation, and erosion are increasing problems along most populated coasts. In addition the fishing has long ago exceeded the carrying capacity of the coastal waters, and fishermen use more effective and destructive techniques now than ever before.

Vulnerability in the coastal zone has increased – consider e.g. the effects of the tsunami in December 2004. And the environmental situation has become even more strained due to global change. The temperature increase of the atmosphere as a result of the greenhouse effect is increasing the water temperatures to lethal levels for corals and bleaching – the sign of dying coral reefs – now occurs almost every year in the Indian Ocean.

Since 1999, Sida, through its research department, SAREC, has supported the CORDIO program. CORDIO was originally a research program to assess the background and consequences of the 1998 El Niño and of other local phenomena which resulted in the degradation of the coral reefs of the Indian Ocean countries. The program which is driven by local scientists in 11 countries of the Indian Ocean has now evolved into a comprehensive program in areas such as ecological monitoring, management and policy advice, targeted research on different alternative livelihoods, education and awareness building, and networking and communication. Hence the research program has become an integrated part of a larger management-oriented program. This program aims to provide useful information to managers, as well as the public and local stakeholders. In addition the program tries to develop sustainable income generating activities to communities affected by the decreasing productivity of the coastal zone.

It is my hope that the activities conducted so far within the CORDIO program will continue to produce tangible on-the-ground benefits to coral reefs and the people who depend on them in the Indian Ocean region. CORDIO's activities contribute directly to resolving several areas of global concern such as food security, poverty alleviation, and particularly the impacts of global climate change and conservation of biodiversity – all necessary components of a sustainable future.

*Mats Segnestam*

Head, Sida's Environmental Policy Division

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## SYNOPSIS

The assessments of 50 contributing authors focusing on coral reefs and related coastal ecosystems, and dependent communities in 9 countries in South Asia and the central and western Indian Ocean report that:

### Status of Coral Reefs

- The bio-physical condition of many reefs continues to decline.
- Recovery from bleaching associated coral mortality is generally slow and patchy with widespread changes in species composition of adult and juvenile coral communities.
- Recovery is more rapid on reefs that are situated within managed areas or are remote from the influence of other human disturbances.
- Recovery in areas subject to human influences has been retarded.
- The primary causes of coral reef degradation are:
  - ❏ Bleaching, which is occuring more frequently and has accelerated the degradation caused by:
  - ❏ Overexploitation of fish and of other organisms on reefs throughout the region;
  - ❏ Destructive fishing, which become an increasing problem as fish stocks decline; due to lack of enforcement destructive fishing has destroyed reefs in formally protected areas (MPA's) during the last couple of years;
  - ❏ Pollution and sedimentation, mainly from land-based human activities.
- The impacts of the tsunami of 26th December 2004 on coral reefs was highly variable and ranged from negligible (Gulf of Mannar, India, Maldives, East Africa) to moderate (parts of Andaman and Nicobar Islands) to extreme (parts of Sri Lanka, Nicobar Islands).
- The primary factors determining the severity of damage caused by the tsunami were:
  - ❏ How exposed a reef was to the direct force of the wave;
  - ❏ The local bathymetry surrounding a reef;
  - ❏ The geological composition of a reef;
  - ❏ The condition of the reef; reefs that had sufferred extensive coral mortality as a result of the 1998 El Niño were more vulnerable to the force of the tsunami.

- The reasons for continued coral reef degradation are:
  - ❏ High dependence on coral reef resources as a result of few alternative sources of food and income;
  - ❏ Open access; fishing and exploitation of other coastal resources are unregulated in many countries; as a result, unemployment and a lack of opportunities elsewhere in society are directly linked with coastal degradation;
  - ❏ Low awareness of the importance of healthy coastal ecosystems and the impacts of human activities;
  - ❏ Inadequate laws and regulations;
  - ❏ Poor enforcement of existing laws and regulations;

- ❑ Responsabilities dispersed among several agencies and a lack of coordination between these agencies;
- ❑ Insufficient political will to strengthen laws and regulations and improve enforcement.

### Actions Necessary to Achieve Sustainable Use of Coral Reef Resources

*Research and Monitoring*

- Continue to strengthen environmental monitoring programmes in each country so that management decisions are made using the best available information and so that management strategies can be adapted to cope with changing situations.
- Engage communities in monitoring and management in order to raise awareness of the importance of coral reefs, establish behaviours that are not environmentally degrading and secure community support for sustainable resource use.
- Continue to develop research capacity in the region to specifically address management issues.

*Management and Governance*

- Increase the area of coral reefs currently under management and incorporate management strategies within the broader frameworks of integrated coastal zone and catchment management in order to effectively deal with land-based issues such as pollution, sedimentation and coastal development.
- Ensure participation of all stakeholders in the development and revision of management strategies in order to open channels of communication and achieve ownership and transparency of process.
- Improve management capacity among local and national authorities. Years of inactivity, often deliberate, must be stopped. In many cases the roots of the problem is at the political level where deep-rooted cronyism, unwillingness to follow laws and regulations because key voter groups may be affected, and outright corruption prevents responsible behaviour.
- Strengthen laws and regulations where necessary. Clarify the responsabilities of different agencies.
- Enforcement of laws and regulations must be strengthened. Punishments against destructive behaviour must be such that they are genuine disincentives.
- Improve enforcement by providing greater manpower, equipment and financial resources.
- Encourage community-based protection and enforcement in partnership with government agencies by devolving to stakeholders the responsibility for direct conservation of resources and enforcement of laws.
- Strengthen political will through the education of decision makers of the tangible benefits of management.

*AlternativeLivelihoods and Income Diversification*

- Stimulate the introduction of income diversification and alternative livelihood schemes that are environmentally sustainable and economically viable and socially acceptable. Examples of such activities can be found in areas related to agriculture, aquaculture, waste management, tourism and manufacturing. A wide range of activities should be encouraged in order to ensure long-term viability.
- If necessary, establish financial mechanisms targeted specifically at improving the economic development of the poor.
- If necessary, secure government support for alternative livelihood and income diversification schemes.

*Education and Awareness*

- Raise awareness of the importance of healthy coastal ecosystems and the impacts of various human activities through:
  - ❑ the introduction of marine studies in school curricula;
  - ❑ community-based monitoring and management activities;
  - ❑ awareness raising programmes targeting specific sectors of society;
  - ❑ the use of mass media.

## EXECUTIVE SUMMARY

Throughout the Indian Ocean region the relationship between human population growth and ecosystem degradation is unequivocal. As human populations increase and techniques to harvest dwindling natural resources become more efficient, the pressure on coral reefs and associated ecosystems to provide food for dependent populations is escalating well beyond sustainable limits resulting in the universal overexploitation of fish stocks and the widespread use of destructive fishing techniques. In addition, the expansion of urban and industrial centres to accommodate the influx of people to coastal areas has resulted in unregulated or poorly planned developments that have been established at the expense of productive coastal ecosystems and have degraded surviving habitats through the discharge of untreated effluents and accumulation of solid waste.

Physical destruction, overexploitation, destructive fishing, sedimentation and pollution influence directly the condition of coral reefs and other productive shallow-

### The CORDIO Programme

The dependence of coastal populations on coral reef and their vulnerability to climate change demanded action that would promote sustainable use of natural resources. CORDIO is a research programme that was initiated in 1999 in response to the degradation of coral reefs in the Indian Ocean where they support large sectors of the countries' populations and economies through fisheries, tourism and large-scale investments. CORDIO is a locally driven, regional initiative that supports more than 45 research and monitoring projects that are conducted by no less than 50 scientists at local institutions in 11 countries throughout the western and central Indian Ocean. CORDIO builds on existing capacity in the Indian Ocean region that was established through more than a decade of dedicated support from Sida's Regional Marine Science Programme. The activities of CORDIO are arranged into 6 broad but interlinked themes:

1. *Ecological and socio-economic monitoring* of the health of coral reefs, the impacts of human activities and climate change and the consequences for coastal populations dependent on coral reef resources.
2. *Targeted Research* focused on understanding ecological processes that are essential for healthy, functioning coral reefs, processes of recovery and options for rehabilitation.
3. *Management and Policy Actions* that use the results of monitoring and research programmes to mitigate future damage to coral reefs and improve the quality of life for dependent populations.
4. *Alternative Livelihoods* that improve the quality of life of coastal people by providing sustainable alternative sources of income that do not rely on harvesting coral reef resources.
5. *Education and Awareness* of the impacts of human activities on coral reefs and the need for management.
6. *Networking and Communication* to disseminate results and strengthen capacity and develop collaborative partnerships within the regional network.

The activities conducted within these themes will produce tangible on-the-ground benefits to coral reefs and the people within the central and western Indian Ocean who depend on their resources. CORDIO's activities contribute directly to resolving several areas of global concern such as food security, poverty alleviation and particularly, the impacts of global climate change and conservation of biodiversity.

water ecosystems and can therefore be managed through direct interventions. Until 1998, mitigating these stresses were the primary foci of coral reef management worldwide. However, in 1998, the consequences of mass coral bleaching driven by global climate change became tragically obvious and an immediate priority requiring action from the environmental agencies in the affected countries and the international community to combat global climat change. Although it is widely accepted that coral bleaching on such enormous geographic scales is primarily attributable to abnormally elevated sea temperatures, the underlying causes of these increased sea temperatures are far less tangible and are not amenable to direct management interventions. While the impacts of future coral bleaching events can be ameliorated through the analysis of patterns of bleaching (identify species that are less susceptible to bleaching and areas where these species are abundant, identify areas that are less prone to increased sea temperatures, etc.) and then taking measures to adequately preserve these areas as a potential source of new corals to assist recovery of degraded areas, the management of factors causing increased sea temperatures or global climate change lies outside the realms of local, national or even regional authorities. Mass coral bleaching is a global problem that requires a global solution.

Since 1999, scientists and partner institutions collaborating in the CORDIO programme have documented the condition of coral reefs, the impacts of human activities, the extent of coral bleaching throughout South Asia and the central and western Indian Ocean (Status Report 1999), the magnitude of subsequent coral mortality and resultant degradation of coral reefs throughout the region (Status Report 2000) and the extent and processes by which recovery is occurring (Status Report 2002). In this, the fourth CORDIO Status Report, we present the current status of coral reefs and the problems that continue to degrade reefs in the region and document more recent patterns of recovery and the resultant changes in coral community structure. In addition, we highlight the achievements that the CORDIO programme and its partners have made in establishing alternative livelihoods and options for income diversification for people solely dependent on the productivity of shallow-water ecosystems and the successes in raising awareness among people in coastal communities of the importance of coastal marine ecosystems and the impacts that their activities have had on these systems.

## Status of Coral Reefs

The condition of coral reefs across South Asia and the central and western Indian Ocean varies according to the severity of coral mortality suffered during previous bleaching events; the degree of protection from human disturbances; and the intensity of natural resource extraction.

### *Unbleached Reefs*

The few coral reefs that escaped the 1998 coral bleaching event or experienced only minor damage are generally in better condition than those that suffered extensive mortality. The cover of live hard coral on these reefs ranges from 20% in Tanzania to 80% on the deeper reefs of Mozambique. The condition of these reefs is dictated primarily by their accessibility and the type and magnitude of activities that are being conducted on them. The cover of live hard coral on reefs that are inaccessible or are not affected by land-based influences is high (>40%) and has remained stable. Accessible reefs, on the other hand, have suffered declines in live hard coral cover attributable to a variety of stresses including the use of destructive fishing practices, particularly the use of explosives and seine nets, sedimentation and pollution from land-based sources.

### *Bleached Reefs*

The condition of coral reefs that were affected by the bleaching in 1998 varies according to the severity of subsequent coral mortality. Those reefs that experienced only mild bleaching and mortality are in better condition with live hard coral cover generally ranging up to 20%. On the majority of reefs that suffered severe coral mortality (>80% reduction in coral cover), live coral cover remains very low (<10%). In addition, these coral communities are generally dominated by small colonies (<15 cm) which have settled after 1998.

### *Recovery*

Generally recovery has been slow and has varied between sites. In many cases, recovery is being retarded by additional pressures associated with human activities such as coral mining, destructive fishing, pollution and sedimentation. Reefs that suffered the greatest coral mortality, such as those in the Maldives where the cover of live hard coral in the overwhelming majority of sites was reduced to less than 2%, recovery has ranged between 1–24%. On average though, increases in coral cover at these sites have been less than 5%.

On some reefs, particularly Tutia Reef at Mafia, Tanzania and the deeper sites at Kiunga in northern Kenya, the competition from macro-algae is hindering coral growth and recruitment. In Kiunga, this is attributable to the upwelling of cool nutrient rich waters which promotes the growth of competitive algae and suspension feeders, while on Tutia Reef, algal dominance is the result of overfishing and nutrient influxes from land-based sources. In each case though, there is considerable potential for shifts in community structure from one dominated by coral to one that is principally algal. Such changes will undoubtedly affect the composition of associated fish communities and the long-term structural integrity of the reef itself.

Fortunately, there are a number of exceptions. Deeper reef sites and those exposed to vigorous water exchange have exhibited more rapid increases in live coral cover. In addition, sites that are included within marine protected areas (MPAs) or conservation areas have fared better. For example, the live coral cover on Bar Reef in Sri Lanka declined as a result of bleaching-related coral mortality from 84% to less than 1%. The live coral cover on this reef has now recovered through the rapid growth of tabulate *Acropora cytherea* and branching *Pocillopora damicornis* to 19% by 2003 and to 41% by 2004. Similar increases have been recorded on some of the protected reefs in the Quirimbas Archipelago in Mozambique, where the cover of live coral had been reduced to only 19% in 1999 but has since recovered to 56% in 2002.

### *Recruitment*

At most reefs in South Asia, the central Indian Ocean and core sites along the east African coast, recruitment of new coral colonies has been substantial with recruit densities ranging between 0.5–6 recruits per $m^{-2}$. At sites in Sri Lanka and Maldives, coral communities are dominated by small colonies less than 15 cm in diameter indicating that recruitment is not a limiting factor for recovery at these sites. In contrast, on marginal reefs in South Africa, which are situated at the southern extremity of the geographic range of coral reefs in east Africa, and those influenced by cool current in northern Kenya, recruitment does appear to be a limiting factor for recovery, particularly for the previously dominant genus *Acropora*. In Kiunga in northern Kenya, recruitment of new colonies in 1999 immediately following the bleaching event, was negligible but has since increased to 2 recruits per $m^{-2}$ in 2000/01 and was between 1–1.5 recruits per $m^{-2}$ in 2003/04. Ironically, in South Africa, where the gradual increase in sea temperatures during the last 20 years has favoured the growth of hard corals so that they are now displacing traditionally dominant soft corals, recruitment of new hard corals to the population is extremely low. In fact, in 2001, no recruitment of new corals was recorded at all.

### *Region-Wide Changes in the Composition of Coral Assemblages*

Coral reefs throughout South Asia and the central and western and Indian Ocean seem to be undergoing significant changes in coral community composition as a result of differential mortality among adult colonies of different genera during periods of elevated sea temperature (i.e. variation in bleaching susceptibility) and differences between the taxonomic composition of recruit assemblages settling following the 1998 bleaching event and the pre-bleaching adult coral communities. At a number of sites throughout the region, corals of the genera *Acropora*, which was easily the most abundant and diverse genus comprising pre-bleaching coral communities in the Indian Ocean, are now conspicuously absent. Although settlement of *Acropora* spat on settlement plates in South Africa and recruitment of new *Acropora* colonies to post-bleaching populations in Tanzania has been reported, it appears that along the east African coast, the geographic range of *Acropora* has been restricted to core areas in southern Tanzania and northern Mozambique. *Millepora*, a once dominant genus in shallow coral communities throughout the Indian Ocean, is also noticeably absent and is now represented at some sites only by dead standing skeletons. Previously dominant genera are now being replaced by those that are less susceptible to bleaching, such as *Porites*, *Diploastrea* and several others belonging to the family Faviidae.

Changes in the composition of recruit assemblages are also marked. Prior to 1998, *Acropora* would have dominated most recruit assemblages. At present, *Pocillopora* dominates recruit communities in most areas while slow growing faviids and poritids are also common. In the central Indian Ocean, agariciids, particularly *Pavona*, are abundant and in northern Kenya, *Coscinaraea* is most common among recruit assemblages. These changes suggest that the coral reefs of the future might look rather different from those before 1998. With the reduction in the range and abundance of branching *Acropora* species this could also influence the distribution and abundance of those fish species relied upon the arborescent structure of these corals for shelter.

#### *Benefits of Marine Protected Areas (MPAs)*

Throughout the Indian Ocean, there is an irresistible trend demonstrating that legal protection and regulation of human activities in some areas has enhanced recovery of coral populations. In Sri Lanka, Socotra, Tanzania and Mozambique, sites within MPAs showed greater increases in the cover of live hard coral than similar sites where human activities remain unregulated. Advantages of protection are also exhibited by fish and invertebrate populations. In Tanzania, the density of fish within protected areas was greater than adjacent areas subject to fishing. In protected areas in Mozambique, the abundance of economically valuable carnivorous fish species was considerably greater than on unprotected reefs, which were dominated by small specimens of low-value herbivorous species In Tanzania, the density of sea urchins, which is often used as an indicator of fishing pressure, was far greater (>5 per $m^{-2}$) in unprotected areas than in protected areas (<1 per $m^{-2}$) illustrating the benefits of management and the effects of overfishing on different trophic levels.

Unfortunately however, there are many examples of 'paper parks' in the region. These are MPA that are only protected 'on paper' but where destructive fishing and other similar activities are going on as if the legal protection did not exist.

#### *Recurrent Bleaching Events*

Bleaching events were recorded along the coast of east Africa in Tanzania and Kenya in April/May 2003. In Tanzania, the magnitude of bleaching was minor and its only likely impacts were to further impede reef recovery. In Kenya, mortality of corals, while considerably less than that which occurred in 1998, was about 10%. Differences in the proportion of colonies that exhibited bleaching was noted between genera, with *Pocillopora* and *Montipora* being the only genera that exhibited complete (100% of the colony) bleaching in substantial numbers. Less than 10% of *Porites*, *Pavona*, *Galaxea*, *Echinopora* and *Favia* colonies were completely bleached. Interestingly, at one site north of Mombasa, none of the colonies of *Acropora* exhibited bleaching, yet greater than 80% of these colonies succumbed to the stresses caused by the increased sea temperatures. A similar inverse relationship was observed among several species of *Pocillopora*, where all colonies that exhibited greater than 20% bleaching survived and all colonies that did not show any signs of bleaching died indicating that bleaching in fact protected some colonies of *Pocillopora* from the stress of increased sea temperatures. Mortality among other genera varied with *Astreopora*, *Echinopora*, *Montipora* and *Pocillopora* exhibiting greater than 20% mortality.

Between March and May 2005, a low to medium level bleaching event was observed at many sites around Sri Lanka when sea surface temperatures ranged between 30–32° C. Again, susceptibility to bleaching varied between coral genera, with many *Acropora* colonies appearing paler than usual and several faviid species seemed particularly vulnerable. In contrast to previous events however, a number of genera that survived past events seemed particularly sensitive to increased water temperatures on this occasion. Alarmingly, on June 22nd, 2005, near total bleaching of all zooxanthellate hard and soft corals was reported from the reefs near Batticaloa on the east coast of Sri Lanka threatening to produce impacts of a similar magnitude to those experienced during 1998.

### Impacts of the Tsunami of 26th December, 2004

The damage done to coral reefs throughout the Indian Ocean by the tsunami varied enormously across scales ranging from international to intra-reefal. Analysis of the patterns of damage caused by the tsunami across sites stretching from the Andaman and Nicobar Islands in the east, across South Asia, Maldives and Seychelles, to the coast of east Africa in the west showed that the primary factors that determined the magnitude of impacts were:

- The degree of exposure to incident tsunami waves;
- The bathymetry of the area within which a reef is situated;
- The geomorphology of the reef;
- The condition of the reef.

The degree to which reefs were situated in the direct path of the tsunami and how the direction of travel and energy of the wave was influenced by the bottom topography of the area determined the force with which the wave struck various coral reef habitats. The geological composition of the foundation of a reef (i.e. consolidated coral limestone or volcanic rock supporting coral growth) and its condition determined how well it was able to absorb or dissipate the energy of the tsunami.

Generally, reefs that were not in the direct path of the tsunami suffered very little damage. For example, most reefs around the island of Mahé in the Seychelles escaped major damage because they were sheltered from the full force of the tsunami by the adjacent northern islands of Praslin and La Digue. On the Indian coast of the Gulf of Mannar and along the coast of east Africa, the force of tsunami was greatly reduced and the damage to coral reefs was negligible.

Reefs that were located in very deep water without a shallow coastal shelf, such as those atolls comprising the Maldives, were also not seriously affected because the tsunami was not able to build up into a tall breaking wave. Damage to 1–2% of branching and tabulate corals occurred with some accumulation of sediment but otherwise damage was minimal.

Reefs located on shallow coastal shelves and adjacent to deeper channels often exhibited significant damage because these channels often diverted the path of the tsunami and concentrated the energy of the wave onto specific portions of the reef and adjacent coastline causing considerable physical damage. This was particularly evident at Dutch Bay, Trincomalee on the east coast of Sri Lanka, and on some of fringing reefs surrounding the northern granitic islands of the Seychelles. At Dutch Bay, nearly half the reef area has been turned into fields of rubble and sand and more than 75% of the remaining reef has been severely damaged by large coral blocks and dead coral that have razed the reef, tearing off the live coral and eroding the limestone foundation of the reef. Virtually all remaining live corals were damaged, with many tabulate *Acropora* colonies having been uprooted and many massive corals toppled and transported large distances, including some *Porites* colonies over 2 m in diameter. Further south on the east coast of Sri Lanka at Kirankulam, large *Porites* colonies >2 m in diameter have been deposited 150 m inland from the shoreline.

On other reefs located on shallow coastal shelves, the damage caused by the tsunami was highly varied between sites and was dictated primarily by the geomorphology of the reef and its condition. Reefs that have formed on

## Critical Data – Region by Region

### South Asia

- Reefs continue to be degraded by coral mining, destructive fishing practices, overexploitation, pollution and sedimentation.
- Recovery from bleaching-related coral mortality of 1998 is slow and patchy. The best recovery has been recorded in areas where human activities are managed, such as in MPAs and marine sanctuaries. Where human activities remain unregulated, recovery has been poor.
- The impacts of the tsunami on coral reefs were highly variable and ranged from negligible (Maldives, Gulf of Mannar, India) to moderate (Andaman and Nicobar Islands) to severe (parts of Sri Lanka, Nicobar Islands). The most severe damage to coral reefs and adjacent coastlines occurred where coral mining has been rampant.
- Considerable changes have occurred in the composition of coral communities where previously dominant species (e.g. *Acropora*) are being replaced by species that either survived the 1998 bleaching event or have dominated assemblages of new recruits.
- The establishment of awareness raising programmes and community-based restoration projects has resulted in significant declines in destructive coral mining and fishing practices.
- The introduction of several alternative livelihood and income diversification schemes in the Gulf of Mannar has reduced pressure on coral reef resources and improved the economic status of fisher families.
- Despite efforts to address the underlying causes of coral reef degradation, the condition of reefs continues to decline as a result of inadequate laws or regulations, poor enforcement, lack of political will to strengthen laws and improve enforcement, insufficient awareness of the impacts of human activities, few options for alternative livelihoods or income diversification.

### East Africa

- The current condition of coral reefs reflects the severity of bleaching-related mortality in 1998. Reefs that largely escaped are in good condition with a healthy cover of live hard coral. Reefs that suffered severe coral mortality are in poor condition and have shown little recovery.
- Overexploitation, destructive fishing activities, pollution and sedimentation continue to degrade coral reefs in east Africa and hinder recovery.
- Recovery in marginal environments (South Africa, northern Kenya) has been limited by the low influx of new coral recruits and competition of other benthic inhabitants.
- Considerable changes have occurred in the composition of coral communities where previously dominant species are being replaced by species that either survived the 1998 bleaching event or have dominated assemblages of new recruits. For example, the distribution of *Acropora* has receded to core areas in Tanzania and northern Mozambique.
- A repeat coral bleaching event occurred in 2003 killing ~10% of corals in Kenya, and having negligible impacts on coral reefs in Tanzania.
- Fish densities in areas where human activities are managed are greater with increased abundances of economically valuable carnivorous species. In areas that are not managed, fish communities are dominated by small specimens of low-value herbivorous species.
- Community-based monitoring programmes and education has successfully raised awareness and lead to the establishment of several marine conservation areas under community management.

solid volcanic rock substrates, such as the granitic reefs in the Seychelles, exhibited very little damage as the dense rocky foundation of the reef was able to resist the energy of the tsunami. However, genuine coral reefs, founded on less dense limestone accumulated through millennia of coral growth, were more vulnerable to damage by the tsunami but the magnitude of damage to these reefs was dependent on their condition. Healthy reefs with a consolidated limestone foundation and good live coral cover were better able to absorb or dissipate the energy of the tsunami and generally escaped without damage to the reef framework and only minor damage to the coral community. Reefs degraded by severe bleaching-related coral mortality, overfishing, chronic sedimentation or pollution suffered considerably more damage primarily as a result of the tsunami moving fields of unconsolidated rubble which abraded and destroyed living coral colonies and smothered areas of reef.

The exacerbation of the impacts of the tsunami by coral reef degradation was amply demonstrated at some sites in Sri Lanka and the Seychelles. On the reefs along the eastern and southern coasts of Sri Lanka which have been degraded by bleaching, overexploitation and rampant coral mining, damage, although patchy, was frequently severe with large coral blocks and live branching and massive colonies up to ~50 cm being overturned and extensive stands of *Acropora* demolished by shifting rubble. The redistribution and increase in the proportion of substrate covered by coral rubble was almost ubiquitous and likely to have been caused by the disintegration of dead standing corals that were killed previously by bleaching.

In the Seychelles, the structural integrity of many carbonate reef structures surrounding many of the northern granitic islands has been compromised by severe bleaching associated coral mortality in 1998 and the subsequent bio-erosion and disintegration of the reef framework. As a consequence, the superficial reef structure of many of these reefs is composed of unconsolidated rubble which was easily moved by the tsunami abrading living corals and breaking branching corals. The resulting damage was severe and in some cases, coral mortality approached 100%.

### Threats

In South Asia and along the coast of east Africa, widespread overexploitation of fish and invertebrate populations has degraded the condition of coral reef communities. Moreover, the failure of diminished catches to meet basic food and livelihood requirements is driving more and more fishers to use increasingly destructive fishing techniques. In Tanzania, the use of explosives and poisons is common, while in other areas throughout the region, particularly Sri Lanka, the use of small-mesh nets and beach seines is causing considerable damaged to fish and coral communities. In India, the influence of lucrative international markets has increased demand for reef fish exacerbating the existing overexploitation resulting from satisfying domestic and subsistence needs. In addition, land-based activities, particularly along the coasts of South Asia and east Africa, are resulting in widespread sedimentation and pollution of near-shore coral reef areas.

In South Asia and East Africa coral mining remains a significant threat to the functional integrity of coral reefs. Throughout the region living shallow-water corals are used as sources for calcium carbonate. The corals are broken loose from the substrate and trasported to kilns on land where they are baked to produce lime. Despite the widespread ban on mining activities, poor and intermittent enforcement of regulations allows this destructive activity to continue in both Sri Lanka, India, Madagascar, Tanzania and Mozambique.

Often the activity has the character of back-yard productions on a relatively small scale. However, in Tanzania, it is practiced on an industrial scale with large kilns operated also in the city of Dar es Salaam very close to the agencies in charge of environmental protection. The large-scale operation is fed by corals that are broken i shallow-waters along the coast and transported to the city using different types of vessels.

As a result, the abundance and diversity of both coral and fish populations on many reefs has declined. Moreover, the damage caused to the reef framework by mining has reduced the effectiveness of near-shore fringing reefs as breakwaters. The consequences of this were tragically demonstrated when the tsunami was able to breach fringing reefs causing widespread damage to coastal communities, infrastructure and coastal erosion. In the worst cases along the eastern and southern coasts of Sri Lanka where coral mining is rampant, the width of beaches was reduced by half and losses in beach height of more than 1 m were common. In addition, the shifting rubble fragments left behind from mining impede reef recovery by offering little suitable substrate for settlement of new corals and abrading surviving colonies and other benthic organisms. In the short-term, coral mining can be curbed by instituting regular enforcement and improving regulations that presently allow offenders to evade prosecution and by increasing fines so that they are a genuine disincentive to those engaged in this activity. In the long-term, sustainable and equally lucrative alternative employment options must be offered to miners if coral mining is to be stopped.

Such alternative income-generating scheems have to be combined with vigorous education and awareness-building campaigns focusing on various sectors of society, particularly school children, fishers and women.

While coral bleaching and mortality is a sporadic phenomenon that has accelerated the degradation of coral reefs throughout the Indian Ocean, pressures exerted by other human activities remain a constant and, as such, should receive the constant attention of management efforts.

### Income Diversification and Alternative Livelihoods

In several coastal fishing villages along the Tuticorin Coast on the Gulf of Mannar, India, three projects providing opportunities for income diversification and alternative livelihoods have been introduced. Women belonging to 13 families from Thirespuram, Punnakayal, Vellapatti and Tharuvaikulam have been trained in the production of organic fertilizer using earthworms to break down organic matter and other bio-degradable household wastes produced every day. With buyers for the compost being organised for the women, ensuring a market for the product, the women earn between 1 500 and 2 000 Rs for each crop, which requires less than one month to mature. Vermi-composting, as it is known, has become popular because of the low initial investment required to construct a compost pit and the relatively high return for effort spent maintaining the pits. As a result, the practice has spread to other villages in the area providing an environmentally sustainable option to diversify the income of fisher families in the region.

In Vellapatti, a practice known as crab fattening was introduced where recently moulted, soft-shelled crabs, which have very little market value, are maintained in tanks until the shell has hardened and can be sold at fair market value. With the construction of a number of tanks within a crab fattening facility, women within five co-operative Self Help Groups have been trained and are now responsible for stocking, feeding, harvesting and selling the crabs. The principal species used is *Portunis pelagicus* because their shells harden more rapidly and can be stocked in higher densities than the alternative crab species *Scylla serrata*. Earnings from this activity range from 1 000–1 500 Rs per month and it has raised considerable interest among neighbouring villages and also among donor organisations that are keen to replicate this venture at other coastal villages in the region.

The third activity introduced is the production of value added goods using the meat of gastropods which are caught in large numbers as by-catch in the crab fishery and are discarded because they are not part of the traditional diet of local people. Twenty-five women were trained in the preparation of products such as pickles, soup and chutney powders and other local products using the meat from these gastropods, which could serve as an alternative source of protein in the future. These activities raised considerable interest among local villages to protect and manage coastal marine resources and serve as models for other coastal communities in India and throughout the region.

A review of experiences and lessons learned from the implementation of alternative livelihood programmes in Sri Lanka has identified a number of key factors that must be considered for the success of any alternative livelihood programme. In order to ensure long term economic development, it is essential that all factors that threaten the sustainability of any alternative livelihoods programme be identified and addressed in an integrated manner in the design and implementation of the programme. Factors that must be considered are:

- *Financial viability* –The alternatives must be at least as financially rewarding as the destructive activity in which people were previously engaged and there must be a market for the product being manufactured or grown within an alternative livelihood scheme. If these criteria are not met, it will be futile.
- *Social norms and perceptions, the demographic composition of the community and gender specific roles* – these factors play an important part in determining the social acceptability of the programme and their implications for the implementation of the programme must be thoroughly understood before it is introduced.
- *Expectations and contributions of the target group* – it is essential that the contribution and efforts required to make an alternative livelihood programme succeed and the expected benefits and income are clearly explained and understood. Allowing unrealistic expectations of unprecedented wealth to persist is a sure recipe for failure.
- *Assisted economic development* – financial services that are designed specifically to assist poor people with limited repayment options or collateral should be established in order to imporve the economic development of many coastal communities and also to secure the long term sustainability of alternative livelihood programmes. Along the Tuticorin Coast of India, this has been successfully achieved through the establishment of a number of Self Help Groups (SHGs), which are comprised of 20 women with similar interests. The primary function of each SHG is the economic development of each of its members through the saving and wise use of financial resources. Each SHG is registered with the Tuticorin Multiservice Social Service Society (TMSSS) and receives a disbursement based on the amount of savings it has accumulated from the TMSSS who takes a single large loan from a bank on behalf of all the SHGs in the region. The money received by each member of the SHG must be repaid within 21 months at 9% interest. This scheme has improved the economic situation of families in the region by allowing them to escape the financial control of middlemen and loan sharks. Moreover, the financial support obtained and provided by the women involved in the SHGs has empowered them to take a much stronger role in social and economic domains and in planning decision making processes.
- *Information exchange* – establishing a dialogue and an atmosphere of trust between the executing agency and the various stakeholders is essential for the success of any alternative livelihood programme.
- *Monitoring* – constant monitoring is required in order to respond to change and address problems as they arise.
- *Ownership and empowerment* – in situations where natural resources are threatened by an external source (e.g. foreign investors or fisherman from another region), it is important that the local community is empowered to manage their own resources.
- *Integration and participation* – introduction of alternative livelihoods should be seen as an integral component of a broader strategy that involves all stakeholder and resource users to develop and better manage the coastal zone and its resources. Furthermore, establishing alternative livelihoods is a long-term undertaking. While the initial phases are often completed with donor assistance, governments should be prepared to offer technical and financial assistance once the donor funding has finished.

It is clear that the only way to break the cycle of poverty, unemployment and environmental degradation is to offer alternative income generating options that are environmentally sustainable, financially viable and socially acceptable. The establishment of such activities will make people less vulnerable and more adaptable to changes in food supply and income. In addition, these activities must be conducted in conjunction with programmes specifically designed to educate and raise awareness of the environment, the impacts that their activities have and the need for and benefits of sustainable resource use. Only through making people aware will it be possible to entrain environmental sustainability into their behaviour.

### Awareness Raising

Although coral mining and the use of destructive fishing methods are illegal, they are sill widely practiced largely because:

a) the returns are more profitable than less destructive alternatives;
b) the risk of being caught and subsequently punished is low because enforcement of laws and regulations is inadequate;
c) the knowledge of the impacts of their activities on the reef are low.

Within fishing villages along the Tuticorin Coast, surveys showed that only 29% of men and 3% of women knew the ecological significance of corals for coral reefs and their associated fish populations. In the short term, compliance with laws and regulations can be obtained through strong enforcement backed up by appropriate punishments. However, if long term environmental improvements are going to be achieved, improved governance must be augmented with education of the importance of coral reefs and the damage that destructive activities do to these habitats.

Through a series of programmes conducted along the Tuticorin Coast, which targeted women and focussed on the importance of corals and the impacts of illegal activities such as destructive fishing and coral mining, the level of awareness among men and women increased to 80% and 20% respectively. Moreover, as a result of these campaigns, coral mining and the use of destructive fishing practices have ceased in one village and are in decline elsewhere in the region.

Awareness has also been raised through community-based activities. In India, a community-based reef restoration project involving the transplantation of corals has successfully transferred knowledge of the importance of corals and the need to conserve them. In addition, the fisher folk involved in this project improved there ability to communicate issues and concerns affecting their environment. Similar results have been obtained in Tanzania where community-based monitoring projects have illustrated the impacts of overfishing prompting communities to impose self-regulatory mechanisms including voluntary closures, community patrols and enforcement and the establishment of conservation areas.

Another successful strategy has been the implementation of public exhibitions. CORDIO, in conjunction with IUCN, produced an exhibition entitled *A tomorrow for our reefs*. The project was enormously successful attracting more than 4 000 visitors per day at one location. An important by-product of this activity was the production of education materials in Sinhala, Tamil and English that were incorporated into the Sri Lankan school curriculum and introduced to more than 1 000 secondary schools to teach students of the importance of reefs and the conservation of marine resources. This material will be introduced into schools in the Tamil Nadu region of India during this year.

### Building on a Solid Foundation

Since its initiation in 1999, the CORDIO programme has:

- Established and strengthen coral reef monitoring programmes in 10 countries around the Indian Ocean through the provision of financial support and training;
- Established and conducted socio-economic monitoring of the coral reef dependent fishing and tourism sectors in 7 countries around the Indian Ocean and have initiated household level monitoring within coastal communities in 3 countries;

- Supported more than 30 targeted research projects focusing on critical issues affecting the condition, recovery and management of coral reefs, particularly coral bleaching dynamics, sea temperature regimes, coral growth and recruitment, bio-erosion and reef rehabilitation;
- Introduced the results of monitoring and research into management strategies and policy development both at national and regional levels;
- Reduced pressure on coral reef resources and improved the quality of life of many families in coastal communities through enhanced economic development achieved through the introduction of income diversification and alternative livelihood schemes;
- Raised awareness of the importance of coral reefs and the impacts of various human activities among people in coastal villages throughout the Indian Ocean.

In the future, CORDIO will continue to implement activities within its core themes of Monitoring, Research, Management and policy, Alternative livelihoods and Education and awareness. In addition, CORDIO will continue to expand and strengthen its network of scientists, managers, policy makers and governments in South Asia and the central and western Indian Ocean. In particular, CORDIO will continue to build on its collaboration with regional entities, such as the Western Indian Ocean Marine Science Association (WIOMSA), IUCN Marine and Coastal Programmes in East Africa and South Asia, and the Indian Ocean Commission (COI), UNEP Regional Seas Programmes in East Africa and South Asia, and with global partners such as the Global Coral Reef Monitoring Network (GCRMN), Reef Check, the IUCN Global Marine Programme, the International Coral Reef Initiative (ICRI), the International Coral Reef Action Network (ICRAN), the Worldwide Fund for Nature (WWF), the World Bank and the Global Environment Facility (GEF). At this time, when the tsunami of 26th December, 2004 demonstrated all too clearly the importance of healthy coral reefs and coastal ecosystems for coastal protection and the tragic impacts are fresh in our memories, the need for concerted action to reduce the continuing degradation of coral reefs has never been more urgent. In the past, CORDIO has focussed its activities on helping to resolve several issues of global concern, such as food security, poverty alleviation and particularly the impacts of global climate change and the conservation of biodiversity, so as to produce the greatest tangible benefits for both coral reefs and the people who depend on them. This will not change in the future.

## Section 1

# Status Reports

# East Africa – Summary

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*key words:* East Africa, coral reefs, coral bleaching, reef resilience, destructive fishing, socio-economic monitoring

## ABSTRACT

East Africa's coral reefs continue to recover slowly from the ENSO-induced coral bleaching and mortality of 1998. However, fastest recovery has been recorded in reefs previously degraded from other threats such as fishing, and slowest in protected areas and on reefs that were less degraded before 1998. Minor bleaching continues to affect reefs in the region, most notably in 2003, though with some reported in 2005, though mortality in both cases was limited to some vulnerable *Pocillopora* species. Interestingly, many *Acropora* species and *Pocillopora damicornis*, which suffered near 100% mortality in 1998 showed low bleaching and mortality levels in 2003 and 2005. Ongoing increases in other threats continues, most notably fishing, Crown of Thorns outbreaks and now the effects of long term bioerosion related to high mortality in 1998. Dynamite fishing is resurging in northern Tanzania. Social and management oriented research and monitoring are becoming increasingly common, and integrated with biological studies to provide more comprehensive assessments of the status of reefs, and recommendations for mitigating threats. The expansion of socio-economic monitoring through a collaborative programme focused on the GCRMN SocMon system started in 2005, for which CORDIO will serve as the regional coordinator. Greater integration of CORDIO's activities has occurred in the last 2 years through the adoption of a resilience-based approach, combining research and monitoring projects and cutting across biological, socio-economic and management fields.

## INTRODUCTION

Coral reefs of the East African coast cover a range of 40° of latitude between the cool upwellings of the Somali Current (10°N) to the cool temperate waters of the Agulhas Current (30°S), and are fed by warm waters of the South Equatorial Current that hits the Mozambique–Tanzania border (approx. 16°S). Increasingly recognized as the 'East Africa Marine Ecoregion' (WWF 2000), this coastline includes the major reef systems of northern and southern Tanzania (800 km) and northern Mozambique (800 km), the narrow fringing reefs of southern Kenya (200 km), smaller isolated reefs along the southern Mozambique coast (500 km) to South Africa (150 km), and patchy reefs in northern Kenya and southern Somalia (500 km). The latitudinal range and linear structure of the reef system provide an excellent case study on regional variation in vulnerability of coral reefs to climate change, and the spread of monitoring and research sites supported by CORDIO since 1999, as well as those of independent researchers and other programmes, is enabling greater contributions of science from the region to the literature on local to regional resilience questions (Obura, 2005b).

With increasing threats from both local acute uses, such as overfishing, to regional chronic conditions, such as global warming, East Africa's reefs are increasingly threatened (table 1). Greater integration in science and management links, such as that offered by resilience-based concepts may help reduce impacts (Hughes *et al.*, in press), however the prognosis is poor without major improvements in management efforts and capacity across the board (table 1). To adapt to these increasingly complex and linked conditions, CORDIO's activities in East Africa are being oriented towards a resilience-based approach, linking monitoring with research projects, and crossing biological, socio-economic and management boundaries. CORDIO's involvement in the broader context of coral reef health and assessment was illustrated early in 2005 in leading the development of a recommended rapid response methodology for assessing damage caused by the tsunami of 26 December 2004 (ICRI/ISRS, 2005).

## STATUS OF REEFS

CORDIO has continued to support coral reef monitoring, summarized in the national reports in this volume (Motta & Costa, 2005; Mohammed *et al.*, 2005; Obura, 2005a). The extent of coral reef recovery since the ENSO in 1998 has been very variable, with close to 30% being classified by scientists at high risk or 'seriously damaged/totally destroyed' (table 2). Thirty percent are regarded as showing strong recovery. However, many of the reefs that have shown 'full recovery' to pre-bleaching conditions were already degraded by other human pressures before bleaching. Their rate of recovery was more rapid, but only to a state that had already lost many slow growing and vulnerable coral species and was instead dominated by opportunistic and stress resistant species. In contrast reefs showing the least recovery since 1998 are those that were in better health prior to bleaching. Many have been affected by chronic and local threats that include minor bleaching, increasing overfishing (regional) and crown-of-thorns starfish infestations. Repeat coral diseases and Harmful Algal Blooms have not been reported since the major scare in 2001 (Obura, 2002). The Asian Tsunami of 26 December 2004 reached the East African coast in Kenya and Tanzania, but damage to coral reefs was negligible though some lives were lost.

Seagrass monitoring has generally been neglected in coral reef monitoring programmes, highlighted recently in Kenya when an explosion in populations of the herbivorous sea urchin *Tripneustes gratilla* caused an uproar among local fishermen when it denuded seagrass beds, the primary habitat for artisanal fishing activity (Mwaura *et al.*, 2003). In response, CORDIO collaborated with Kenya Marine and Research Institute (KMFRI) scientists to pilot participatory monitoring methods on sea-

**Table 1.** Summary status of coral reefs in East Africa, extracted from Obura 2004 in Wilkinson 2004

| | |
|---|---|
| **100 years ago** | coral reefs largely pristine, except for localized extraction around towns and villages, and point-source pollution around towns |
| **1994** | at a coastal population of 10-15 million, subsistence and small scale fishing were the dominant threats to coral reefs in East Africa |
| **2004** | coral bleaching in 1998 and a coastal population of 22 million are the two primary threats to East Africa reefs, the former causing declines in some 30% of the region's reefs, the latter probably slowing recovery. On the positive side, management is improving in all countries, in Marine Protected Areas, fisheries management and environmental legislation |
| **2014** | with a likely coastal population of 39 million people and probably repeat of a coral bleaching event similar in magnitude to that in 1998, the prognosis is poor. Significant investments in capacity must be made in all areas, in particular finance, to mitigate the hardships likely to impact vulnerable coastal communities |

**Table 2.** National summary of reef state in 2004 (Obura 2004 in Wilkinson 2004)

| | Kenya | Tanzania | Mozambique | South Africa | Overall |
|---|---|---|---|---|---|
| **1.** seriously damaged or totally destroyed | 10 | 10 | 10 | 0 | 7.5 |
| **2.** strong recovery since 1998 | 30 | 30 | 30 | NA | 30 |
| **3.** high risk: clear damage | 30 | 20 | 20 | 10 | 20 |
| **4.** medium risk: moderate damage | 30 | 30 | 10 | 30 | 25 |
| **5.** low risk: healthy and relatively stable | 0 | 10 | 30 | 50 | 22.5 |

**1.** 90% of the corals are gone and unlikely to recover soon.
**3.** 50 to 90% loss of corals and likely to join category 1 in 10 to 20 years.
**4.** moderate signs of damage – 20 to 50% loss of corals and likely to join category 1 in 20 to 40 years.

grass health, as well as sea urchin reduction studies. These are being expanded through a new KMFRI research project (J. Uku, unpublished data) to establish permanent monitoring of seagrass beds in the Diani area, Kenya, and integrate this with fisheries and coral reef monitoring.

### Destructive and Over-Fishing

The largest local threat to reefs in East Africa is considered to be fishing (McClanahan *et al.*, 2000), although the specific impacts vary at different sites (e.g. according to the relative impact of excess harvesting, destructive gears and migrant fishermen). Beach seines and other types of drag-nets are the most common form of destructive gear that cause significant damage to habitats, juvenile fish populations and vulnerable species. Their use increases as catch rates using more selective and individually-operated traditional gears decline, and as the supply of unemployed youth and men increases to work on large nets as labourers. The increasing amount of migrant fishing in larger reef systems is rated as a serious problem in places such as Tanga, Tanzania, and Kiunga, Kenya, posing specific challenges to locally-based management. Commitment to comanagement is a complex issue, and while significant efforts are underway, greater attention to devolution and real sharing of responsibilities will be increasingly necessary (Alidina, 2004; this volume).

A resurgence of dynamite fishing on reefs in northern Tanzania (Dar es Salaam, Tanga) in 2003/04 has been reported, a reversal of the successful eradication practices by the Tanzanian government in the late 1990s. The Tanga Dynamite Fishing Monitoring Network (TDFMN 2005) reports over 60 observations from January-May 2005, of 1–4 blasts per day focused on the reefs of Kigombe and Karange reef. Many of the newly impacted reefs were recovering from dynamite fishing of the 1980s and 1990s and were beginning to show recovery of fish populations as a result (Horrill, 2001).

### Coral Mining

Throughout the region living shallow-water corals are used as sources for calcium carbonate. The corals are broken loose from the substrate and transported to kilns on land where they are baked to produce lime. The practice of using live coral has been banned for many years in most of the region. However, this destructive practice is still going on in Madagascar, Mozambique and Tanzania. Often the activity has the character of back-yard productions on a relatively small scale. In Tanzania it is practised on an industrial way with large kilns operated also in the city of Dar es Salaam very close to the agencies in charge of environmental protection. This large-scale operation in Tanzania is fed by corals that are broken in shallow waters along the coast and transported to the city using different types of boats. Particularly the large-scale operations are likely to be very destructive to the coastal environment, affecting both productivity of fish and the protection of the coastline. However, small-scale coral mining can also have similar effects if the practice is widespread.

### Coral Bleaching

Reports of significant bleaching were made in Kenya and Tanzania during the peak of the local summer in March/April 2003, and in April/May 2005. However mortality was generally low, and in some cases the species that suffered the most damage from bleaching in 1998 showed less response than others, for example, *Pocillopora damicornis* and common small *Acropora* species. Coral bleaching reported in March/April 2005 in the southern islands of the Indian Ocean (Mauritius, Reunion and western Madagascar) was also then reported in Mayotte in May. However it appears that the bleaching occurred too late in the season to cause significant mortality. Some speculation has it that the northern part of the Indian Ocean remained in a cool state during March and April perhaps due to mixing caused by the tsunami of 26 December 2004, and certainly no persistent hotspots were visible on NOAA hotspot charts from January–April 2005 as usually occurs during this season.

CORDIO projects are participating in broader scale research initiatives on coral reefs, most notably with the recently started World Bank-Global Environment Facility Coral Reef Targeted Research Project (GEF-CRTR) with representation in the Bleaching Working group. Work under this group will build on recent studies on recovery of zooxanthellae populations following bleaching (Visram, 2004, 2005) and integrating these studies with ecological studies on resilience (Obura, 2005a). Through research grants from CORDIO and the GEF-CRTR, further capacity will be built at the region-al level to broaden participation in such global initiatives.

### Crown of Thorns Seastars

A patchy but widespread increase in COTS numbers was recorded in 2003 and 2004 in Tanzania (M. Richmond, pers. comm.; Mohammed *et al.*, this volume, 2005; C. Daniels, pers. comm.) and Kenya (J. Mwaura & S. Mangubhai, pers. comm.). The first reports in February 2003 were of aggregations of 10–30 individuals per 10 $m^2$ spread over 100 m of reef front on an inner patch reef in the Songo Songo Archipelago. In 2004, COTS aggregations appeared on reefs in Tanzania around Unguja Island (Zanzibar), Pemba, Mafia Island, Dar es Salaam, Tanga, and north to Mombasa in Kenya. Some were reported on an isolated reef near St. Lucia, South Africa. COTS numbers have increased on reefs on the west coast of Zanzibar, by a hundred-fold from initial densities of 10 per 1,000$m^2$ in early 2003, to 10 per 10$m^2$ in August 2004; these are the largest populations in Zanzibar for the last 7 years. There are ongoing attempts at controlled removal of COTS in Chumbe Island Coral Park by park staff with more than 500 COTS removed between April and July 2004. They were assisted by dive operators who have removed some COTS and started collaborative monitoring program. There has been up to 50% mortality of corals from these COTs populations in some areas, and extending down to 30 m depth, and monitoring is continuing to determine the wider implications.

### Bioerosion and Coastal Protection

The long term impacts of coral bleaching and mortality on reef erosion are starting to become apparent now, some 6 or more years after the bleaching event. Surveys in Mozambique in 2004 showed that some reefs had small decreases in coral cover, attributed to a collapse in the reef framework, while coral diversity and community complexity was still increasing. Examples of coral tables and plates that died in 1998 and subsequently collapsed due to bioerosion have been observed elsewhere in the region, such as southern Tanzania, similar to reports from the Maldives and Chagos Archipelago (Sheppard *et al.*, 2002). Weakening of reef frameworks by bioerosion is also implicated in tsunami-related damage (see below).

### The Tsunami

The tsunami of 26 December 2004 was felt as tidal surges of 1–1.5 m in Kenya and Tanzania, with a period of 10–15 minutes, decreasing in size from north to south and spread over 6–8 hours (Obura, in review). Fortunately they were most severe at low tide, thus did not exceed high tide levels, and only in the north did they potentially extend below spring low tide levels. Beach erosion occurred in northern Kenya due to super-strong currents in complex channel systems, and redeposition occurred changing the shape of some beaches. No damages were reported to subtidal reef communities. Only one instance of overturned corals has been observed, of *Turbinaria* plates some 2–3 m across in a high current channel feeding extensive mangrove systems in the Kiunga Marine Reserve, Kenya. Large plates are easily lifted and overturned by the tsunami surges (e.g. in the Seychelles, Obura & Abdulla, 2005) due to their high surface area: volume ratio and low density carbonate skeletons. While the tsunami may also have caused the slumping of some large bioeroded boulders in parts of East Africa this could not be distinguished from more general toppling from storms and waves.

## SOCIO-ECONOMIC STUDIES

CORDIO initiated a pilot socio-economic monitoring programme in 2001 in Kenya, with activities spreading to Tanzania in 2003 (Malleret-King & King, 2002; Wanyonyi *et al.*, 2003). The programme targeted fisheries and MPA applications, using local resource users as key participants in data collection. In 2005, with assistance from NOAA and ICRI, a regional workshop to identify monitoring priorities, participating sites and develop a GCRMN SocMon manual for East Africa will start a 2 year expansion of this programme to other sites in East Africa and the WIO, and formal collaboration with other organizations interested in socio-economic monitoring.

As a complement to the basic monitoring variables captured in the participatory monitoring programmes, CORDIO has participated in more in-depth socio-economic coral reef assessments in Tanzania and Kenya. An independent study, funded by DFID in 2003, examined fisheries-associated livelihoods and constraints to their development (Malleret-King *et al.*, 2003). A comprehensive socio-economic assessment of the communities and use of resources of the MPA was funded through IUCN at the Mnazi-Bay Ruvuma Estuary Marine Park in southern Tanzania in 2004 (Malleret-King, 2004). It also included a detailed study of the occupational structure of villages adjacent to and in the MPA boundaries. This was the first use of detailed socio-economic data in a MPA Management Plan for East Africa. At a broader level, these studies provide detailed baseline data for future assessments of benefits from MPA and fisheries management at the sites, which can then serve as reference areas for understanding the dependence of local communities on coral reef goods and services.

## MANAGEMENT INITIATIVES

Potential and actual climate change impacts are perhaps the most severe threats to East African reefs, but unfortunately are beyond the management capacity of local and national MPA authorities. The examples of Kiunga (Kenya) and Tanga (Tanzania) are pertinent, where participatory monitoring programmes have been established with local communities as the primary implementers of coral reef monitoring. These have stimulated strong education and communication programs with local stakeholders to raise their awareness of the threat of climate change. This learning has contributed at a broader scale to developing guidelines on management responses to climate change (Obura *et al.*, in review).

Tourism is often cited as a threat to coral reefs, and unmanaged growth of tourism development and direct-use activities such as uncontrolled scuba diving often results in reef degradation. An MSc study from southern Mozambique (Pereira, 2003, 2005), supported by CORDIO, of the cross-border diving industry with South Africa, however, found that while scuba diving use is increasing at relatively unmanaged levels, the damage to destination reefs is still minimal. Nevertheless recommendations concerning their carrying capacity, improved study and management were made, and could be usefully applied to reefs were diver impact is apparent.

Two new tools to assist managers were developed in the region by the World Conservation Union (IUCN) East Africa Regional Office in collaboration with the Western Indian Ocean Marine Science Association (WIOMSA): 'Toolkit for MPA Practitioners in the Western Indian Ocean' (IUCN, 2004), and 'Management Effectiveness Workbook'. These were undertaken on the recommendation of an IUCN Regional Task Force to provide more locally accessible and applicable materials for use by MPA managers within the Western Indian Ocean.

As an example of increased use of research and monitoring in management, coral reef research and monitoring efforts in South Africa are being focussed on assessing the entire coral reef system in order to develop a comprehensive management plan. Scientists of the Oceanographic Research Institute in Durban characterized and mapped the reefs of KwaZulu-Natal using underwater digital image analysis, hydrographic surveys and remote sensing techniques. They will make recommendations on the establishment and efficacy of sanctuaries to protect sensitive areas and important biodiversity targets (Schleyer & Celliers, 2005).

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# Coral Communities of the Socotra Islands, Yemen:

## Status and Recovery Following the 1998 Bleaching Event

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*key words:* long-term monitoring, coral recovery, coral bleaching, Socotra

### ENVIRONMENTAL AND BIOGEOGRAPHIC SETTING

Corals of the Socotra Islands, Arabian Sea, Yemen form small, comparatively discrete communities, rather than large accretional reef structures, probably because of the harsh environmental conditions imposed by the Southwest summer monsoon and upwelling associated with the Somali Current. Despite the lack of major reef-building, the islands support a diverse stony coral fauna of 253 scleractinian species (58 genera, 16 families), some of which were previously unknown from Arabian Seas (DeVantier *et al.*, 2004). Whilst sharing strong zoogeographic affinities with Arabian Seas and the western Indian Ocean, the communities contain a unique composite fauna from these and other faunal provinces, including rare species with restricted and/or highly disjunct global distributions. Community composition is consistent with replenishment from both local and external sources, the latter mediated via long-distance larval dispersal in several ocean currents that seasonally sweep the islands. The islands are thus likely to be important 'stepping stones' connecting coral and other reef-associated populations in the northwest Indian Ocean (Kemp, 1998; DeVantier *et al.*, 2004).

The possession of a diverse coral fauna yet lack of substantial reef-building demonstrates that Socotra's coral communities are finely poised in relation to their ecological and physico-chemical environment and thus are uniquely placed as a monitoring site to provide insights into phenomena such as climate change. The northwest Indian Ocean is sensitive to climate shifts such as those caused by the El Niño-Southern Oscillation and the Indian Ocean Dipole, and indeed global warming (Hoegh-Guldberg, 1999; Wilkinson *et al.*, 1999).

### IMPACT OF THE 1998 BLEACHING EVENT

These climate factors may be implicated in the global coral reef bleaching event of 1997–98, which affected the Socotra Islands in May 1998. Studies prior to the event indicated that coral communities around the islands were generally in good condition, and supported a diverse reef-associated fish fauna (Kemp, 1998; Kemp & Obura, 2000). Coral mortality from bleaching around the islands was patchy (DeVantier *et al.*, in press). Some areas, particularly on the main Socotra Island, were badly affected, with loss of more than half their coral cover, yet other areas were little or unaffected, particularly on the outer islands (Turner *et al.*, 1999; DeVantier *et al.*, 2004; Klaus & Turner, 2004; DeVantier *et al.*, in press). The islands and their marine communities were designated as protected areas (Di Micco De Santo & Zandri, 2004), and a long term reef monitoring program was established (DeVantier *et al.*, 2000).

## GLOBAL CORAL REEF MONITORING NETWORK

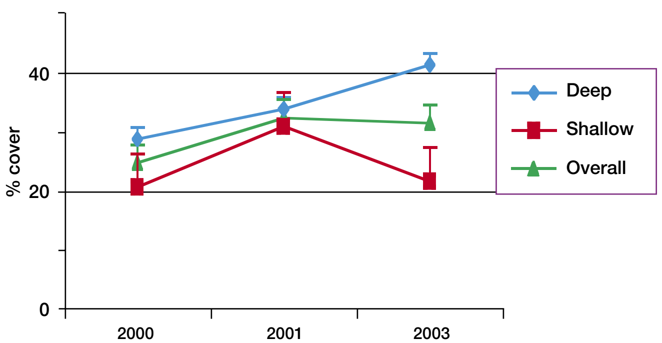
The monitoring program followed the Global Coral Reef Monitoring Network protocols (English *et al.*, 1997), with some modifications necessary because of the lack of reef development around the islands. Permanent monitoring stations were established around the islands in 2000, and patterns and trends in benthic cover and community structure of the coral communities were assessed between 2000 and 2003. Three monitoring stations, each with two depths (4 m and 10 m) were monitored on Socotra Island in 2000, 2001 and 2003; and two stations of one depth (10 m depth) were monitored on the outer Brothers Islands (Samha & Darsa) in 2000 and 2002. The stations were mostly within Nature Sanctuary protected zones of the Marine Protected Area, with the exception of one station on Socotra Island, located in the General Use Zone at the seaport.

## TRENDS IN CORAL COVER

### Socotra Island

The overall average coral cover in the 6 surveyed sites on Socotra Island increased from 25% in 2000 to 32% in 2001, with a slight decrease to 31% in 2003 (figure 1a). The decline was attributable to the major loss of hard coral cover at one shallow site at the seaport. In the three deep sites on Socotra Island, an overall increase in average hard coral cover from 28% in 2000 to 33% in 2001 and 41% in 2003 occurred. The three shallow sites showed an increase in hard coral cover from 20% to more than 30% between 2000 and 2001, with a major decline in 2003 to 21%, which was again attributable to the decrease in coral cover at the shallow site at the seaport. All other shallow sites showed an overall increase in hard coral cover across all survey years.

The increase in hard coral cover at 5 of the 6 monitoring sites indicates that most of Socotra Island's coral communities impacted by the bleaching event of 1998 are recovering. The major decline in hard coral cover in the shallow site at the seaport between 2001 and 2003 was probably attributable to the combined effects of two factors; elevated sea surface temperature to over 31°C during May 2001, which was only 1°C less than the sea surface temperature in 1998; and changes in water quality due to anthropogenic pollution resulting from development activities tacking place within the port and the newly constructed road. At the seaport, branching corals, particularly *Acropora*, were a major structural component of the shallow coral community, and were significantly impacted by the recent disturbances. In contrast, massive corals were the dominant hard



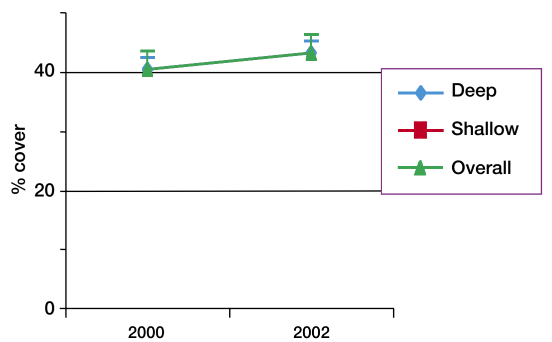




**Figure 1.** Mean percent cover (and s.d.) of hard corals at Socotra during 2000, 2001 and 2003 (left) and the Brothers Islands during 2000 and 2002 (right).

coral growth-forms at most deep sites, and were unaffected.

### Outer Islands

The outer island sites were not impacted during the 1998 bleaching event, and no major changes in hard coral cover have occurred subsequently, although cover did increase slightly, from 40% in 2000 to 43% in 2002 (figure 1b). The Brothers Islands sites did however differ significantly from each other in hard and soft coral cover, with Samha averaging more than 50% cover of hard corals and Darsa about 30%. Differences in cover of branching and tabular *Acropora* and Xeniid soft corals, which are the most common hard and soft coral growth-forms, are primarily responsible for the dissimilarity.

Comparison of coral communities on Socotra and the Brothers Islands in 2000 revealed significant differences in benthic cover, with hard corals and algae contributing most of the dissimilarity between the two island groups. Among the hard corals, branching *Acropora* and massive corals were the major growth-forms responsible for the dissimilarity.

## RECOVERY FROM THE 1998 BLEACHING EVENT

Overall, the coral communities of the Socotra Islands demonstrated strong and consistent recovery from the major bleaching event of 1998, particularly at sites in the Nature Sanctuary protected zones of the Marine Protected Area on Socotra Island and the Brothers Islands, and with the exception of one shallow site at the seaport in the General Use Zone. Coral communities of the port area may require particular management attention.

Monitoring the longer-term ecological trajectories of these coral communities, particularly in relation to their capacity for resilience to climate change, should provide insights both for community ecology and management effectiveness.

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# Kenya – Coral Reef Resilience Studies

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*key words:* Kenya, coral reefs, coral bleaching, coral recruitment, reef resilience, sea surface temperature

## INTRODUCTION

Activities supported by CORDIO in Kenya started in 1999, focusing on a long term coral reef monitoring programme in the Kiunga Marine Reserve to track recovery of reefs from the 1998 El Niño coral bleaching event (Obura, 1999). In addition, a range of biological studies were supported (Obura *et al.*, 2000), including studies on temperature/UV interactions, benthic community structure, coral recruitment and bleaching, coral/zooxanthellae dynamics, macro- and micro-algal community structure and bio-erosion, many of them led by scientists from the Kenya Marine and Fisheries Research Institute. Community-based participatory monitoring activities started in 1997 in the Diani-Chale area of southern Kenya were also added to CORDIO's portfolio, to facilitate raising awareness among resource users of the need for management, and to trial new techniques for generating data on coral reef status where resources and technical staff are limited. See reports in Linden and Sporrong (1999), Souter *et al.* (2000), Linden *et al.* (2002).

At the end of 2004/beginning of 2005, CORDIO activities in Kenya included several long term monitoring initiatives and associated research projects to improve interpretation of the monitoring information. These are being integrated into a more unified structure to research the resilience of Kenya's reef ecosystems in relation to thermal stress and mass bleaching impacts caused by global warming (Obura, 2005). On a regional scale, this approach is being extended through support to studies in Tanzania and Mozambique to undertake a regional vulnerability analysis of coral reefs. Increasing interest is being placed on the concept of resilience in understanding the impacts of climate change and other threats to coral reefs (Nyström & Folke, 2001; McClanahan *et al.*, 2003; Bellwood *et al.*, 2004; Obura, 2005) in an attempt to synthesize existing knowledge on reef ecology and provide recommendations for direct interventions to reduce or reverse the current decline in coral reef health worldwide (Wilkinson, 2004). This report outlines how the various components of CORDIO's coral monitoring and research programme contribute to this overall structure of studying resilience.

## COMPONENTS IN STUDYING RESILIENCE

Table 1 and figure 1 on next pages show a hierarchical structure of low intensity/broad scale methods such as ecological monitoring applied to many sites, combined with increasingly detailed more restricted-locality studies. The components of this structure are described below. The strong basis of ecological monitoring over multiple years and at many sites representative of local habitats is critical for developing a broad foundation of information. More intensive but

**Table 1.** Components of coral reef resilience research integrating CORDIO supported reef monitoring and studies in Kenya

| Component | Objective | Methodology | Status |
|---|---|---|---|
| 1. Ecological Monitoring | To identify long term trends of bleaching vulnerability and recovery. | GCRMN/participatory methods applied by each site/country team, upgraded where possible. | Ongoing in northern Kenya, partial in Mombasa. |
| 2) Sea surface temperature (SST) | To monitor in situ temperature trends relevant to coral bleaching, differences among habitats/zones and ground-truthing of remotely sensed data. | in situ placement of temperature loggers at reef monitoring sites; 1 hourly sampling retrieved after 6–12 months. May be placed at different depths and zones to investigate differences in temperature and coral bleaching. | Mombasa and Kiunga. |
| 3. Coral population structure and bleaching condition | To develop improved indicators of coral population stress and recovery. | Haphazard $1m^2$ quadrats or circles; measurement of size, species and colony condition. For detailed size class distributions use of 50x2 m belt transects; selected species, measure maximum diameter. | Haphazard circles applied in Kiunga (1998 to present), Mombasa (2003 to present). Belt transects to start in 2005. |
| 4. Permanently marked corals | To monitor colony-level bleaching and survival dynamics of key coral species at key sites. | Permanently marked corals using 50 m reference tape, monitoring 2–3 times yearly for growth/condition. | Mombasa (2003 to present), Kiunga (started 2005). |
| 5. Experimental manipulation | To identify causal relationships between temperature, bleaching and mortality for key corals and related organisms. | Known colonies from sections 3 and 4 used for experimental manipulations for bleaching resistance. | To be started in 2005, building on findings in Visram (2004, this volume) |
| 6. Tissue sampling/ zooxanthellae analyses | To monitor zooxanthellae population parameters corresponding to coral organismal measurements. | Tissue analysis for zooxanthellae identification, health assessments, measurement of population parameters, etc. | Ongoing since 1999, to be improved and upgraded (see Visram 2004, this volume) |
| 7. Bleaching resilience | To assess the resilience of individual study sites, sub-regional and regional reef systems to coral bleaching and other threats. | Analysis of results from 1–6 with other regions and studies. Identification of thermal protection, resistance and tolerance, and resilience variables for testing through 1–5. | Outline to be developed in 2005. |
| 8. Graduate study grants | To build capacity in coral reef science and monitoring. | Degree support for graduate students working on components 1–7 above. | Under development, integration with GEF-CRTR scholarship support. |

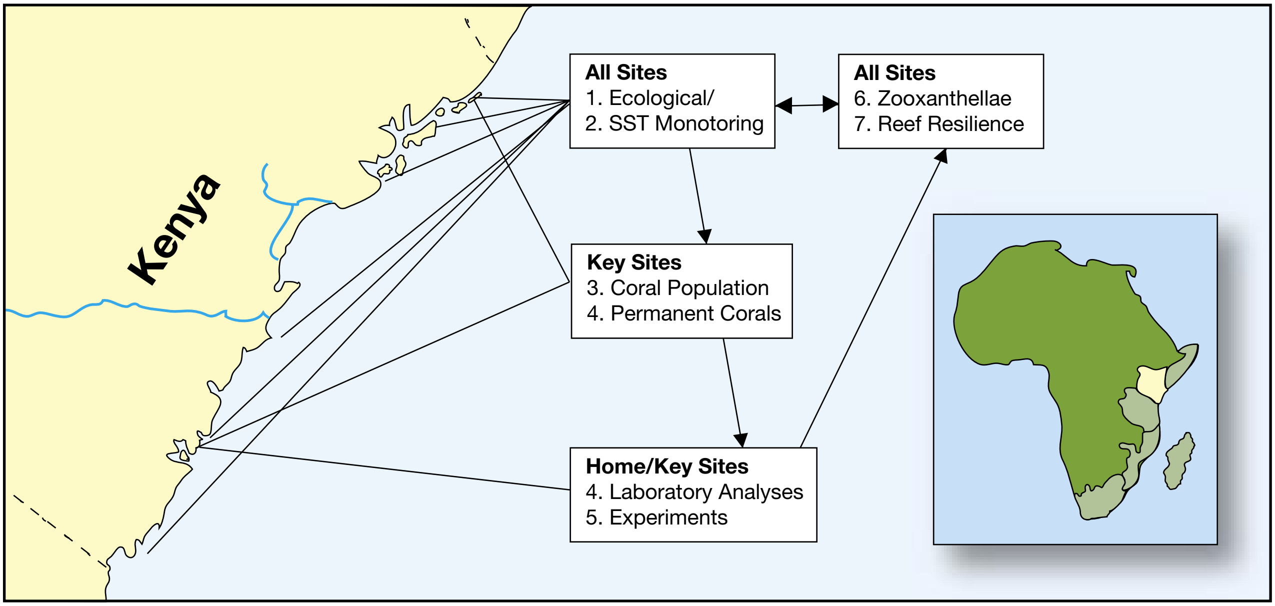


**Figure 1.** Schematic diagram of the hierarchical components of resilience studies of coral reefs in Kenya listed in table 1. Primary study sites are the Kiunga and Mombasa Marine Parks in the north and south, respectively, marked by stars.

localized studies then help to identify cause and effect scenarios, which can be extrapolated to the larger scale through interpretation based on the monitoring programme.

### 1. Ecological Monitoring

In Kenya, CORDIO support to ecological monitoring started by filling the most significant geographical gap in availability of coral reef information by collaborating with Kenya Wildlife Service (KWS) and Worldwide Fund for Nature (WWF) in the Kiunga Marine National Reserve (KMNR) in northern Kenya (Obura, 2002; Obura & Church, 2004; Church & Obura, in press). This initiative started with basic ecological monitoring of benthic cover, invertebrate and fish populations, and has grown to incorporate more variables relevant to coral bleaching and recovery, including many of the resilience research components listed in this report (see later sections). Ecological monitoring is also conducted in the Diani-Chale area on the southern coast of Kenya, though this focuses on participatory techniques with fishers being the primary data collectors, and outputs are targeted towards raising awareness locally.

In 2004, the KWS requested CORDIO to undertake further training of its marine rangers and to assist it in developing its first internal coral reef monitoring programme. Working with the research department and rangers and wardens from a number of marine protected areas (MPAs), a programme and training course were conducted in 2004, and surveys repeated in 2005.

Results of the Kiunga monitoring programme have shown significant recovery of many coral reef sites from the bleaching and mortality of 1998. However, recovery has been patchy, with highest recovery rates on shallow channel and some shallow outer reef sites. The primary findings of the Kiunga coral reef monitoring programme are (Church & Obura, in press; Obura, in review):

- The strong decline (50–80%) and patchy recovery of coral communities following the El Niño of 1998. The marginal nature of KMNR coral reefs is emphasized by the deeper reefs remaining in an algal-dominated phase, probably due to cool nutrient-rich water upwelling directly over the reefs and suppressing coral recruitment and growth while promoting the growth of algae and suspension feeders.

- A strong influence of recruitment-limitation due to the separation distance of ≈150 km from the more extensive reef system of southern Kenya.
- The impact of fishing on fish populations of the KMNR, highest in the south where access by fishing communities outside the reserve is easiest.
- The large impact of stochastic events, including a harmful algal bloom and coral disease in 2002 (Obura, 2002) in addition to the El Niño of 1998. Negative interactions among these and with fishing are likely to increase in severity and/or frequency in coming years and strongly undermine the already low resilience of reefs in the area.

## 2. SST and Climate Monitoring

With the debate on the long term ramifications of warming sea surface temperatures (SST) from global climate change on coral bleaching raging (Hoegh-Guldberg, 1999; Hughes *et al.*, 2003), monitoring SST has become a standard activity of reef monitoring programmes, as well as regular tracking of SST hotspots through alerts and products made available by the National Oceanic and Atmospheric Administration (NOAA). In Kenya, CORDIO has placed *in situ* temperature loggers in the Kiunga Marine Reserve and Mombasa Marine Park (figures 2 & 3). In both areas, loggers have been placed in shallow water (<2 m at mean low water) and on deep reefs at 20–25 m. The continuous record from 2000 to the present at Mombasa indicates that most years have been relatively cool during the local summer maximum in March-April compared with the El Niño year of 1998, except for 2003, when temperatures exceeded those in 1998. Nevertheless, bleaching and mortality of corals in 2003 was less than in 1998 (see later section).

To better interpret temperature-bleaching relationships, and to compare the two bleaching years of 1998 and 2003, meteorological data from the Kenya Meteorological Department, and Pathfinder SST data from NOAA have been compiled. The former dataset includes measures from 1997 to 2003 and will be updated to the present, comprising daily readings of maximum and minimum air temperature, solar radiation, number of sun hours, precipitation, evaporation, wind run, and wind speed and direction and atmospheric pressure at

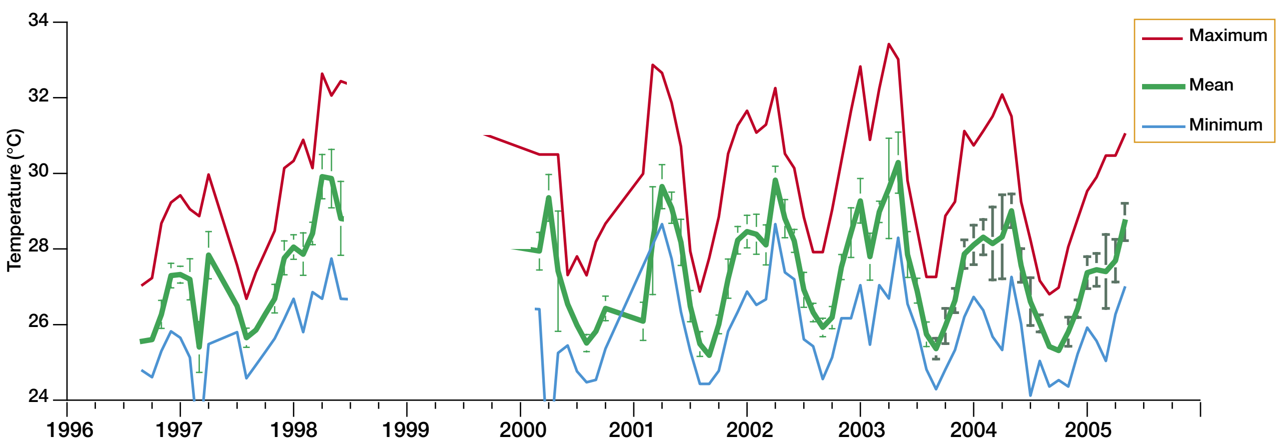


**Figure 2.** Long term sea temperature record for Mombasa Marine Park from 1996 to present, for depth <1 m at MLW. Data shown are monthly mean and standard deviation, minimum, maximum values. A data gap for May 1998–December 1999 was due to a faulty logger.

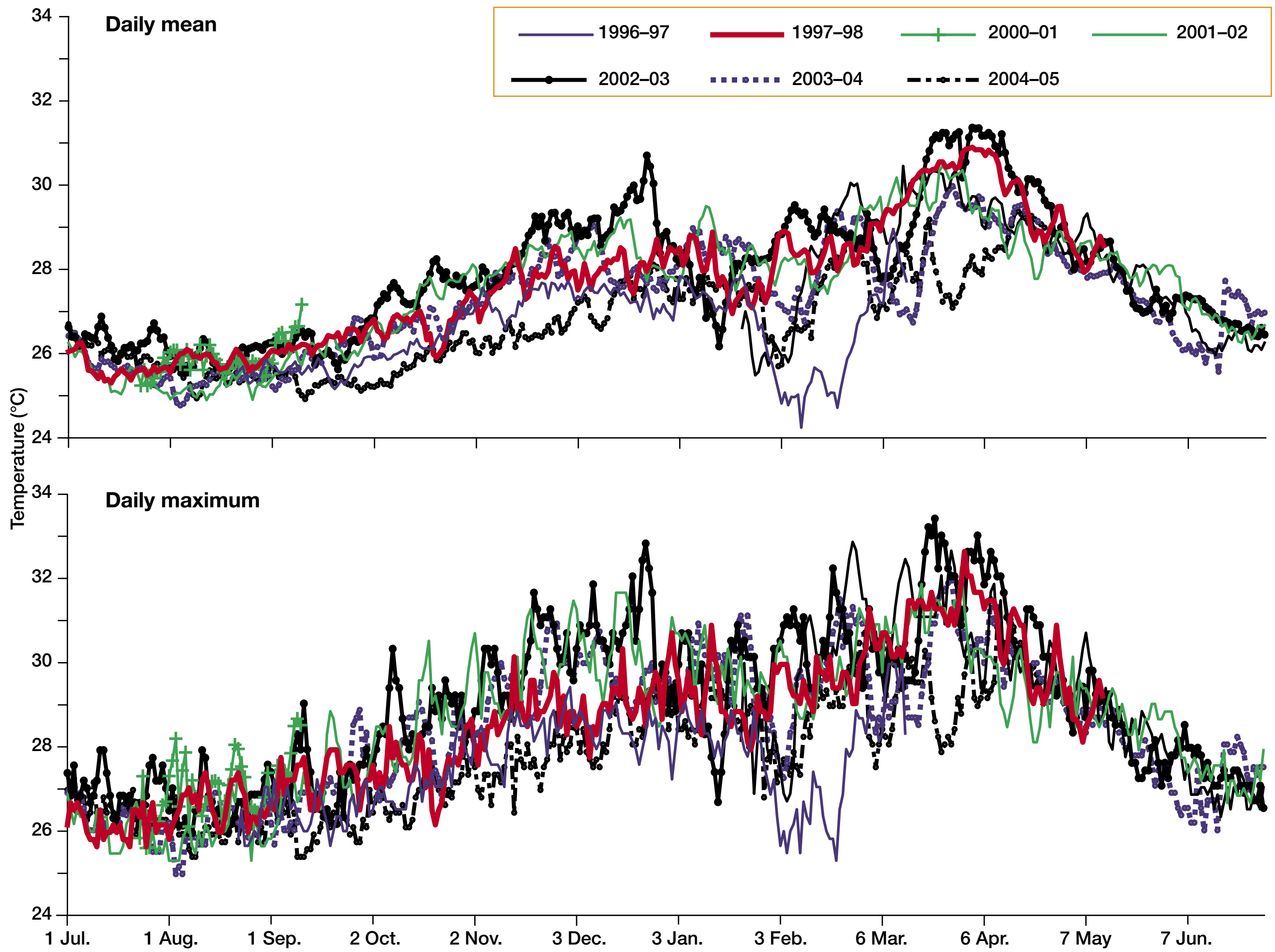


**Figure 3.** Annual daily temperature records (mean and maximum) for Mombasa Marine Park. The annual period is shown from July to June to show the increase in temperature from August to March. Same dataset as presented in figure 2. The dark red line shows the temperature profile for 1997–98 which culminated in mass bleaching and mortality of corals.

9:00 AM and 3:00 PM. Pathfinder SST data from 1991 to 2003 will be used with the *in situ* logger data to investigate local variation in the temperature signal from larger scale hotspot data.

### 3. Coral Recruitment and Size Class Structure

Coral recruitment data collected during the long term monitoring programme in Kiunga has been used to analyze recruitment limitation in this northern region and the possible influence on this of separation from the southern reef system and cooler water from the Somali current system (Obura, in review). The dataset comprises 5 275 coral colony records from 1998–2004, sampled by dropping haphazard 1 $m^2$ circles and documenting all hard corals <10 cm diameter, as well as condition of larger colonies to determine size class structure. Coral recruitment was negligible in 1999 (table 2 on next page), the year following mass bleaching and increased to ≈2

**Table 2.** Summary statistics of recruitment in the Kiunga Marine National Reserve, 1999-2004, showing total area sampled, mean, standard deviation and maximum recruit density ($m^{-2}$) and the average proportion of empty quadrats per site

| Year | Area sampled ($m^2$) | Density ($m^{-2}$) mean | sd | maximum | Empty quadrats (%) |
|---|---|---|---|---|---|
| 1999 | 131 | 0.138 | 0.078 | 2 | 88 |
| 2000 | 162 | 2.219 | 2.422 | 27 | 35 |
| 2001 | 177 | 2.201 | 2.395 | 18 | 37 |
| 2002 | 188 | 1.007 | 0.618 | 8 | 52 |
| 2004 | 45 | 1.574 | 1.507 | 15 | 30 |

*Source:* Obura (in review)

**Table 3.** Permanently marked corals at two sites in the Mombasa Marine National Park, showing the number of colonies in 2003 and 2005, and the proportion of pale, bleached and dead colonies at selected times during the bleaching event of 2003

| | Nyali | | | Mombasa | | | No. of colonies | |
|---|---|---|---|---|---|---|---|---|
| | May-03 | | Aug-03 | May-03 | | Aug-03 | 2003 | 2005 |
| Genus | pale | bleach | dead | pale | bleach | dead | | |
| *Pocillopora* | 19 | 47 | 18 | 6 | 68 | 37 | 81 | 133 |
| *Favia* | 10 | 0 | 0 | 17 | 2 | 4 | 80 | 121 |
| *Porites* | 18 | 6 | 1 | 6 | 2 | 0 | 90 | 107 |
| *Favites* | 15 | 0 | 0 | 16 | 0 | 0 | 62 | 101 |
| *Platygyra* | 4 | 1 | 4 | 3 | 0 | 0 | 54 | 83 |
| *Pavona* | 4 | 7 | 13 | 0 | 0 | 25 | 46 | 61 |
| *Galaxea* | 17 | 4 | 12 | 27 | 0 | 6 | 43 | 55 |
| *Hydnophora* | 20 | 0 | 7 | 26 | 0 | 8 | 26 | 39 |
| *Echinopora* | 24 | 7 | 5 | 49 | 0 | 20 | 26 | 36 |
| *Acropora* | 5 | 0 | 11 | 0 | 0 | 83 | 18 | 33 |
| *Astreopora* | 8 | 0 | 26 | | | | 10 | 19 |
| *Montipora* | 9 | 30 | 17 | 18 | 9 | 26 | 18 | 19 |
| *Goniopora* | | | | 21 | 0 | 0 | 9 | 16 |
| *Goniastrea* | | | | | | | | 16 |
| *Cyphastrea* | | | | | | | | 11 |
| *Leptoria* | | | | | | | | 10 |
| Other | 19 | 14 | 0 | 14 | 10 | 8 | 48 | 30 |
| Overall | 14 | 11 | 8 | 14 | 9 | 9 | 611 | 890 |

$m^{-2}$ in 2000 and 2001 before declining slightly to 1–1.5 $m^{-2}$ in 2002-2004. These rates are at the lower end of measurements of coral recruitment in 1992–1994 on reefs in Malindi and Watamu in southern Kenya, which varied from 0.52 to 4.40 $m^{-2}$ (Obura, 1995). Conclusions from this study included (Obura in review):

- Reefs in the area are recruitment-limited, in quantity and diversity, due to the dispersal barrier of ≈ 150 km of non-reef environments separating them from the East African fringing reef systems of southern Kenya and the East African Marine Ecoregion.

- Recruitment limitation appears stronger for some genera previously dominant in the area, such as *Acropora*, such that other genera showing more successful recruitment, such as *Coscinaraea*, may become more prominent in the near future.
- Upwelling of cool nutrient-rich waters may reduce coral survival in the KMNR compared with warmer oligotrophic conditions farther south, and particularly on deep reefs directly in the flow of tidal and seasonal upwelling currents.
- The above factors are facets of the marginal nature of the reefs, at the transition between warm and cool water environments, making them more vulnerable to large scale threats such as climate change, by reducing their capacity for recovery.

## 4. Individually Marked Coral Colonies

Widespread but moderate bleaching was documented in 2003 in Kenya and Tanzania, but mortality was low compared with 1998 (Obura, 2005). Permanently marked colonies were established at two nearby sites in the Mombasa Marine Park in early 2003 to track the fate of individual colonies during bleaching events, and to investigate species-specific responses to bleaching. The number of colonies marked in 2003, and following addition of further colonies in 2005, were 611 and 890 respectively (table 3), covering some 26 genera in 2005. For the genera with reasonable sample sizes (>10 colonies in 2003), table 3 shows that paling was noted for all genera in May 2003, except for *Acropora* colonies at the Coral Gardens site. Full bleaching was only significant for *Pocillopora* and *Montipora* at 47/68% and 9/30% respectively, with small amounts <10% in *Porites*, *Pavona*, *Galaxea*, *Echinopora* and *Favia*. Mortality varied, with some genera showing high levels >20% (*Astreopora*, *Echinopora*, *Montipora*, *Pocillopora*) and a maximum of 83% for *Acropora* at the Coral Gardens. Overall bleaching and mortality levels varied around 10%.

Inter- and intra-specific differences in bleaching patterns were analyzed briefly in Obura (2005) for *Pocillopora* spp. Of three abundant species with high levels of sampling, *Pocillopora eydouxi* showed the highest levels of bleaching and *P. damicornis* showed lowest levels of bleaching, but both suffered similar mortality rates (figure 4).

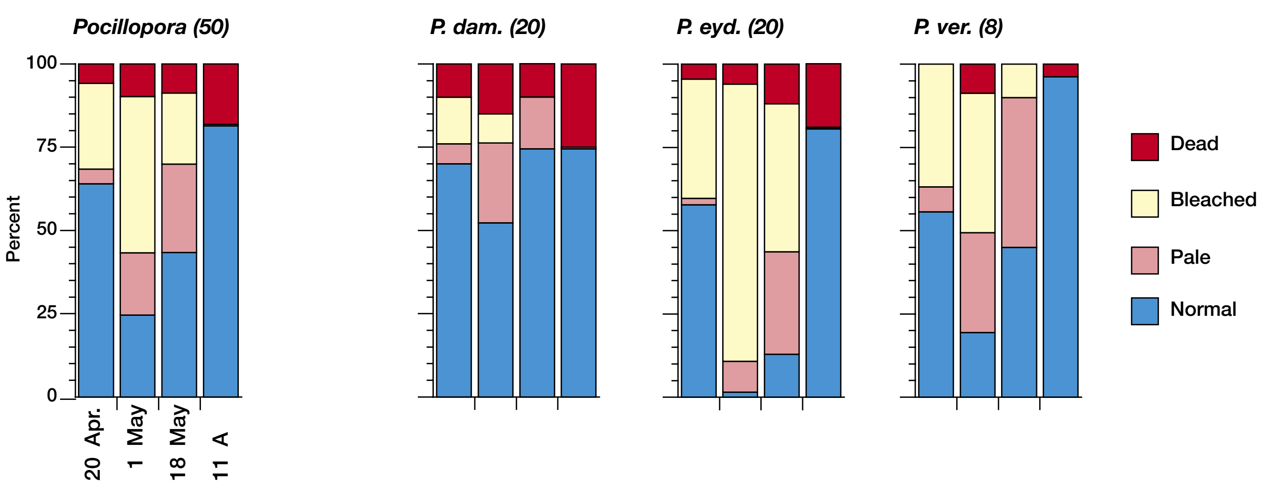


**Figure 4.** Differences in bleaching resistance between *Pocillopora damicornis*, *P. eydouxi* and *P. verrucosa* at Nyali Reef, Mombasa, April–August 2003. The y-axis shows the percentage of colonies showing normal, pale and bleached condition, and mortality.

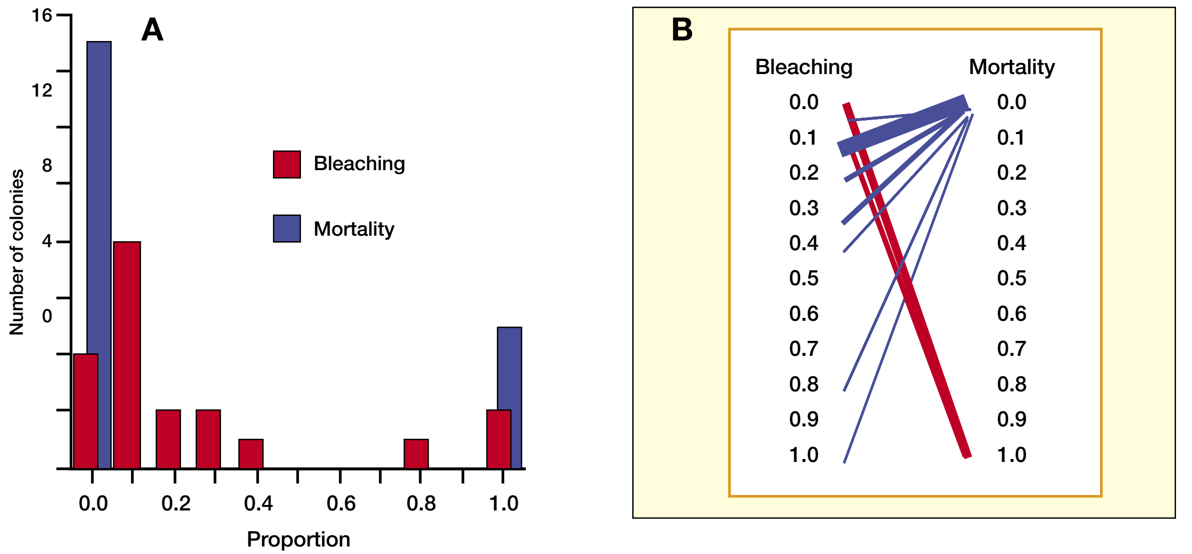


**Figure 5.** Maximum levels of bleaching and mortality of individual colonies of *Pocillopora damicornis* in Mombasa Marine National Park in 2003 (from figure 4). Bleaching was noted shortly after 20 April, 2003, and observations were recorded on 1 and 18 May, and after all bleaching had ceased on 11 August 2003. Maximum bleaching was generally recorded around 1 May 2003, and maximum mortality was recorded on 11 August 2003. Left – frequency distribution of maximum bleaching and mortality (proportion from 0 to 1) for each colony; b) pairwise comparison of maximum bleaching (May) and mortality (August) by colony. Spearman's rank correlation of maximum bleaching and mortality R = –0.516, p = <0.05. Data and figures adapted from Obura (2005).

*P. verrucosa* showed intermediate levels of bleaching, but lower mortality rates. Intra-specific variation in coral bleaching and mortality were shown in *P. damicornis.* In this species, bleaching reached an average of 21% by 18 May, varying between zero and 100% among individual colonies, and declined to zero on 11 August. Mortality of *P. damicornis* increased to an average of 25% by August, composed of colonies that recovered fully (blue lines, figure 5) and those that died (red lines). Maximum bleaching and mortality levels shown by a colony were inversely related (Spearman's coefficient of rank correlation, R = –0.516, p <0.05): all colonies that underwent bleaching levels ≥20% showed full recovery, and all colonies (n=3) that were recorded with zero bleaching in May suffered 100% mortality by August. Two colonies were already dead by the first survey of 1 May, so it is not known if they bleached between 20 April and the beginning of May, or died without having bleached. This result suggests that under mild conditions, bleaching protected the *P. damicornis* colonies from greater stress caused by high temperatures, as those that did not bleach died.

### 5. Experimental Manipulations

These have not yet been implemented as an integral part of CORDIO studies, but will be built up from the findings reported in Visram (2004). See Visram (this volume) for the first experiments in researching the recovery of zooxanthellae populations in bleached corals.

### 6. Tissue Samples/Zooxanthellae

Developed as a KMFRI-CORDIO project in 1999, monitoring of zooxanthellae populations (density, degradation/division indices) in 12 species of corals has continued to date (table 4). This baseline data will be used to

**Table 4.** Coral species being monitored for seasonal/annual variation in zooxanthellae population structure, Mombasa Marine Park

| Coral species |
|---|
| *Acropora* sp. |
| *Astreopora myriophthalma* |
| *Echinopora gemmacea* |
| *Favia* sp. |
| *Favites pentagona* |
| *Fungia* sp. |
| *Galaxea fascicularis* |
| *Goniopora* sp. |
| *Hydnophora microconos* |
| *Montipora spongodes* |
| *Pavona decussata* |
| *Platygyra daedalea* |
| *Pocillopora damicornis* |
| *Porites cylindrica* |

interpret changes in zooxanthellae densities and other variables during a bleaching event. During 2002–2004, a PhD study on zooxanthellae diversity and recovery of zooxanthellae populations in bleached *Porites cylindrica* colonies was completed (Visram, 2004; see also Visram, this volume)

## 7. Resilience

As a foundation for studying patterns of resilience at local to regional scales, taxonomy and species identification play a critical role. The East African scleractinian coral fauna has not been revised since work in the 1970s (Hamilton & Brakel, 1984) with the result that species occurrences and distributions are poorly known, and the region shows a relatively low diversity in ocean-scale and global assessments (Veron, 2000). Significant effort from 2002–2005 has been put into compiling an updated species list showing relative abundance and distributions along the mainland coast of East Africa. Primary survey sites have included Kiunga (northern Kenya); southern Kenya; Mtwara, Songo Songo and Mnazi Bay (central and southern Tanzania); and Pemba (northern Mozambique). While numbers are preliminary, species diversity of corals is highest in northern Mozambique and southern Tanzania, with over 270 species recorded within sites covering approximately 10 km of coastline. Diversity of corals declines northwards into Kenya, and is lowest in Kiunga, with some 200 species. A preliminary assessment of distribution patterns shows affinities with both the main Indo-Pacific and the Gulf of Aden/Red Sea scleractinian faunae. Regional endemics such as *Horastrea indica*, *Gyrosmilia interrupta* and *Anomastrea irregularis* are present but in restricted marginal environments. Differential susceptibility of coral taxa to the mass bleaching and mortality of 1998 has impacted regional distribution patterns, such as in restricting the distribution of *Acropora* species to core areas in southern Tanzania–northern Mozambique and their near-elimination from peripheral areas in northern Kenya.

Consideration of other aspects of resilience will be built up to improve on the basic analysis conducted for East Africa by Obura and Mangubhai (2003) based on survey questionnaire responses. The findings of that study were that depth and steep reef slopes were associated with low bleaching, likely due to thermal protection afforded by proximity to cool water. However, a variety of other factors expected to do the same, such as high levels of temperature fluctuations, high levels of turbidity, and a robust reef community (Salm *et al.*, 2001; West & Salm, 2003) did not. The analysis needs to be improved through more rigorous quantification of factor levels and coordinated data collection in separate places, which will be attempted through aligning CORDIO's Kenya programme with collaborating projects (see below).

## 8. Graduate Studies Support

Many of the staff and researchers that have implemented CORDIO projects have moved onto further studies both directly and indirectly facilitated and supported by their work with CORDIO. In the case of the coral reef resilience studies, the following degrees are underway or have been completed:

- PhD, UK – completed, study on zooxanthellae recovery and resilience patterns with CORDIO as the local institutional host (Visram, 2004);
- Masters, Kenya/Sweden sandwich programme – in progress, to focus on coral recruitment;
- Masters, Belgium – tentative, to focus on ecological monitoring and the use of information in marine management and policy development

## DISCUSSION

The component studies described above will be integrated into an analysis of the resilience of coral reefs in Kenya. This will enable the ecological monitoring programmes to go beyond documenting impacts that have already happened to projecting scenarios for recovery or further degradation, and provide proactive advice to managers. On the scientific and capacity building side, the wide range of linked studies will deepen the capacity for coral reef research within the national research community, and promote higher standards through cooperation and collaboration, as well as competition.

The study of resilience is made difficult by the generality of the term and that it can be applied to any different component or threat of ecological systems (e.g. fishery impacts and pollution, see McClanahan *et al.*, 2003). With respect to coral bleaching and climate change West and Salm (2003) provide the beginnings of a mechanistic framework, while Nyström and colleagues (Nyström & Folke, 2001, Bengtsson *et al.*, 2003, Elmqvist *et al.*, 2003) provide the concepts of functional redundancy and response diversity to help organize thinking on resilience as it relates to thermal stress and coral bleaching (Obura, 2005). Putting these together, continuing function of coral reefs will depend on the diversity of corals showing broadly similar responses to bleaching (e.g. fast growing branching corals that are vulnerable to bleaching vs. slow-growing massive corals that are resistant; Obura, 2001), the ecological roles they play, and the diversity of their responses to other threats. For example, if encrusting, massive and small corals that are more resistant to coral bleaching come to predominate in the Kiunga Marine Reserve, then the provision of habitat for some fishes, and the rate of reef accretion will be low, and reef structures and resilience may decline over the years. Additionally, if these bleaching-resistant corals do not show a diversity of responses to other threats, such as pollution, bleaching-impacted reefs will show even lower capabilities to resist these other threats.

Resilience studies necessarily need to be conducted and interpreted over multiple areas and spatial scales as individual sites may show unique characteristics and behaviours. Thus, the work in Kenya described here will be expanded to include sites in Tanzania and Mozambique through collaboration with CORDIO's partners there, and through new initiatives, listed below. Additionally, networking and international collaborations will be used to assess results from East Africa with other areas in the Indian Ocean and globally.

The multiple levels of monitoring and research identified here are consistent with the following programmes:

- Work under the Bleaching Working Group of the GEF/World Bank Coral Reef Targeted Research Project (GEF-CRTR) similarly will investigate coral bleaching dynamics from molecular to ecological levels, though with a greater focus on sub-organismal levels. Through the Bleaching Working group, the work described above will contribute to the GEF-CRTR and be compared with results from the Great Barrier Reef, Mexican Caribbean and the Philippines.
- A Climate Vulnerability study coordinated by WWF and funded by the GEF, for 2005–2007 will include the Mafia-Rufiji region as a study site, in which CORDIO will implement a subset of the methods described here to determine the vulnerability of coral reefs in the region to climate change. This will be done in collaboration with Tanzanian partners, with a view to replicating this work at other sites in Tanzania and Mozambique.
- CORDIO has been a lead participant in promoting the establishment of a scientific working group hosted

by IUCN to bring together scientists interested in coral reef resilience and climate change issues. This aligns with the establishment of a management-oriented network, the *Resilience Alliance* spearheaded by The Nature Conservancy and its R2 toolkit (TNC, 2004).

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# Status of Coral Reefs in Tanzania

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*key words:* Tanzania, coral reefs, coral bleaching, coral recruitment, fish communities, community monitoring

## ABSTRACT

In Tanzania, there has been considerable recovery of coral reefs since the 1998 bleaching event, despite the occurrence of a minor coral bleaching episode in April 2003. The live coral cover on Unguja (Zanzibar), Tanga, Dar es Salaam, Songo Songo, and Mtwara reefs was medium (20–35%) to good (35–55%). However, at sites that suffered severe mortality (70–80% mortality) as a result of the 1998 bleaching event and where macro-algal abundance is high (e.g. Kitutia, Mafia) recovery has been very slow. Recent studies have indicated a slight change in coral species composition and an increase in settlement and recruitment rates in 2003 compared with 2001. The density of reef fish has shown a slight decline in unprotected areas and a slight increase in protected areas (e.g., Mafia Island Marine Park and Chumbe Island Marine Sanctuary). Similarly, increases in the proportion of herbivores comprising reef fish communities have been observed in some Unguja reefs. Changes in the density of macro-invertebrates have varied between sites over the past five years depending on exploitation levels and recruitment success. For example, at Pemba they have increased, while at Mafia fewer macro-invertebrates were observed. The use of destructive fishing practices, overexploitaion, sedimentation and pollution are the main anthropogenic threats to coral reefs in Tanzania. Algal competition and, to a lesser extent, crown-of-thorns starfish predation (in Unguja) also contributed to slow recovery of coral reefs. Environmental education, community resource monitoring programmes and the establishment of more marine protected areas are some of the efforts taken to enhance sustainable coral reef exploitation.

## INTRODUCTION

Coral reefs occur along almost the entire 800 km coastline of Tanzania's mainland. The coast has a number of indentations in areas of high fresh water influence such as the Rufiji and Pangani River mouths. These result in two main reef types:

- shallow patch- and fringing reefs on the small islets and sand banks in inshore waters sheltered by the islands of Pemba, Unguja (Zanzibar), Mafia and the river systems;
- the exposed reef systems on the eastern ocean-facing shores of the main islands and southern mainland coast.

Because virtually all coastal communities are engaged in fishing and depend completely on artisanal fishing in coral reef areas, the health of coral reefs is crucial not only for biological and ecological processes but also for socio-economic well-being of the coastal communities.

## BENTHIC COMMUNITIES

The coral reefs of Mafia and Pemba Islands were amongst the worst affected by the 1998 coral bleaching event (Mohammed *et al.*, 2002). Two sites on Misali Island suffered a decline in coral cover from 74% to 17% and 51% to 7%, while coral cover at sites on Mafia Island decreased from 80% to 15%. The reefs most affected at the two islands were those close to greater depths, i.e. Misali Island reefs at Pemba and Tutia Reef at Mafia Island Marine Park. The severity of the damage was more pronounced on shallow areas (e.g. reef flats) and decreased in deeper water (Mohammed and Machano, pers. obs.). On reefs without any deep zones, such as Tutia Reef at Mafia, the damage was uniform throughout the reef (Mohammed *et al.*, 2002).

In general, coral reef recovery has been good in areas that experienced mild bleaching and low coral mortality in 1998. At present, live coral cover ranges from 20–35% in Unguja (Zanzibar), Tanga, Dar es Salaam, Songo Songo, and Mtwara, to higher levels of 35–55%. A minor bleaching episode occurred in April 2003, and increases in crown-of-thorns starfish (COTS, *Acanthaster planci*) densities have, however, had a negative impact on hard coral recovery. There are reports of significant coral mortality due to COTS on reefs off Zanzibar town and Dar es Salaam (Muhando, pers. obs.). The report also details mortality of corals belonging to the family Acroporidae and a significant reduction in the number of recruits, notably in the genera *Acropora* and *Pocillopora*.

Recovery has been very slow in sites that were severely hit by the 1998 bleaching event. There are signs that show recovery has been faster at deeper sites compared with shallow areas in Misali, Pemba (Mohammed & Jiddawi, 2001), where growth of fast growing benthos, such as macro-algae and soft corals, has been slower. Recovery at Tutia Reef, Mafia Island, was likely to have been affected by the high cover of macro-algae (44.9% ±15.5 SD) which may reduce settlement of hard coral spat and suppress coral growth (Mohammed & Machano, 2001). Tutia Reef appears to be in a transition phase and if present conditions persist, we may witness a shift from coral dominated community to one dominated by fleshy algae.

### Coral Recruitment

At Mafia, the density of coral recruits was higher at Tutia Reef than at Utumbi Reef, despite the high cover of macro-algae (table 1) and both reefs exhibited greater coral recruitment in 2003 than in 2001. The density of acroporid and pocilloporid recruits was greater on the upper reef slopes (61.3 per 100 $m^2$ and 99.7 per 100 $m^2$) than on lower reef slopes (20.6 per 100 $m^2$ and 35.9 per 100 $m^2$). However, the density of poritid recruits and those belonging to other families was not significantly different between upper and lower slopes or between sites.

## FISH COMMUNITIES

Coral reef fish communities in the study sites are typical of shallow reefs, with the most common fish families being the Pomacentridae, Scaridae, Labridae and Acanthuridae. These families contribute more than three quarters of total fish population (Machano, 2003). Pomacentrids are by far the most common (Machano, 2003). The den-

**Table 1.** Density of coral recruits at sites sampled in Mafia Island Marine Park, 2003 (number per 100 $m^2$)

| | Kitutia | | | | Utumbi | | | | Miliman | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Acroporidae | Pocilloporidae | Poritidae | Others | Acroporidae | Pocilloporidae | Poritidae | Others | Acroporidae | Pocilloporidae | Poritidae | Others |
| Mean | 40.94 | 67.81 | 6.09 | 46.41 | 35.38 | 53.75 | 8.00 | 40.75 | 15.00 | 17.81 | 2.19 | 31.09 |
| n | 16.00 | 16.00 | 16.00 | 16.00 | 20.00 | 20.00 | 20.00 | 20.00 | 16.00 | 16.00 | 16.00 | 16.00 |
| SD | 26.58 | 65.08 | 7.90 | 35.46 | 20.00 | 20.06 | 6.72 | 23.38 | 15.08 | 6.94 | 3.01 | 18.28 |
| SE | 6.65 | 16.27 | 1.98 | 8.87 | 4.47 | 4.48 | 1.50 | 5.23 | 3.77 | 1.74 | 0.75 | 4.57 |

**Table 2.** Species richness and relative diversity index (J') for Utumbi and Tutia Reefs, Mafia Island Marine Park

| Site | Species per transect Mean ( ± SE) | Relative diversity (evenness, J') |
|---|---|---|
| Utumbi | 46 ± 2.13 | |
| Kitutia | 33 ± 3.87 | 0.412 |

sity of reef fish declined slightly in unprotected areas and increased slightly in protected areas (Mafia Island Marine Park, Chumbe Island Marine Sanctuary). The proportion of herbivores comprising reef fish communities has increased on some Unguja reefs.

Mafia reefs are known to have higher abundance and diversity of fish, with almost 400 species recorded in the shallow reefs areas (<10m depth, Garpe & Ohman, 2003). Reefs within Mafia Island Marine Park that do not receive full protection from fishing have fish abundance and diversity similar to fully protected reefs such as Kisite in Kenya, and Chumbe Sanctuary, Zanzibar (Machano, 2003). Comparing Utumbi and Tutia Reefs (table 2), the former has a slightly higher abundance of fish (<10% higher), and significantly higher diversity (p<0.001). The trophic structure of fish communities was similar for the two reefs, except for corallivores and spongivores, which were more abundant at Utumbi

Between 1999 and 2003, there has been increase in total fish density at the Mafia sites, which is statistically significant for the families Chaetodontidae, Scaridae, Serranidae and Zanclidae at Utumbi (Kruskall Wallis test, p<0.05). The Lethrinidae was the only family that exhibited a decrease in abundance. At Tutia Reef, an increase was noted in the Haemulidae (table 3). Overall fish communities at Utumbi have increased more than

**Table 3.** Kruskall Wallis test comparing the densities of each fish family at Tutia and Utumbi Reefs, Mafia Island Marine Park, between 1999, 2001 and 2003

| | Kitutia | | | | | | | Utumbi | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Median* | | | *Mean Rank* | | | | *Median* | | | *Mean Rank* | | | |
| **Family** | **1999** | **2001** | **2003** | **1999** | **2001** | **2003** | **p-value** | **1999** | **2001** | **2003** | **1999** | **2001** | **2003** | **p-value** |
| Acanthuridae | 73.0 | 42.0 | 32.0 | 14.3 | 9.5 | 7.1 | <0.05 | 36.0 | 28.0 | 38.0 | 9.0 | 7.3 | 9.5 | n.s. |
| Balistidae | 0.0 | 0.0 | 0.0 | 8.5 | 8.5 | 10.3 | n.s. | 1.0 | 1.0 | 3.0 | 7.1 | 8.3 | 9.9 | n.s. |
| Chaetodontidae | 17.0 | 10.0 | 13.5 | 10.8 | 6.3 | 9.8 | n.s. | 11.5 | 12.0 | 32.5 | 3.6 | 4.5 | 12.5 | <0.001 |
| Haemulidae | 0.0 | 0.0 | 6.5 | 5.5 | 6.7 | 12.4 | <0.05 | 0.0 | 0.0 | 0.0 | 8.0 | 8.0 | 9.7 | n.s. |
| Kyphosidae | 0.0 | 0.0 | 0.0 | 11.8 | 8.0 | 8.8 | n.s. | 1.0 | 0.0 | 2.0 | 9.0 | 4.1 | 10.4 | n.s. |
| Labridae | 2.0 | 0.0 | 3.5 | 8.7 | 7.3 | 10.6 | n.s. | 1.0 | 0.0 | 2.0 | 9.0 | 4.0 | 10.5 | n.s. |
| Lethrinidae | 9.0 | 3.0 | 11.0 | 7.8 | 8.5 | 10.6 | n.s. | 2.0 | 0.0 | 1.0 | 10.6 | 3.5 | 10.0 | <0.1 |
| Lutjanidae | 7.0 | 1.0 | 3.0 | 9.3 | 7.0 | 10.5 | n.s. | 0.0 | 0.0 | 1.0 | 5.5 | 8.6 | 10.5 | n.s. |
| Mulidae | 7.0 | 1.0 | 7.2 | 10.9 | 6.5 | 9.7 | n.s. | 1.0 | 6.0 | 3.0 | 6.7 | 12.6 | 8.8 | n.s. |
| Nemipteridae | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | n.s. | 0.0 | 0.0 | 0.0 | 7.5 | 7.5 | 10.0 | n.s. |
| Pomacanthidae | 1.0 | 1.0 | 1.0 | 10.5 | 7.8 | 9.5 | n.s. | 3.0 | 5.0 | 14.0 | 4.5 | 4.3 | 12.2 | <0.01 |
| Scaridae | 36.0 | 44.0 | 36.0 | 9.2 | 11.0 | 9.2 | n.s. | 24.0 | 103.0 | 44.0 | 4.4 | 14.0 | 9.4 | <0.05 |
| Serranidae | 0.0 | 1.0 | 0.0 | 6.5 | 12.7 | 10.0 | n.s. | 1.0 | 5.0 | 1.0 | 7.4 | 15.2 | 7.8 | <0.05 |
| Siganidae | 0.0 | 0.0 | 0.0 | 10.6 | 7.0 | 9.7 | n.s. | 0.0 | 0.0 | 0.0 | 8.0 | 8.0 | 9.7 | n.s. |
| Zanclidae | 1.0 | 1.0 | 0.0 | 11.5 | 12.3 | 7.6 | n.s. | 0.0 | 0.0 | 2.5 | 6.4 | 5.0 | 11.2 | <0.05 |
| Grand total | 157.0 | 105.0 | 177.0 | 9.6 | 6.0 | 10.5 | n.s. | 81.5 | 158.0 | 153.5 | 3.0 | 11.0 | 10.8 | <0.05 |

*Source:* Machano 2003

those at Kitutia, reflecting the lesser impacts of coral bleaching at Utumbi in 1998.

The observed changes in the density of each family over the study periods and later in trophic groups are indicative of changing community, which might reflect the changing coral reef community in Kitutia but not in Utumbi. Therefore, the changes can be seasonal and temporary, caused by input of new juvenile fishes in the site, or it can be a response to fishing pressure.

## INVERTEBRATES

Changes in the density of macro-invertebrates have varied between sites over the past five years depending on exploitation levels and recruitment success. For example, at Pemba they have increased, while at Mafia fewer macro-invertebrates were observed. Changes in invertebrate abundance were not consistent between areas that suffered most in the 1998 bleaching event. Misali Island, Pemba, showed an increase in density of all invertebrates surveyed (i.e. sea urchins, COTS, giant clams, sea cucumbers, gastropods and other bivalves of commercial importance) (table 4). Though not sighted in study plots, two COTS were seen in Misali Island in 2001.

At Mafia Island Marine Park (MIMP), the macro-invertebrate densities were surprisingly low compared with many reef areas in Unguja and Pemba (Mohammed & Machano, 2001) The main contributors to macro-invertebrates in Unguja and Pemba were sea urchins, clams, sea cucumbers and starfish. These organisms, though common, occurred in relatively low densities in MIMP. The densities of lobsters and large gastropods, invertebrates with considerable economic values, were very low. It is not clear whether this is due to overexploitation or due to natural causes (e.g. habitat suitability). Only one COTS was observed in Milimani. Similarly, no COTS were observed in Kitutia and Utumbi in previous studies.

High numbers of COTS were observed on Changuu, Bawe and Chumbe (west coast of Unguja) in early 2003 and 2004, and on Utalimani (part of Misali Island Marine Protected Area) in early 2004 (Tyler; Muhando and Daniels, pers. obs.), representing a significant increase over previous records when no COTS have been observed at these locations.

From surveys around Unguja in 2002/2003, the density of sea urchins seems to be an indicator of fishing pressure; those sites either unmanaged or known to be heavily fished have higher urchin densities. The density of sea urchins was 5.31 individuals·m$^{-2}$ at Kichwani, Mnemba Atoll compared with only 0.04 and 0.16 individuals·m$^{-2}$ for sites in Menai Bay Conservation Area and Chumbe Island Coral Park respectively (Tyler, unpublished).

**Table 4.** Mean density of macro-invertebrates (in 50 m x 2 m transects) at different localities

| Invertebrates | Misali Island, Pemba | | Mafia Island Marine Park | | Zanzibar |
|---|---|---|---|---|---|
| | 1999 | 2001 | 1999 | 2003 | 1999 |
| Sea urchins | 55 | 83 | 1 | 3 | 105 |
| Giant clams | 6 | 8 | 1 | 3 | 2 |
| Gastropods | 0 | 1 | 0 | 1 | 0 |
| Bivalves | – | 1 | – | – | – |
| COTS | 0 | 0 | | 0 | 0 |
| Starfish | 0 | 2 | 2 | 4 | 1 |
| Nudibranchs | – | 2 | – | – | – |
| Lobsters | 0 | 0 | 0 | 1 | 0 |
| Sea cucumbers | 2 | 5 | 0 | 0 | 3 |

## THREATS

Coral reefs in Tanzania are facing a number of threats; reports of coral bleaching in early 2003 caused by sea temperature increases has affected a number of reefs in the west and northern parts of Zanzibar and along the southern coast of the Tanzanian mainland. The bleaching was mild and no significant coral mortality has been reported. However, Harris *et al.* (2003) reported coral bleaching in some reefs of northern part off Unguja Island. There are no reports of bleaching from the northern part of the country.

COTS outbreaks have been reported from different parts of the country. The extent of these outbreaks has not been established but significant mortality among acroporids has been observed on the some parts of Bawe Reef (Muhando, pers. obs.). It is not clear weather the observed coral mortality is the result of bleaching alone, COTS or a combination of both. Further investigation is required.

## FISHING ACTIVITIES

The main fishing gears used in Tanzania are handlines, basket traps, scoop nets and surround nets. Destructive fishing gears, dynamite fishing, poisons, drag nets and small mesh nets (below 2 inches) are illegal. However, the use of some illegal fishing gears, such as drag nets in coral reef areas, still occurs widely and is a major threat to the well being of coral reefs in the country. In January 2004, 17 dynamite blasts were heard in only 18 hours of diving at Pemba (Tyler, pers. obs.), though this destructive and indiscriminate form of fishing has since been brought under control.

## TOURISM

Tourism is the major contributor to the economy in Unguja (Zanzibar) and is becoming increasingly important in Pemba and Mafia. The tourism industry increases the demand for fish and can have direct impacts on coral reefs through diving, snorkeling and anchoring of boats. Coral damage caused by anchoring and inexperienced divers can be observed in some places. Selling of shells collected from coral reefs as souvenirs is widely practiced. Giant tritons (*Charonia tritonis*), a major COTS predator, are highly valued in the curio trade and they have become very rare on Tanzanian reefs.

## EFFORTS

The well-being of coral reefs is becoming an important issue at different levels in Tanzania. Awareness and environmental consciousness are increasing not only on a national level but even at the village level. A few years ago, villagers were a major obstacle in establishing MPAs. The situation has now reversed, as communities are taking a leading role in initiating the establishment of MPAs, with a supportive role played by the Government. Zanzibar has been an exemplary place in this context where Menai Bay and Mnemba Island Conservation Areas have been initiated in this way. There are also informal reef closures in some villages. All these are signs of increasing environmental awareness amongst community members. Establishment of MPAs is an important tool in coral reef protection and contributes to the efforts taken to enhance sustainable coral reef exploitation. The MPAs that have been legally gazetted or proposed in Tanzania are listed in table 5 on next page.

Community resource monitoring programmes are good tools in raising awareness and morale on conservation issues. Community coral reef monitoring in Tanzania has been established for many years in some places, such as the Tanga Coastal Zone Development Programe where village teams are involved in regular coral reef monitoring. More places are now engaged in participatory resource monitoring. Recently, Menai Bay Conservation Area in Zanzibar has trained fishermen in coral reef monitoring procedures. Mnemba Island Conservation Area has initiated a community based patrol programme to enforce conservation regulations, with respect to both fishermen and tourists.

School environmental education programmes are

**Table 5.** Marine Protected Areas in Tanzania

| Location | Status | Name | Notes |
|---|---|---|---|
| Dar-es-Salaam reserves | Established 1975 | 1. Mbudya Marine Reserve<br>2. Bongoyo Marine Reserve<br>3. Pangavini Marine Reserve<br>4. Fungu Yasini Marine reserve | Paper Reserves (not effectively managed). Part of the Kunduchi Marine Conservation area. Frequently visited by tourists. Sites could recover if properly managed. |
| Tanga | Established 1975 | 5. Maziwe Island | There is no effective management of resources in this MPA. |
| Mafia Island | Established 1994 | 6. Mafia Island Marine Park | Effective management structure in place. |
| Mtwara | Established 2000 | 7. Mnazi Bay-Ruvuma Estuary Marine Park | Newly declared as the second Marine Park in Tanzania. |
| Pemba | Established 1998 | 8. Misali Conservation Area | Declared as Conservation Area (MCA). Managed by Department of Commercial Crops, Fruits and Forestry (DCCFF ). Supported by CARE Tanzania. Technical assistance provided by IMS. |
| Pemba | Proposed | 9. Pemba Channel Conservation Area (PECCA) | Preparation of declaration underway. Probably will be declared mid-2005. |
| Zanzibar | Established 1994 | 10. Chumbe Marine Sanctuary | This MPA is managed by a private investor (CHICOP). Coral and reef fish diversity is relatively high. |
| Zanzibar | Established 1992 | 11. Mnemba Marine protected area | The area is protected by private investor, Conservation Corporation Africa (CCA). High coral and fish biodiversity. |
| Zanzibar | Established 1997 | 12. Menai Bay Conservation Area | The area has been declared as a Marine Conservation Area in 1997. It is managed jointly by the Fisheries Division and local communities. Technical assistance is provided by WWF and IMS. |
| Zanzibar | | 13. Chwaka Bay and Jozani Forest | Managed by Department of Commercial Crops, Fruits and Forestry (DCCFF ). |

Updated from Mohammed *et al*. (2001).

now being incorporated in school curricula and teachers are attending workshops designed to increase environmental awareness in schools and in communities in general. Chumbe Island Coral Park conducts excursions for school children to visit and learn about the reef. This is being replicated in Misali Island.

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# Status of Coral Reefs of Mozambique: 2004

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*key words:* Mozambique, coral reefs, coral bleaching, marine protected areas, fish communities, coral reef monitoring

## BACKGROUND

Mozambique lies on the east coast of Africa between latitudes 10° 20' and 26° 50' S and possesses the third longest coastline in the western Indian Ocean at 2700 km. A variety of habitats characterizes the coastline: delta estuaries, sandy beaches, rocky shores, mangroves, islands and coral reefs (Rodrigues *et al.*, 2000). The extensive coral reefs along the coastline of Mozambique are a valuable national resource. These reefs exhibit great biodiversity (e.g. Riegl, 1996; Pereira, 2000; Benayahu *et al.*, 2003). They provide food and income for a large proportion of the country's coastal communities and have great potential for generating substantial economic growth within the tourism sector. The Government of Mozambique has recognized the importance of coral reefs and has initiated a number of actions aimed at the sustainable management and conservation of these resources.

## CORAL REEFS IN MOZAMBIQUE

The coral reefs of Mozambique are southern continuations of the well-developed fringing reefs that occur along major sections of the narrow continental shelf of the East African coast (Rodrigues *et al.*, 2000). These reefs represent the main attraction for the coastal tourism industry (Bjerner & Johansson, 2001; Abrantes & Pereira, 2003; Pereira, in review). Most tourism occurs where the best infrastructure for tourism is established; especially near the reefs of Pemba, Mozambique Island, Bazaruto Archipelago, Inhambane, Inhaca Island and Ponta de Ouro.

Coral reefs are also important for artisanal fisheries, especially in the northern sections of the country, contributing substantially to the livelihoods of coastal communities (Pacule *et al.*, 1996; Loureiro, 1998). About 90 000 people are involved directly in fish processing and marketing. Marine fisheries represent more than 80% of the country's total fisheries production and provides more than 90% of the jobs in this sector (Lopes & Pinto, 2001).

The extension of the Bazaruto Archipelago National Park in November 2001 and the creation of Quirimbas National Park in 2002, which includes 1 500 km² of coral reefs, mangroves and islands, are significant contributions to the conservation of the country's marine ecosystems. In addition, this represents a five-fold increase in the area included within the country's marine protected areas. The government is now interested in declaring Primeiras and Segundas a marine protected area, which is considered an area of regional importance, particularly within context of the Eastern Africa Marine Ecoregion.

## THE CORAL REEF MONITORING PROGRAMME IN MOZAMBIQUE

MICOA initiated the National Coastal Zone Management Programme for Mozambique in conjunction with DANIDA and in close collaboration with a number of institutions and donors. The programme addresses the entire coastal zone of Mozambique and adopts a multidisciplinary approach. One of the programme's foci is specific ecosystems such as coral reefs. During the development of the Mozambique Coral Reef Management Programme (MCRMP), four large areas of activity were recognised as vital for the achievement of the primary goal of sustainable management of coral reef resources. These areas were: capacity building; basic and applied research on the ecology of coral reefs; assessment of the integrity and status of the coral reef fishery; and assessment of the coral reef fishery in terms of its significance for coastal communities and for the welfare of the community at large.

In December 2001, a Memorandum of Understanding (MoU), between the WWF-Mozambique Coordination Office, the Coral Reef Degradation in the Indian Ocean (CORDIO) programme and Centro de Desenvolvimento Sustentável das Zonas Costeiras (CDS-ZC) was signed in order to implement various activities of the MCRMP. The most important aspect is the annual biophysical monitoring of coral reefs, training of Mozambican marine scientists in taxonomy of various coral reef taxa, and monitoring and research methodologies, postgraduate programmes and baseline surveys of priority coral reef areas.

## ACTIVITIES RELATED TO CORAL REEF MONITORING

Monitoring surveys were conducted in 1999, 2000, 2002 and 2004 (Schleyer *et al.*, 1999; Motta *et al.*, 2002), with the northern set of sites completed in May 2004. Due to logistical and funding constraints not all selected sites were visited each year, such is the case of Primeiras and Segundas. All sites were surveyed using a modification of the GCRMN-recommended methodology (English *et al.*, 1994)using video to record benthic cover along transects, instead of traditional line intercept transects (LIT). For further details on locations and the methodology adopted, see Rodrigues *et al.* (1999) and Motta *et al.* (2002). This report summarizes the results obtained since 1999.

## ACTIVITIES RELATED TO TRAINING

A training course on coral reef monitoring and taxonomy was conducted in Xai-Xai in 1999. The aim of the course was to develop Mozambican capacity and expertise in reef research through a practical and intensive approach. A second Advanced Coral and Reef-Fish Taxonomy course, held in August 2002, was supported by CORDIO, with logistical support from the WWF Mozambique Coordination Office and technical support provided by the Oceanographic Research Institute (ORI), Durban. The participants were undergraduate or recently graduated students with special interest in coral reef research and management. Eleven participants attended the course (4 male and 7 female). The capacity-building component of the MCRMP also includes support to students with interest in coral reefs. The programme has already supported one MSc and four BSc Honours (table 1 on next page).

## TRENDS IN THE CONDITION OF CORAL REEFS IN MOZAMBIQUE

Figures 1 and 2 on next page show the changes in the average percent cover of live hard coral on reefs surveyed since 1999. A distinction is made between protected (located within gazetted protected areas or at great depth) and unprotected reefs.

### Quirimbas Archipelago

*Sencar Channel Reef*

Mean live hard coral cover at Sencar Channel in Quirimbas Archipelago increased from 27.1% (± 9.1) in 1999 to 55.9% (± 8.9) in 2002. This reef is showing good recovery

**Table 1.** Achievements of the capacity-building component of the Mozambique Coral Reef Management Programme (MCRMP)

| Programme/Name | Year | Title | Institution |
|---|---|---|---|
| ***MSc*** | | | |
| Pereira, M. A. M. | 2003 | Recreational SCUBA diving and reef conservation in southern Mozambique | University of Natal, Durban |
| ***BSc Honours*** | | | |
| Costa, A. C. D. | 2003 | Alguns aspectos ecológicos e efeitos antropogénicos sobre os recifes de coral da Barreira Vermelha e Ponta Torres na Ilha da Inhaca | Universidade Eduardo Mondlane, Maputo |
| Videira, E. J. S. | 2002 | Influência do habitat sobre as comunidades de peixes-borboleta (Chaetodontidae) em recifes de coral no sul de Moçambique | Universidade Eduardo Mondlane, Maputo |
| Pereira M. A. M. | 2000 | Estudo comparativo das comunidades ictiológicas de dois recifes de coral da Ilha da Inhaca e sua relação com a estrutura do habitat | Universidade Eduardo Mondlane, Maputo |
| Gonçalves, P. M. B. | 2000 | Estudo e comparação das comunidades de coral dos recifes da Barreira Vermalha e Ponta Torres na Ilha da Inhaca | Universidade Eduardo Mondlane, Maputo |

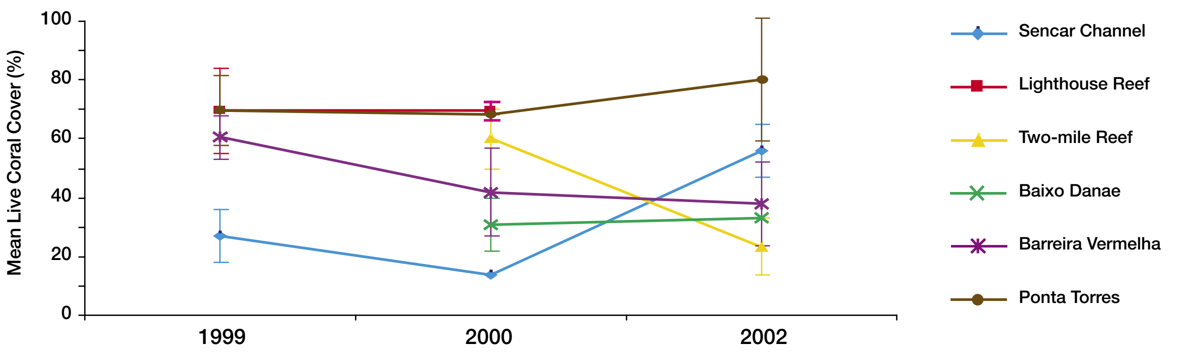


**Figure 1.** Trends in live hard coral cover at six protected reefs surveyed between 1999 to 2002.

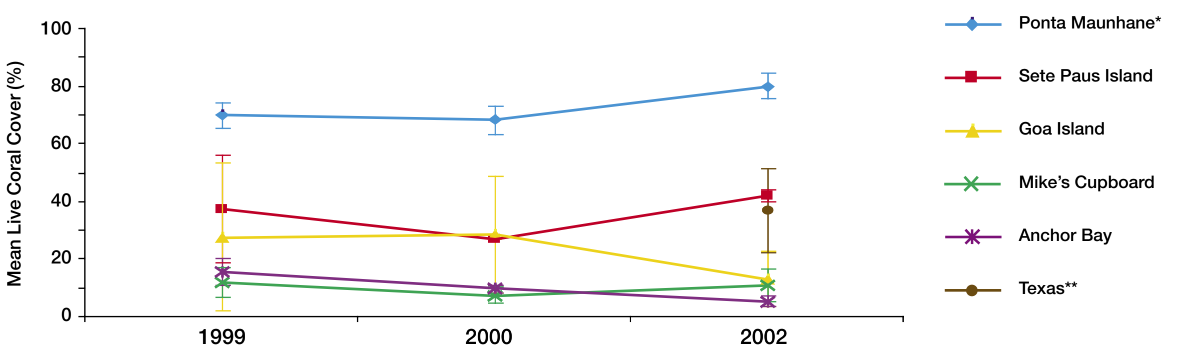


**Figure 2.** Trends in live hard coral cover at six unprotected reefs surveyed between 1999 and 2002. *This reef is not legally protected reef but is located deeper than 25 m and access is restricted to experienced divers only. **Monitoring station established in 2002.

from the 1998 bleaching event (Schleyer *et al.*, 1999), but the coral community structure seems to be changing. A number of coral species were conspicuous by their absence, particularly *Millepora* spp. and large *Acropora* spp., such as *A. palifera.* Mono-specific stands of *Galaxea astreata*, the foliaceous *Echinopora lamellosa* and patches of *Porites* (*synarea*) *rus* were also observed. In 1999, large patches of dead coral were conspicuous, possibly including "imploded" areas resulting from storm and/or anchor damage. Sea anemones (*Heteractis magnifica* and *Stylodactyla* sp.) and the giant clam (*Tridacna* sp.) were also abundant in 2000. Overall, remarkable recovery of live hard coral cover was observed in 2002 (figure 1). This reef has been protected as a sanctuary since 2001 and was later included within the Quirimbas National Park in 2002.

### Pemba

#### *Ponta Maunhane*

This reef is in good condition. There was a clear improvement in mean live hard coral cover, from 69.7% (± 14.5) in 1999 to 80.0% (± 4.4) in 2002. Laminar corals arranged in tiers and foliaceous *Montipora*, *Echinopora* and *Pachyseris* dominate the coral community. *Galaxea astreata* was also common. The live coral cover on this reef was consistently greater than at any other monitoring site. Very few motile invertebrates were observed in all years of monitoring. This reef is deep (28 m) which confers protection from waves, high sea surface temperatures and fishing.

### Mozambique Island

#### *Sete Paus Island*

Interesting developments have occurred on this reef. Overgrowth of *Galaxea astreata* by algae has increased and has been accompanied by the collapse of the coral framework in some places. Patches of the reef consist only of rubble and sand. In most areas, the coral community was dominated by the soft coral *Sarcophyton* but includes nearly every species of soft coral found in the area, with some hard coral. However, the coral community is not as diverse or abundant as that of Goa Island. This site is a shallow coral reef, which is easily accessible to fishermen in the area; consequently, fish were heavily exploited.

#### *Goa Island*

The fact that this reef is shallow makes it easily accessible for fishermen. The reef exhibits some degradation, with the average percent live hard coral cover falling from 27.7% (± 25.5) in 1999 to 13.2% (± 9.5) in 2002. Similar to the situation observed at Sete Paus Island, algae have overgrown *Galaxea astreata* colonies. Rubble has been replaced by a high diversity of corals dominated by *Porites (Synarea) rus, Porites nigrescens* and a number of colonies of *Echinopora lamellosa.*

### Bazaruto Archipelago

#### *Lighthouse Reef and Two-mile Reef*

These reefs are in good condition and are dominated by acroporids and massive corals such as faviids. Due to rough conditions, only the outer sections of Two-mile Reef was surveyed in 2002, thus contributing to the lower (<30 %) coral cover recorded in 2002. Nevertheless, the reef showed very little change since previous surveys. Two-mile Reef has high numbers of crown-of-thorns starfish (*Acanthaster planci*; COTS) and *Diadema* urchins.

### Tofo, Inhambane

#### *Mike's Cupboard and Anchor Bay*

Mike's Cupboard is a sandstone reef colonized by corals. This reef showed a very low mean percent cover of hard corals (11.9 % ± 5.3 in 1999 and 11.0 % ± 5.8 in 2002). This reef showed very little variation during this period. The invertebrate fauna of the Mike's Cupboard was dominated by the sea stars *Linckia* spp. with an average of 8.5 individuals per 250 m$^2$, followed by sea urchins (*Echinos-*

*trepus molaris*, *Diadema* spp. and *Echinotrix* sp.). Anchor Bay consists predominantly of rock covered by turf algae. It's a sub-tidal reef exposed to offshore water, which was systematically destroyed by COTS between 1999–2001 and is heavily fished.

## Inhaca Island and Baixo Danae

### *Barreira Vermelha*

The average live hard coral cover of Barreira Vermelha Reef was 60.5% (± 7.3) in 1999, 41.9% (± 14.9) in 2000 and 37.8% (±14.2) in 2002 and was dominated by acroporids and encrusting forms. The general condition of the reef seems to be deteriorating with a great increase in the cover of dead coral and rock and algae. This seems to have been caused by the use of destructive fishing practices and high levels of siltation and turbidity resulting from land erosion.

### *Ponta Torres*

Ponta Torres is a shallow reef of *Porites* bommies, faviid and *Acropora* colonies, fringing a sandbank channel. The reef has shown little variation in the mean live hard coral cover. The sea urchins (*Diadema* sp.) were present and *Tridacna* sp. was common.

### *Baixo Danae*

Baixo Danae is a sub-tidal reef with a scattered coral community that is dominated by encrusting forms. The condition of the reef appears stable with little change in average live hard coral cover between 2000 and 2002.

## Ponta do Ouro

### *Texas Reef*

In 2002, Texas Reef was established as a permanent monitoring site because it is an important dive site and is a typical reef of southern Mozambique in that it is moderately deep (15–18 m) and is dominated by soft corals, especially *Sinularia, Lobophytum* and *Sarcophyton*.

## Fish Surveys

Since the commencement of the monitoring programme, 236 species belonging to 50 families of fish, including sharks and rays, have been recorded. The results of surveys show that carnivores and herbivores are the dominant trophic groups on those reefs surveyed. In general, carnivores are marginally more abundant than herbivores on protected reefs (figure 3), while herbivores dominate the fish community on unprotected reefs (figure 4). The abundance of carnivores is considerably greater on pro-

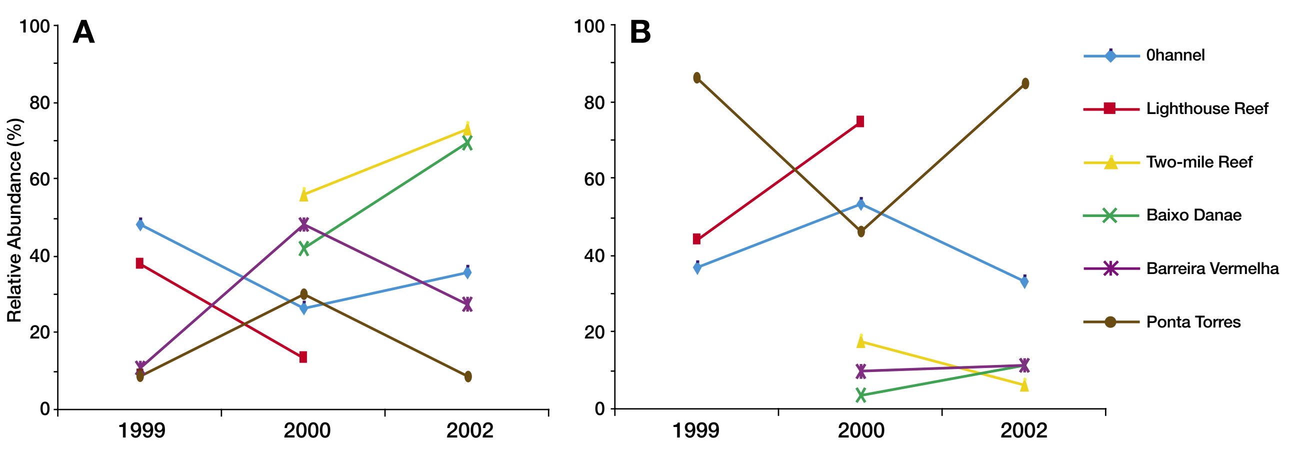


**Figure 3.** Trends in the relative abundance of (a) herbivorous and (b) carnivorous reef fish at six protected reefs surveyed between 1999 and 2002. Sencar Channel Reef has been protected since 2001.

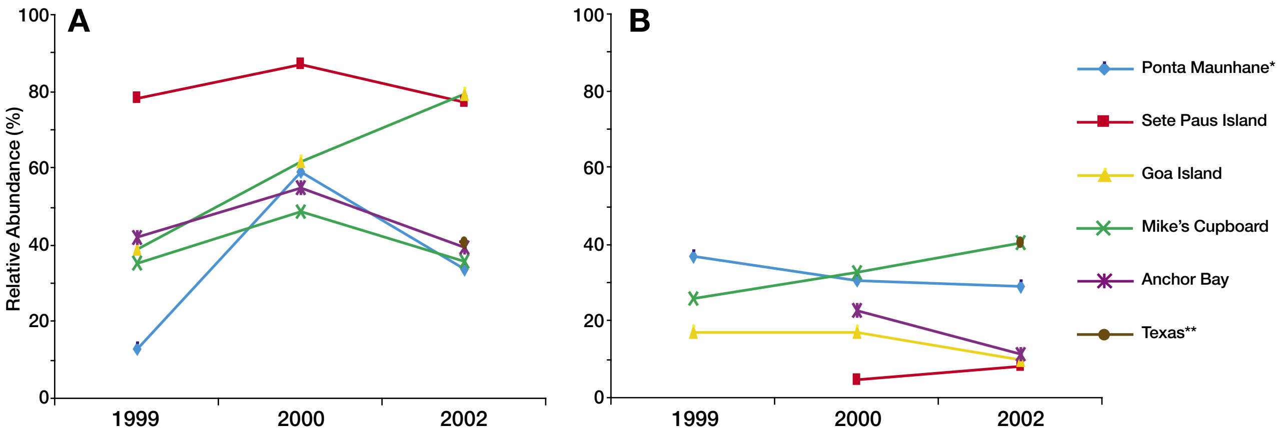


**Figure 4.** Trends in the relative abundance of (a) herbivorous and (b) carnivorous reef fish at six unprotected reefs surveyed between 1999 and 2002. *This reef is not legally protected reef but is located deeper than 25 m and access is restricted to experienced divers only. **Monitoring station established in 2002.

tected reefs than on unprotected reefs. The abundance of representatives of the families Haemulidae Lutjanidae and Mullidae is highly influenced by fishing pressure and, as a consequence, these groups are considerably more common on protected reefs (Rodrigues *et al.*, 1999; Motta *et al.*, 2002; Pereira *et al.*, 2003).

Herbivores are most abundant on shallow reef flats, which could be due to the increased cover of coralline and turf algae that now cover considerable areas of coral killed during the 1998 bleaching event. In addition, some of the unprotected reefs, such as Sete Paus, Goa Island and Baixo Danae, are heavily fished resulting in a fish community that is dominated by smaller size classes of herbivorous species (Rodrigues *et al.*, 1999; Motta *et al.*, 2002; Pereira *et al*, 2003).

Although not legally protected, Ponta Maunhane Reef exhibits similar fish community composition to protected reefs, where herbivores and carnivores are the dominant groups (figure 4) but carnivores are considerably more abundant than on other unprotected reefs (figure 4b). It is likely that because Ponta Maunhane Reef is located at depths greater than 25 m, access is limited to experienced divers only, which seems to contribute to the maintenance of an apparently undisturbed fish community.

## CONCLUSIONS

The selected sites and methodology have proved to be functional and realistic for conditions in Mozambique. The results from only a few years of this coral reef monitoring programme provide a preliminary indication of reef condition.

Coral reefs such as Ponta Torres, Bazaruto Lighthouse and Ponta Maunhane have maintained a relatively stable high percentage cover of live hard coral, most probably because of their protected status or inaccessibility.

Herbivorous fish are the dominant trophic group on unprotected reefs, while on protected reefs, carnivores and herbivores exhibit similar relative abundances. At Sete Paus and Goa Islands, overfishing has altered the fish community, which is now dominated by small-sized herbivores.

It is a cause for concern that there is no control of fishing effort or the use of destructive fishing gear on some reefs, for example Barreira Vermelha and Ponta Torres Reefs. Sete Paus, Goa Island and Mike's Cupboard Reefs, which are subject to heavy fishing pressure, have few fish and those that remain occur within smaller size classes.

Trends in the condition of coral reefs in Mozambique, however, should be considered over longer time scales, with more years of routine monitoring and increased number and representation among sites. For example, although Sencar Channel is strictly protected, it is important to establish a second monitoring site at a nearby location that is subject to fishing in order to allow comparison between sites to determine the impacts of fishing on fish communities and to assess the effectiveness of protection.

There are also significant stretches of coast that need monitoring, such as the Primeiras and Segundas Archipelagos. There is a need to increase the number of monitoring stations in other places such as at Ponta do Ouro, which has become one of the fastest growing destinations for tourists engaged in recreational scuba diving during the last decade.

## ACKNOWLEDGEMENTS

The authors would like to express their gratitude to MICOA, CORDIO, and WWF for funding and logistic support. ORI has also contributed with technical support throughout the years. A number of individuals have supported the monitoring teams providing transport, diving equipment, and accommodation.

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# Coral Reef Research in Northern KwaZulu-Natal, South Africa

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*key words:* coral reefs, South Africa, long-term-monitoring, climate change, coral recruitment, reef surveys

## INTRODUCTION

In southern Africa, coral communities form a continuum from the more typical, accretive reefs in the tropics of Mozambique to the marginal, southernmost African distribution of this fauna in KwaZulu-Natal (figure 1). Over the last 15 years, the Oceanographic Research Institute (ORI) has collected, analysed and published information on several aspects of the coral reefs in the region. These have included studies on coral taxonomy as well as the ecology and the condition of the reefs, contributing to an understanding of coral community development at high latitude.

While the South African reefs are limited in size, they are gaining increasing attention. They all fall within marine reserves in northern KwaZulu-Natal (Maputal) and constitute one of South Africa's most diverse and valuable yet scarce and fragile ecosystems. They have a number of notable attributes, are rich in biodiversity and offer tremendous potential for ecotourism. Soft coral cover, comprising relatively few species, exceeds that of scleractinians over much of the southern reefs and the soft coral communities attain a biodiversity peak at this latitude (27°S) on the East African coast. The reefs provide a model for the study of corals at latitudinal extremes and in terms of many of the stresses to which these valuable systems are being globally subjected. They

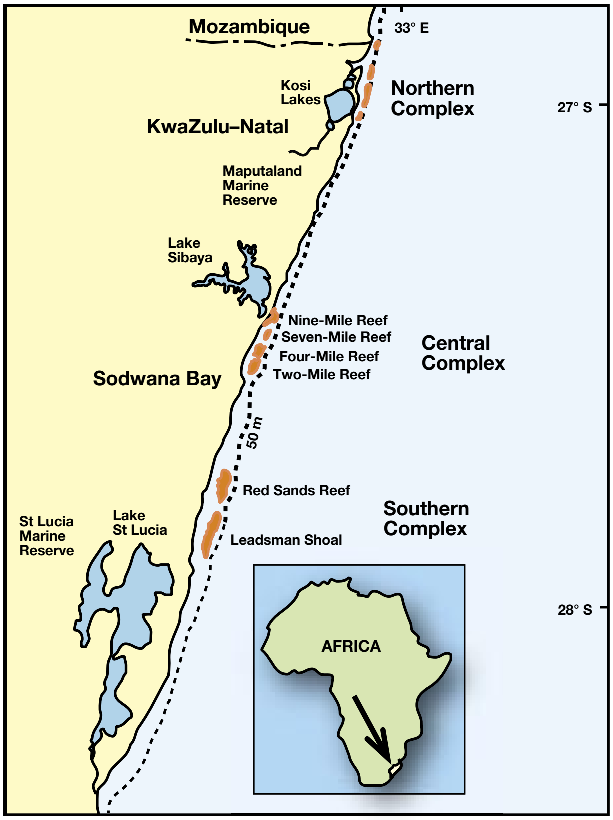


**Figure 1.** The northern, central and southern reef complexes of northern KwaZulu-Natal, South Africa (after Schleyer, 2000).

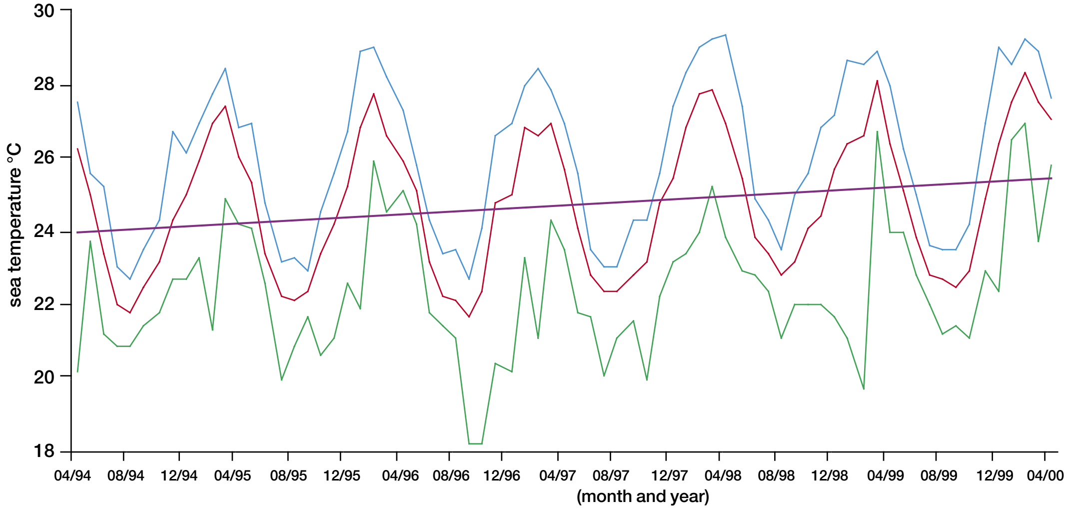


**Figure 2 a.** Monthly maximum, mean, and minimum sea temperatures recorded at a depth of 17 m (low tide) at a fixed monitoring station located at Sodwana Bay between May 1994 and April 2000. The regression line for the mean temperature data is included (temperature increase=0.27°C.y$^{-1}$).

are becoming increasingly popular as sport diving venues and visitor pressure in some areas presently constitutes a cause for concern.

## LONG-TERM MONITORING OF CLIMATE CHANGE

The marginal nature of these coral communities provides an opportunity for monitoring the effects of climate change under these conditions and a long-term monitoring site was established for this purpose. Quadrats of 0.25 m$^2$ have been photographed annually within fixed transects since 1993 and hourly temperatures have been logged on one of the reefs since 1994. While a consistent increase in sea temperature of 0.27°C p.a. has been measured at the site up to 2001 (figure 2), summer maxima associated with high irradiation have caused only limited bleaching. The recent temperature increase appears to be part of a cyclical phenomenon as IGOSS NMC data indicate that the temperature rise averaged only 0.01°C p.a. over the last 50 years. Since 2001, the temperature trend has flattened and may have even become negative, providing further support for the existence of longer term cycles in temperature patterns.

A combination of GIS mapping and merging of the quadrats with subsequent image analysis was developed for the study and has revealed that the coral community structure is changing and the scleractinian cover is increasing. The technique has also provided measurements of recruitment, colony growth and mortality. The results show that a gradual shift in coral community structure has occurred as sea temperatures have increased with climate change, with an increase in the cover of hard corals and decrease in soft corals. Recruitment has simultaneously decreased and mortality has increased, reaching extremes after 2000 when slight coral bleaching occurred at Sodwana Bay: zero recruitment was recorded at the monitoring site in 2001. There can thus be no doubt that we have reached the bleaching threshold of corals in our region. While rising temperatures appear to have promoted scleractinian growth, they also appear to be having a detrimental physiological effect on the coral community and have caused slight bleaching at recent maxima.

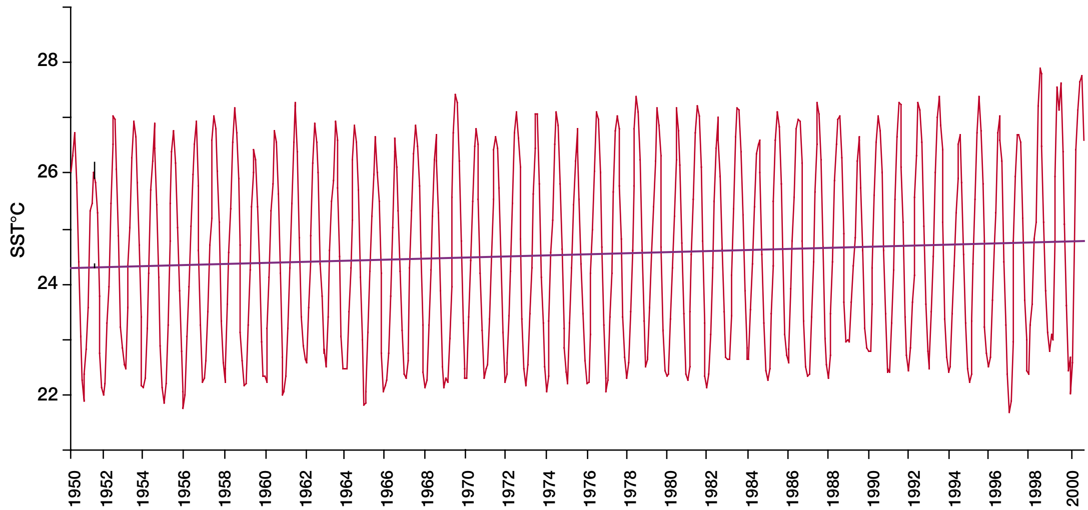


**Figure 2 b.** Monthly mean sea surface temperatures for the 2° latitude x longitude block incorporating Sodwana Bay. The regression line for all points is shown (reconstructed SST fields supplied by the South African Weather Service; temperature increase =0.01°C.$y^{-1}$).

Some published projections on the long-term effects of climate change indicate that more reefs will become marginal as a result of global warming. Current monitoring on the South African reefs is being expanded to include oceanographic measurements, PAR intensities and aragonite saturation state. It is hoped that the combined studies on these marginal reefs will elucidate the future of more typical, tropical coral reefs.

## CORAL RECRUITMENT

Coral larval settlement tiles were deployed on the reefs after 2001 to supplement the above data. Recruitment peaks were encountered on tiles removed from the reefs during March–May in subsequent years, this period falling after periods of coral spawning found in earlier reproduction studies. Maximum settlement occurred on tiles that had been deployed for at least three months and the bulk of the recruits were acroporids and pocilloporids. The findings will hopefully be interpretable in terms of reef connectivity using supplementary oceanographic data derived from instruments (a wave height recorder, ADCP, UTRs and CTD profiler) deployed during the study period.

## REEF SURVEYS

Concurrent with the above work, ORI has been surveying all of the South African reefs, employing rapid digital transect imaging techniques developed for this purpose. Reef community structural analysis of the digital recordings is being undertaken in the laboratory and is at an advanced stage. All of the transect images have been entered into a common database and data extraction from them is approaching completion. The data is being subjected to comparative analysis in terms of reef biodiversity before compilation in GIS maps of the reefs, these then being zoned for sustainable use according to their susceptibility to damage (figure 3 on next page). Recommendations will also be made concerning the establishment and efficacy of sanctuaries for the protection of sensitive areas and important biodiversity targets.

A database is being developed for the integration of all of this information on South Africa's limited coral reefs.

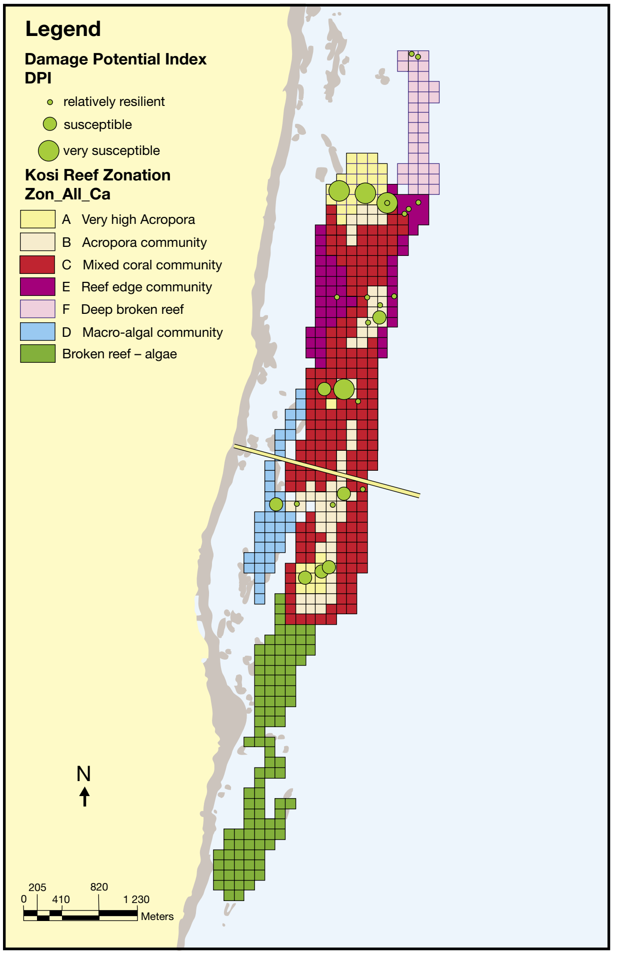


**Figure 3.** Biotic zonation of the Kosi reef system, showing the damage potential index (DPI) within the zones and recommended boundary between the Kosi Reef sanctuary in the north and diving concession area in the south (after Schleyer and Celliers, *in press*).

This will provide conservation managers with a valuable tool to assist in sustainable reef management and for the education of users. Software is being developed for the operation and interrogation of the meta-database. Appropriate material is being collated and incorporated in it, including illustrative material and disturbance information (bleaching, crown-of-thorns starfish outbreaks and SCUBA diver damage). One of the final products will incorporate other relevant geophysical, biological and socio-economic data in a multi-authored, GIS-based CD-Rom.

## CORAL GENETICS

The wide-spread scleractinian genus, *Stylophora*, is found in the area and has been studied in terms of its genetic and morphological variability along the southeast African coast and at one site in Madagascar. Specimens were collected at sites between eastern Madagascar and the Pondoland coast in South Africa (18°S to 31°S). The samples manifested a wide range of morphologies over this latitudinal range. Colonies were analysed in terms of their skeletal morphology, endosymbiont inter-specific genetic composition and host genetic variability. Skeletal morphology showed vast variability for a single species of hard coral. Several clades of endosymbiont were found to inhabit the specimens, with both inter- and intra-colonial heterogeneity. Coral host genotyping manifested heterogeneity resulting from polymorphisms caused by either insertion/deletion events or hybridisation in the recent evolutionary past (*circa* 10 000 y). However, the latitudinal gradient in the material does not appear to warrant differentiation into separate species.

## FUTURE WORK

The ORI work is now being expanded into more process-orientated research to further elucidate reef function. Representative species are to receive the attention of the combined skills of the ORI team in terms of the candidate species' growth, reproduction, physiology, genetics and dispersion. Species differing in the afore-mentioned parameters, but resilient or susceptible to bleaching, are to be selected with a view to the provision of management-related information on the function and future of the reefs, as well as the potential of the candidate species for reef rehabilitation.

Lastly, ORI collaborates extensively with coral reef researchers and monitoring programmes in Mozambique, at the same time providing the main technical assistance to projects funded by CORDIO. Two training courses in coral reef monitoring have been conducted and annual surveys have been undertaken from 1999 to the present. In 2004, a Mozambican student completed his MSc and graduated, and will now progress to a PhD that will slot into the mainstream of the process-management-orientated research described above. Additional Mozambican students are currently registering for MSc degrees through ORI, adding to the capacity within Mozambique to conduct further work on coral reefs.

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# Assessing the Status and Improving Management of Coral Reef Resources:

## Experiences and Achievements in South Asia

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*key words:* coral reefs, South Asia, coastal zone management, coral reef fisheries, alternative livelihoods

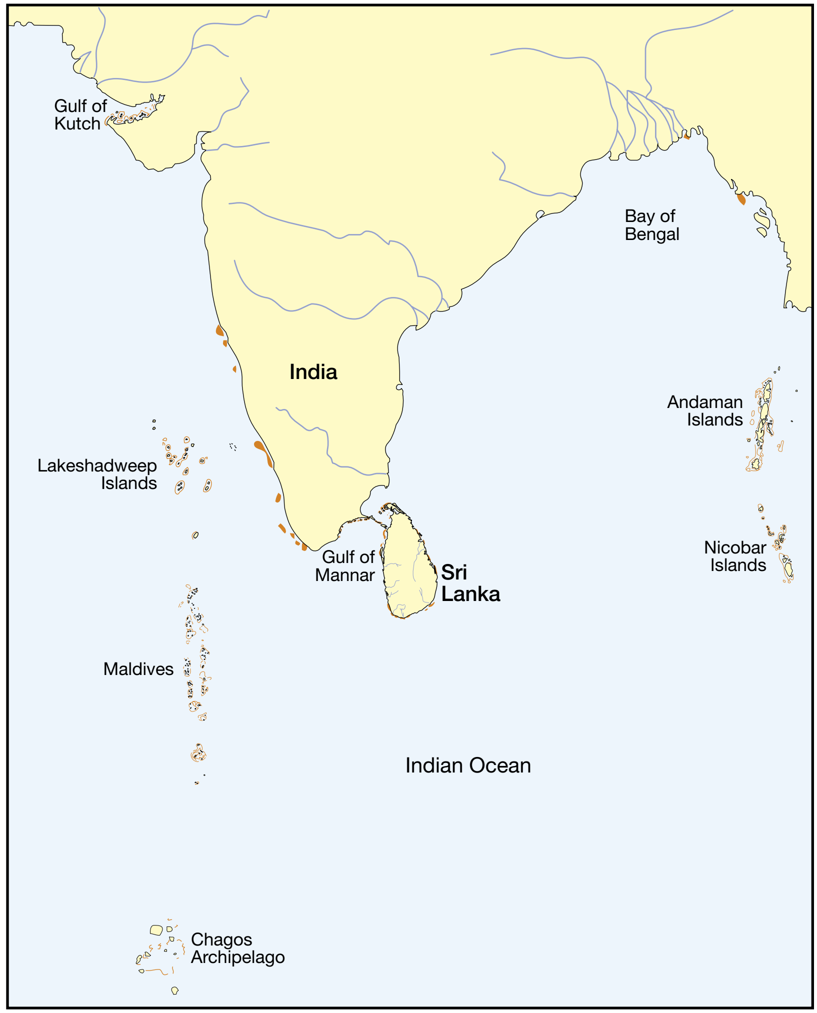
### INTRODUCTION

Close to half of the world's poor people live in South Asia (UNICEF, 2001; Samarakoon, 2004). Ramachandran (2002) identified population growth, insufficient food production, and underdevelopment as the major problems in the region. Open access to the sea, poverty, and an increasing demand for fishery products has escalated pressure on coastal resources (e.g. James, 1994; Devaraj & Vivekanandan, 1999; Bhattacharya & Sarkar, 2003; Perera *et al.*, this volume). For example, in India, the number of fishermen in coastal villages increased from two million to six million between 1980 and 1997 (Meenakumari, 2002). Moreover, growing commercial fleets operating in near-shore waters to supply expanding export markets cause habitat destruction and deprive local communities of fish products and a cheap source of nutrition (Jayashree & Arunachalam, 2000; Bavinck, 2003; Bhattacharya & Sarkar, 2003). About 10% and 15% of the total fish catches in India and Sri Lanka respectively are derived from coral reefs by small-scale fishermen (Wafar, 1986; Rajasuriya *et al.*, 1995). Although this is a considerable proportion of the national fish catches, these statistics do not adequately illustrate the actual situation in many areas in the region where hundreds of thousands of poor people depend solely on the products of coral reefs for food and livelihood (e.g. Berg *et al.*, 1998, Kannan *et al.*, 2001; Shanthini *et al.*, 2002; Hoon, 2003; Singh & Andrews, 2003; Whittingham, 2003; Patterson *et al.*, this volume).

During the last few decades, most coral reefs in South Asia have been progressively degraded by destructive human impacts, such as coral mining, blast fishing and the use of other destructive fishing methods, overexploitation, increased sedimentation due to poor land use practices, pollution, anchor damage from boats and tourism related activities (Öhman *et al.*, 1993; Rajasuriya *et al.*, 1995; Bakus *et al.*, 2000; Dharmaretnam & Kirupairajah, 2002; Patterson, 2002; Rajasuriya, 2002; Rajasuriya this volume). By 1998, almost half the coral reefs of South Asia were severely degraded, with the greatest impacts recorded on those reefs fringing the densely populated mainland coasts (Hinrichsen, 1998).

In addition, most coral reef areas of South Asia, including those in remote areas with few local human impacts, suffered extensive coral bleaching and subsequent mortality during the severe El Niño event of 1998, which caused significant increases in sea surface temperatures. While the deeper reefs, below ~10 m, generally recovered from bleaching, between 50% and 90% of the corals in many shallow areas were killed (Rajasurya *et al.*, 1999; Wafar, 1999; McClanahan, 2000; Rajasuriya & Karunarathna, 2000; Zahir, 2000). In addition, the tsunami that

**Figure 1.**




hit the coasts bordering the Andaman Sea and Bay of Bengal in December 2004 also caused some damage to the coral reefs.

Coral reef destruction has lead to decreased production of ecosystems services with adverse effects on people's food security and livelihoods, shoreline stability, and national economies (e.g. Spurgeon, 1992; Berg *et al.*, 1998; Westmacott & Rijsberman, 2000; Westmacott *et al.*, 2000; White *et al.*, 2000).

This paper provides a brief overview of the current status of coral reefs in India, the Maldives and Sri Lanka, reports the progress of CORDIO's activities in the region, and presents a number of recommendations for the future.

## THE STATUS OF CORAL REEFS AND MAJOR THREATS

### India

All major coral reef areas in India, including the Gulf of Mannar, Lakshadweep, Andaman and Nicobar Islands, and the Gulf of Kutch are under threat from human activities (Arthur, 2000; Muley, 2000; Rajasuriya, *et al.*, 2004). In addition, the coral bleaching event in 1998 caused a significant decline in the cover of live coral in most areas (Wafar, 1999; Arthur, 2000; Muley *et al.*, 2002; Rajasuriya, 2002; Wilhelmsson, 2002). Bleaching of extensive areas was recorded also during 2002 in Palk Bay, the Gulf of Mannar, and the Andaman Islands (Kumaraguru *et al.*, 2003).

Venkataraman (2002) reiterated Pillai (1996) by stating that the magnitude of destruction of the marine environment in the Gulf of Mannar may be unprecedented. Destructive fishing methods (including blast fishing), near-shore trawling, sedimentation and pollution are causing considerable damage to the coral reefs, threatening the reef fisheries of the Gulf of Mannar (James, 1994; Bakus *et al.*, 2000; Deepak-Samuel *et al.*, 2002; Patterson *et al.*, this volume). Declines in the abundance of coral associated fish due to the bleaching in 1998 have been reported (see Kumaraguru *et al.*, 2003, for reference). Coral mining, which reduces the function of reefs as natural barriers and lead to increased beach erosion, has transformed the coast (Quazim, 1999; Ramanujam & Sudarsan, 2003), and is probably responsible for the submersion of two islands in the Gulf of Mannar (Venkataraman, 2002). The tsunami in 2004 caused little damage to the reefs of Gulf of Mannar (CORDIO, 2005).

The atoll reefs of the Lakshadweep Islands lost between 43% and 87% of their live coral cover during the 1998 bleaching event (Wafar, 1999) declining to only ~10%. Post-bleaching surveys suggested a subsequent increase in live coral cover (Arthur, 2004). The reefs provide an important source of baitfish for the tuna fishery. Food fish are caught on the reefs primarily when tuna catches are low (Bakus *et al.*, 2000). Most of the atoll islands are unpopulated, and human pressure on coral reefs is relatively low, although the population has tripled during the past 20 years (Muley *et al.*, 2002). Dredging and coral mining have damaged the reefs near several islands (Chandramohan *et al.*, 1993; Bakus *et al.*, 2000). A drop in reef fish catches due to coral bleaching or overfishing has been noticed (Muley *et al.*, 2002).

In the Gulf of Kutch, less than 30% of the corals were killed by coral bleaching in 1998 (Wafar, 1999; Pet-Soede *et al.*, 2000). Although the coral reef areas remain important for different fisheries, they are patchy and degraded by coral mining, sedimentation, coastal constructions and discharged waste (Bakus *et al.*, 2000; Muley *et al.*, 2002).

The majority of the coral reefs of the Andaman and Nicobar Islands are comparatively healthy (Turner *et al.*, 2001; Kulkarni & Saxena, 2002), but many reef areas are affected by sedimentation due to logging, sand and coral mining, poaching, blast and cyanide fishing (Bakus *et al.,* 2000; Sundarmoorthy *et al.*, 2004; Venkataraman, 2004). The tsunami in 2004 caused damage to several reef areas in the Andaman and Nicobar Islands (Peninsi, 2005). The population and intensity of development activities are growing rapidly. Also, a growing demand for live fish for export has increased the Indian fishing sector's interest in the coral reefs of the Andaman and Nicobar Islands (Sakthivel, 1999).

### Maldives

Most direct human impacts on the coral reefs of the Maldives are localised to certain atolls or islands. The development of the country since the 1970s, through the expansion of the tourism and fishing sectors, has increased the demand for corals for construction of ports and houses (Naseer, 1997). Extensive reef areas bear the scars of coral mining, and a loss of reef-associated fish at these sites has been recorded (Dawson-Shepherd *et al.*, 1992). Land reclamation projects have also damaged reefs near densely populated islands. Although coral mining still occurs, there is now a certain degree of governmental regulation.

In the Maldives, the collection of bait fish on coral reefs sustains the traditional pole and line fishing for tuna, which is "highly appreciated on the international market for its perceived sustainability and high quality products" (MRC, 2003). Tuna fishers have, however, reported a scarcity of baitfish in recent years that they believe is a result of habitat degradation due to the mass mortality of corals in 1998 and high fishing pressure

(MRC, 2003). Further, the growing tourism and enhanced export facilities have expanded the market for reef fisheries. The grouper, sea cucumber, ornamental fish, giant clam, shark and turtle fisheries have expanded rapidly in the Maldives and signs of overexploitation of some reef resources were recognised in the early 1990s (Naseer, 1997; Shakeel & Ahmed, 1997; Flewwelling, 2001) and is a growing concern (Risk & Sluka, 2000; MRC, 2003).

In terms of live coral cover, the reefs of the Maldives are recovering at varying rates after the mass bleaching and mortality in 1998, when 90–95% of the corals on the shallow reef flats died (Zahir, this volume). New recruitment has been noticed at all sites. However, studies indicate a relatively poor supply of larvae of the genus *Acropora*, which was once the most abundant on these reefs, while other corals, such as *Pavona,* dominate the assemblage of new recruits (Zahir *et al.*, 2002). Results suggest that recovery of coral communities to pre-bleaching levels will be slow or that a change in the coral species composition of these reefs is underway (Zahir, 2002; Zahir, this volume). The deeper reefs are in better condition. Further, the relatively high coral cover recorded during surveys conducted in the Addu region in 2002, suggests that the most severe impacts of the bleaching of 1998 may not have been as geographically widespread as initially thought (Zahir, 2002a). The tsunami in 2004 had a negligible direct impact on overall coral cover, but sediment build up that may make the substrate unsuitable for coral growth, as well as solid waste on the reefs, poses subsequent threats to several reef areas (UNEP, 2005; Zahir, this volume).

**Figure 2.** Coral reef monitoring in the Maldives. *Photo:* HUSSEIN ZAHIR.

**Figure 3.** Mined corals in Batticaloa, Sri Lanka. *Photo:* DAN WILHELMSSON.

#### Sri Lanka

Destructive fishing methods, such as the use of bottom-set nets and blast fishing, continue to damage coral reefs in Sri Lanka (Öhman *et al.*, 1993; Rajasuriya *et al.*, 1998; Perera *et al.*, 2002; Rajasuriya this volume). Coral mining is still practiced resulting in extensive beach erosion, especially along the south-western and eastern coasts. Even the marine protected areas in Sri Lanka are unmanaged and increasing human activities continue to degrade their condition (Rajasuriya & Karunaratna, 2000; Rajasuriya 2002; Rajasuriya *et al.*, this volume). Declines in catches of reef fishes have been reported in several areas in Sri Lanka (Rajasuriya & Karunarathne, 2000; Perera *et al.*, 2002; Wilhelmsson *et al.*, 2002). A significant decrease in the number of butterfly fish (Chaetodontidae), many of which are usually associated with live coral, has been observed on several reefs (Rajasuriya & Karunarathna, 2000; Wilhelmsson *et al.*, 2002).

Uncontrolled tourism has caused considerable damage to coral reefs in Sri Lanka. For example, in Hikkaduwa National Park, the glass-bottom boats and their anchors break the corals, and local visitors trample corals on the reef flats (Rajasuriya, 2002).

Most of the dominant forms of reef building corals in many of the shallow coral habitats (<8 m) were destroyed during the bleaching event in 1998. The dead coral reefs are largely dominated by algae, tunicates, and corallimorpharians (Rajasuriya & Karunaratna, 2000; Rajasurya, 2002). However, survival among corals growing in deeper waters (>10 m) was greater, providing a potential source of new recruits. Recovery of bleached corals in shallow reef habitats has been variable between sites but has in general been slow (Rajasuriya, 2002). Recent surveys indicate that there is better recovery on some patch reefs. In the Bar Reef Marine Sanctuary, *Acropora cytherea* and *Pocillopora damicornis* are replacing areas that were previously dominated by branching *Acropora* spp. (Rajasuriya, this volume).

The tsunami caused considerable damage to coral reefs in Sri Lanka. Although there was no discernible damage to coral reefs in the Gulf of Mannar or Palk Bay in Sri Lankan waters, all other areas were affected by the tsunami. Damage was evident on shallow water coral habitats; damage to sandstone and rock reef habitats was negligible. The damage was very patchy even within a single reef. Coral habitats in areas where the seabed configuration appears to have focussed energy into specific locations along the coast, and reefs in these areas were the most affected.

## THE CORDIO PROGRAMME IN SOUTH ASIA, 1999–2004: OBJECTIVES

The CORDIO programme has worked towards improving management of coral reefs in South Asia since its initiation in early 1999. The programme, supported primarily by the Swedish International Development Cooperation Agency (Sida), has included a number of projects and activities in India, Maldives and Sri Lanka. The objectives of CORDIO's South Asia Programme have been:

- Enhance coral reef related bio-physical and socio-economic research and monitoring;
- Raise public awareness of issues relating to the use and conservation of coral reef resources;
- Investigate the feasibility of restoration of damaged coral reefs;
- Provide alternative livelihoods for people dependent on coral reefs.

The following sections provide an account of the progress of CORDIO's activities in the region.

## ACHIEVEMENTS AND EXPERIENCES

### Coral Reef Related Bio-Physical and Socio-Economic Research and Monitoring

Knowledge of ecological and socio-economic processes, existing problems and risks are essential pre-requisites for making informed decisions and developing appropriate policies and responses to manage coral reefs and their resources effectively. The generation of relevant data is also important to conduct cost-benefit analyses to justify and continuously evaluate management measures. The institutional capacity in South Asia to collect such data is improving but substantial improvements are still to be made.

#### *Ecological Research and Monitoring*

CORDIO supports the monitoring carried out by the national governmental institutes, National Aquatic Research and Resources Agency (NARA) in Sri Lanka (Rajasuriya & Karunarathne, 2000; Rajasuriya, 2002; Rajasuriya, this volume) and Marine Research Centre (MRC) in the Maldives, (Zahir, 2000; 2002; this volume). The environmental data generated by these institutes contributes directly to the National Development Plan (NDP) and National Biodiversity Strategy Plan (NBDSAP) in the Maldives, and the government organisations responsible for the management of fisheries and related activities (Department of Fisheries and Aquatic Resources), implementing integrated coastal zone management (Coast Conservation Department), and conservation of biodiversity and management of protected areas (Department of Wildlife Conservation) in Sri Lanka. The collaboration between CORDIO and NARA in Sri Lanka builds on previous capacity development and support provided by Sida/SAREC between 1989 and 1998. In addition, since 1999, CORDIO has funded a M.Sc. study investigating the spatial and temporal patterns of coral recruitment in the Maldives (Zahir *et al.*, 2002). The degree of erosion of reefs following the extensive coral mortality has also been investigated through field experiments (Zahir, 2002b). The CORDIO programme has also trained several people at MRC in methods to conduct general coral reef surveys and assessments of recruitment and erosion of reefs.

Further, the first comprehensive surveys of the reefs of the Tuticorin Coast in India were conducted by Suganthi Devadason Marine Research Institute (SDMRI) as part of the CORDIO Programme (Patterson, 2002; Patterson *et al.*, this volume). Through the institutional capacity building within the programme, SDMRI has established a research group equipped for repeated monitoring of coral reefs along the Tuticorin Coast (Patterson *et al.*, this volume). Several of the projects carried out by SDMRI provide students with Ph.D. degrees. CORDIO further supported SDMRI in the preparation of proceedings of two coastal management workshops, and the production of *A field guide to stony coral (Scleractinia) of Tuticorin in Gulf of Mannar, Southeast Coast of India* (Patterson *et al.*, 2004) for distribution among researchers entering the field of coral reef research.

With assistance from the National Aquatic Resources Research and Development Agency (NARA) and the Sri Lanka Sub-Aqua Club, CORDIO provided training and basic equipment to students at Eastern University, Batticaloa, on the east coast of Sri Lanka. Eastern University completed the first surveys of the reefs of Passichuda during 2003–2004 (Dharmaretnam & Ahamed, this volume). It is anticipated that this will form the basis of expanded coral reef and socio-economic monitoring along the east and north-east coasts of Sri Lanka. Upon request, CORDIO also organised a training course in coral reef monitoring at Colombo University in 2000. Moreover, CORDIO has provided support for a number of researchers from India, Sri Lanka and the Maldives to attend international coral reef training courses and conferences.

**Figure 4.** Transplanted corals, Tuticorin, India. *Photo:* SDMRI.

*Socio-Economic Monitoring of Household Parameters*

Sen (1995) challenged the activist call 'think globally, act locally' with 'analyse locally before acting globally', emphasising the need to combine macro-system approaches with appropriate micro-system socio-economic analysis particularly to 'identify the distribution of policy benefits and costs' in the coastal communities. Using this approach, SDMRI has conducted socio-economic surveys in five villages along the Tuticorin Coast as a basis for subsequent management projects in the area (Patterson *et al.*, this volume). Further, in the Lakshadweep Islands, the Centre for Action Research on Environment, Science and Society (CARESS) has established a community based monitoring programme to map the coral reef related activities and resource use with CORDIO support (Hoon

& Tamelander, this volume). The data obtained and the enthusiasm generated among community members during a pilot project initiated by the Global Coral Reef Monitoring Network (GCRMN) in 2001 resulted in the perpetuation and expansion of this monitoring programme. This programme can facilitate the development and implementation of future management actions, through the generation of data and information and the successful involvement of the broader community.

Furthermore, CORDIO has co-funded some GCRMN initiatives such as pilot socio-economic surveys in Sri Lanka in 2000 (by NARA), and a training course on socio-economic monitoring for coral reefs, in the Andaman and Nicobar Islands, India, in 2001.

### *Reef Fisheries and Tourism*

The catches obtained in small-scale coral reef fisheries are often not recorded by governmental fishery institutes, or cannot be disaggregated from the national fishery statistics. Therefore, NARA, with support from CORDIO, initiated a programme of monitoring of reef fisheries in three areas in Sri Lanka (Perera *et al.*, 2002). Further, a database to collate and store information describing the collection and trade of marine ornamental fish was developed at NARA (Wilhelmsson *et al.*, 2002). These programmes will hopefully serve as useful tools in the management of the reef fisheries industry in Sri Lanka.

Coral reef related tourism is of particular importance in the Maldives, where about half of the visitors are scuba divers and travel and tourism contribute around 56% to the national economy (Westmacott *et al.*, 2000). In Sri Lanka, the reef related tourism is increasing, particularly in the newly accessible north-eastern and eastern areas. The effects of coral reef degradation on tourism were therefore investigated within the CORDIO programme in both the Maldives and Sri Lanka between 1999 and 2002 (Cesar *et al.*, 2000; Westmacott *et al.*, 2000; Amaralal, 2002). These governmental monitoring efforts of reef fisheries and tourism unfortunately came to a halt in 2002, but the intention is that these activities will resume during 2005.

## Increases in Public Awareness

Attempts to reduce the destructive exploitation of coral reefs in South Asia through legal measures are often short-lived and localised, having little effect at larger scales or over longer periods (e.g. Premaratne, 2003; TCP, 2004). In order for a law or regulation to be generally complied with, it has to be firmly established and accepted in the broader community through the creation of awareness and education. In addition, these measures need to be supplemented with firm law enforcement to avoid a situation where individuals successfully evade the law and thereby discourage voluntary compliance (Flewwelling, 2001). A strong awareness among the public often influences both the local stakeholders and politicians. Further, prospects of financial gains inevitably generate political and social acceptance of a certain strategy of exploitation of natural resources (Ludwig *et al.*, 1993). Thus, the overall as well as long-term economic benefits of non-destructive practices need to be better communicated to policy makers and coastal communities.

In 2001, CORDIO co-funded an educational and awareness project entitled *A tomorrow for our reefs* implemented by the World Conservation Union (IUCN) in Sri Lanka. The awareness campaign started with an eight-day exhibition in Colombo, followed by a mobile exhibition in Hikkaduwa and Tangalle in the south. The number of visitors per day in Tangalle averaged 4 000 resulting in recommendations for the implementation of similar projects in other areas of South Asia (IUCN, 2001). Furthermore, during the educational exhibitions, school teachers often asked for resource material to assist them in teaching subjects related to the marine environment. Thus, CORDIO assisted IUCN in producing educational packages, in Sinhala, Tamil and English, for school children in Sri Lanka during 2003. The resource material was distributed to over 1000 schools in Sri Lanka (IUCN, 2004), enabling secondary school teachers to enhance the knowledge of issues affecting coral reefs among a large number of young people. The distribution of this material to schools in Tamil Nadu, India by SDMRI is planned for 2005.

**Figure 5.** Vermi-compost in Vellapatti village, Tuticorin, India. *Photo:* SDMRI.

**Figure 6.** Crab fattening tanks in Vellapatti village, Tuticorin, India. *Photo:* DAN WILHELMSSON.

During 2002 and 2003, SDMRI conducted a series of awareness raising programmes on the importance of sustaining reef productivity in a number of villages along the Tuticorin Coast. Fisherwomen organised in 'Self Help Groups', who play a vital social role in these communities, constituted the main target group. Surveys investigating the degree of awareness of coral reef related issues conducted in the villages before and after the campaign showed a substantial increase in knowledge among the community members (Patterson *et al.*, this volume). Moreover, coral mining activities at Vellapatti and blast fishing at Thirespuram have ceased completely as a direct result of this and earlier education campaigns. Also, in Tharuvaikalam, the fisherwomen are now strongly opposing coral mining (Patterson *et al.*, this volume).

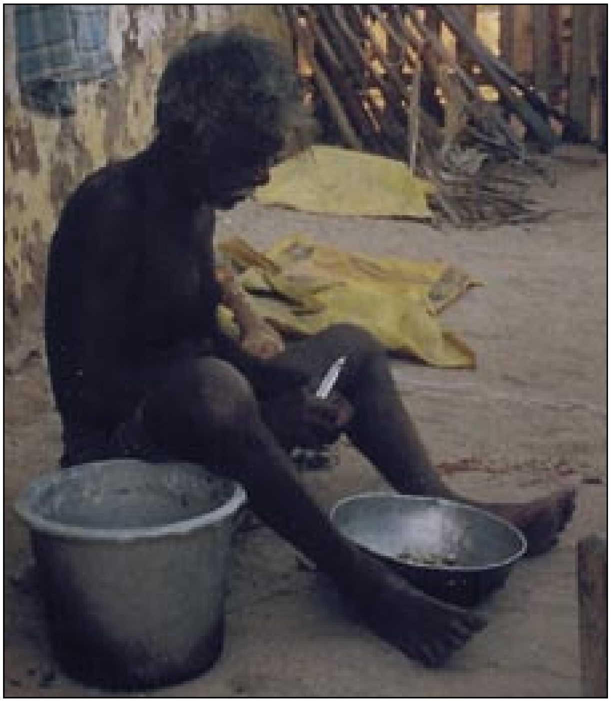


**Figure 7.** Fisherman in Vellapatti village preparing gastropods. *Photo:* DAN WILHELMSSON.

At Rekawa in southern Sri Lanka, coral mining is extensive, and mangroves are harvested for firewood for the production of lime from the mined corals. In an attempt to reduce these highly destructive activities, the Turtle Conservation Project (TCP) organised five workshops during 2003 to educate and raise awareness of issues affecting coral reefs and associated ecosystems among the community members of Rekawa.

In Batticaloa, Sri Lanka, CORDIO assisted in the organisation of a seminar on environmental issues held over two days in July, 2000. During the first day, local school children and teachers were invited to participate in discussions and, on the second day, governmental officers, NGO's, and different stakeholders contributed their views. One of the major topics discussed was the extensive coral mining taking place in Batticaloa.

### The Feasibility of Restoration of Damaged Coral Reefs

The natural recovery of reefs damaged by coral mining or dynamite fishing is often inhibited by unconsolidated substrata that are unsuitable for settlement and, as a consequence, is very slow (Brown & Dunne, 1988). Natural recolonization can be facilitated by transplantation of corals, similar to reforestation programmes used to restore terrestrial habitats (Auberson, 1982). However, transplantation techniques used in one area may not be applicable to other areas since both physical and biological conditions for survival and reef development vary greatly among localities and species (Guzman, 1991; Smith & Hughes, 1999). Also, when considering transplantation of coral, there is a trade-off between costs, in terms of labour and material, and the survival rate of transplants, which in turn affects the amount of damage caused to donor sites. Thus, CORDIO supported SDMRI in investigating the feasibility of low-cost community driven reef restoration through coral transplantation on the Tuticorin Coast. Results obtained to date are presented in Patterson *et al.* (this volume). A valuable spin-off of the involvement of the local community is an enhanced awareness of environmental issues among local fisher folks.

### Alternative Livelihoods for People Dependent on Coral Reefs

"Resource problems are not really environmental problems. They are human problems that we have created at many different times and in many places, under a variety of political, social, and economic systems" (Ludwig *et al.*, 1993). The increasing pressure on coastal resources and the continuous degradation of coral reefs threatens the food supply and incomes for many people. Therefore, CORDIO seeks to make coastal communities in selected pilot areas less dependant on the coral reef resources by providing opportunities for income diversification and alternative livelihoods. This also reduces the pressure on reefs.

In order to optimise the outputs of CORDIO projects, and other efforts at a larger scale, the South Asian Co-operative Environment Programme (SACEP) has reviewed past, present and planned efforts to establish alternative livelihoods in Sri Lanka and other parts of the world. This resource guide, targeting policy makers and ground level managers has analysed the lessons learned and presents a set of recommendations for future initiatives in promoting additional income generating activities (Perera, 2004). It has incorporated the findings of various institutions, such as the Asian Development Bank, universities and governmental departments, as well as individuals with experience in this field. Moreover, there is scope for a regional co-operation on these issues through the intergovernmental mandate of SACEP. The recommendations of this review are outlined in Perera *et al.* (this volume).

In Tuticorin, several village communities are solely dependent on fish resources obtained from the coral reef areas off the coast (Shanthini *et al.*, 2002). Crowded fishing grounds, increasing demand for fisheries products, and declining catches compel fishermen to use more effective and destructive fishing methods (Deepak Samuel *et al.*, 2002). Further, coral mining and blast fishing, which has already destroyed a significant portion of many reefs, still occurs despite increased law enforcement (Deepak Samuel *et al.*, 2002; Patterson, 2002). The Tuticorin Coast is one area that should be given high priority for management interventions providing alternative livelihoods for artisanal fisher families.

Thus, SDRMI, with support from CORDIO, has trained fisherwomen from four villages in preparation, maintenance and harvesting of earthworm composts for the production of eco-friendly fertilizers for the agricultural sector. SDMRI assisted in the installation of facilities, provides technical backup, and organizes the marketing and sale of the products among local farmers. Today, hundreds of fisherfolk in the area are making considerable financial gains from these activities.

Also, in 2002, groups of fisherwomen were trained in crab fattening where recently moulted crabs are maintained in tanks until the shell hardens before selling them at market for higher prices (Patterson *et al.*, this volume). The project has attracted attention from local authorities and the District Administration provided funds for the construction of a shed with tanks for crab fattening. Today, around 60 women in Vellapatti are engaged in this activity, with continuous technical support provided by SDMRI through the CORDIO Program. A strong interest in expanding this project within the Tuticorin region and eventually throughout the Gulf of Mannar has been shown from other villages as well as from governmental and international agencies. The provision of supplementary incomes to coastal populations through development of crab fattening has been encouraged by the Bay of Bengal Programme (BOBP), due to the fast turnover rate, low operating costs, and reliable market demand for the end products (Pramanik & Nandi, 2002).

Further, at Vellapatti, large quantities of gastropods are landed as by-catch from the crab fishery but the meat from the gastropods was not used due to lack of knowledge of its nutritional value. Thus, 25 women in Vellapatti were trained by SDMRI in processing the gastropods for consumption and today it is part of the diet in the village. Nearby villagers are now asking for similar training. The gastropods could also be locally marketed although additional support for facilities, logistics and promotion would then be needed (Patterson *et al.*, this volume). The activities of SDMRI have contributed to a more efficient utilization of marine resources and to some extent reduced poverty in villages of the Tuticorin Coast.

At Rekawa in southern Sri Lanka, coral mining is extensive (Perera, 2004; TCP, 2004). Large areas of the reef have been turned into plateaus of shifting sediments and, as a consequence, beach erosion in the area is severe. Coral mining was temporarily curtailed in mid-1990s through increased law enforcement, which resulted in

**Figure 8.** Coral miners receive training in batik production at Rekawa, Sri Lanka. *Photo:* DAN WILHELMSSON.

the loss of income for a number of people, of which about 200 were women. Due to lack of alternatives, many coral miners turned their attention to another illegal practice, poaching sea turtle eggs (TCP, 2004). Further, the profitable coral mining resumed quickly once beach patrolling by the police ended and is currently continuing on a large scale.

During 2003/04, the Turtle Conservation Project, with support from CORDIO, trained 20 women who were engaged in coral mining to make coir mats, batiks and wood carvings in an attempt to provide them with an alternative livelihood within the tourism sector. After a series of training workshops, a gift house was constructed on the beach by TCP. The women receive assistance in selling the products in conjunction with the turtle-watching tourism that is conducted by TCP. TCP also promotes the outlet at hotels in the area. This is a first step of a long-term effort by TCP to involve coral miners in the community-based tourism industry at Rekawa. It is not expected that all the trained women will venture into the new occupation full time since coral mining is still more profitable. However, when the tourism industry in the area has been further developed, there is scope for shift at a larger scale from mining into tourism, which can build on the experiences from this pilot project (TCP, 2004). Unfortunately, the tsunami on December 26, 2004, caused many casualties as well as damage to the infrastructure at Rekawa. This tragic event will have long-lasting and serious consequences for the development of the area, including the tourism sector.

## DISCUSSION AND FUTURE PERSPECTIVES

The threat of global climate change to coral reefs has come to the world's attention relatively recently, but seems to be here to stay (IPCC, 2001). Increased sea surface temperatures and intensified El Niño events may cause mass mortality of corals and relatively rapid and significant losses in the extent, biodiversity and ecosystem functions of coral reefs in the next few decades (Hoegh-Guldberg, 1999, Stone *et al.*, 1999, Wilkinsson *et al.,* 1999, Reaser *et al.*, 2000). So is there a point in trying to conserve reef functions through extensive local management efforts affecting large numbers of people? Indeed, first the susceptibility to bleaching and mortality vary among species and sizes of corals (e.g. Obura, 2001). Also, thermal adaptations among corals through alterations of the composition of symbiotic algae (*Symbiodinium* spp.) have been suggested (e.g. Rowan, 2004). Many reefs show a degree of resilience to bleaching, and there is "circumstantial evidence for an ongoing evolution of temperature tolerance" (Hughes *et al.*, 2003). Hughes *et al.* (2003) further suggest that the reefs will change rather than disappear entirely. However, no coral is tolerant to coral mining or dynamite fishing. Anthropogenic stressors and fragmentation of reefs undermine reef resilience (Nyström & Folke, 2001; Hughes *et al.*, 2003), and inhibit reef recovery, including the possible recolonisation by more tolerant corals (Loya, 1990; Connell, 1997). Thus, a dense network of effectively managed marine protected areas (MPAs), and an enhanced protection of other reef areas, to improve the prospects of re-colonisation of damaged areas through dispersal of corals from more intact reefs are now a high priority (e.g. Nyström & Folke, 2001; Hughes *et al.*, 2003; West & Salm, 2003, Bellwood *et al.*, 2004).

Secondly, if development of enhanced resilience among coral reefs cannot keep up with the rate of the increase in sea temperatures, and most of the reefs are still doomed, the promotion of sustainable management of reefs will be part of a race against time. A collapse in reef resources can be postponed and more preparatory actions can be taken to mitigate the consequences for coastal communities. Thus, for either scenario, there is no reason to give up on the coral reefs and the people depending on them.

Pertaining to coral reef management in South Asia and elsewhere, repeated urges for enhanced Integrated Coastal Zone Management (ICZM) practices with law enforcement, fisheries management, environmental and socio-economic monitoring, collaboration between institutes, involvement of local communities, and public awareness have been made through a number of organisations and reports of meetings during the past 10 years. While echoing these recommendations, it is worth emphasising some points:

### Enhanced Co-Ordination of Efforts among Donors and Implementing Agencies

There is a certain degree of progress at political and institutional levels in South Asia. A number of programmes and projects adopting the principles of ICZM and including coral reefs have been initiated in the region (e.g. Regional: Bay of Bengal Programme (BOBP) executed by FAO, UNEP Regional Seas Programme, implemented by SACEP in South Asia; Sri Lanka: Coastal Resources Management Project (CRMP) implemented by Coast Conservation Department; Maldives: Integrated Reef Resources Management (IRRM); India: National and State Coastal Zone Management Authorities) (see also Le Tissier *et al.*, 2004). External support has been provided by a number of organisations and governments. However, mitigating the problems affecting coastal communities and marine ecosystems in South Asia to any significant degree is an immense task, and a major breakthrough at ground level is yet to occur.

The CORDIO programme can fill some gaps in the process where national and international institutes and organisations with larger financial and human resources as well as formal authorities carry the main responsibility. CORDIO South Asia can also provide a number of path finding demonstration projects for others to build on. There are often advantages in starting with small-scale projects and building coastal management efforts at larger scales on the progress, trust and confidences gained among the local communities (e.g. Olsen & Christie, 2000; Torell, 2000). This is illustrated particularly in Patterson *et al.* (this volume), where an increasing interest from governmental agencies and donors is allowing the initial project to expand both geographically and financially.

In collaboration with the existing projects and programmes, assistance from additional organisations and institutes is much needed. However, better communication among national and international agencies is essential. For example, in order to promote the influx of new initiatives or strengthening of ongoing programmes, more transparent, concrete and specific reporting is required primarily from the supporting and co-ordinating organisations and institutes in the region. This would facilitate the identification of gaps and needs allowing ameliorative efforts to be more focused and co-ordinated. Moreover, the commitment from the governments needs to be improved to assure a long-term process rather than short-term fragmented interventions by donor driven projects (Perera *et al.*, this volume). Unfortunately, in some cases, the governmental dedication seems to be inhibited by the assumption that the donor driven programmes will succeed each other.

#### Reconstruction after the Tsunami

Large financial, human, and material resources are entering the region in the wake of the tsunami that devastated many coastal communities in south-eastern India, Maldives, and Sri Lanka. It is now of paramount importance that a holistic view is adopted so as not to recreate the pre-existing unsustainable situation in the coastal areas affected. The development of infrastructure, settlements, and economic activities (e.g. aquaculture, tourism) has to a large extent taken place against policies, laws, and regulations, resulting in conflicts of interests, environmental degradation, economic losses and coastal erosion. Also, several governmental and donor driven, rather small-scale, attempts have been made to reduce the pressure on coastal resources, and to mitigate current and future poverty, through helping people into new livelihoods, such as agriculture, aquaculture, off-shore fisheries (e.g. Perera, 2004). Thus, aid resources must be used in accordance with the long-term development needs of the region, and establish economic activities and infrastructure where and how it should be rather than where and how it was previously.

#### Empower Governmental Agencies for More Efficient Surveillance and Law Enforcement

The number of laws and regulations pertaining to the use and protection of marine resources and the number of MPAs established in South Asia is misleading. Enforcement of laws and regulations is very weak (e.g. Rajasuriya, 2002; Premaratne, 2003; Perera, 2004; Rajasuriya *et al.*, 2004). As indicated earlier, in the long run, we will not succeed in promoting a change in behaviour among fishermen who use relatively effective but rather destructive seine nets on the reefs, while their neighbours use explosives. Thus, law enforcement needs to be strengthened urgently to primarily stop the people destroying marine habitats for profitable but short-term gains (e.g. Weerakody, 2004). However, this should be done concurrently with awareness raising activities among the broader public and policy makers, not only to influence the behaviour of more stakeholders, but also to create general support for law enforcement and supplement it with social pressure. One example, of many, that illustrates the need to influence public and political opinion is the event in Seenigama, Sri Lanka, in 2002, where the police had to release a number of coral miners after strong protests by fellow villagers and local politicians (Perera, 2004). For the segment of the people involved in illegal activities, such as coral mining and destructive reef fishing, that are poor with no access to alternative income sources (e.g. Dharmarethnam & Kirupairajah, 2001), increased law enforcement needs to be accompanied by extensive development programmes providing other livelihood opportunities.

### Consider Research Efforts as Only a Contribution to the Process, Not a Solution

The call for more resources for research and monitoring should only be made in the context of enhancing the capability to set priorities, continuously assess and optimise the decision-making processes and actions taken. Support to research and monitoring should not be seen as a way to show deed and replace or delay uncomfortable management measures. With fluctuating and complex ecosystems such as coral reefs, a scientific consensus that specifies in detail the levels or means of exploitation that are sustainable will take a long time to accomplish if we will ever get there other than through trial and error. Policy makers will have to live with some uncertainty in decision-making (Ludwig, 1993; Olsen & Christie, 2000), and we certainly know enough about the most urgent threats to the coral reef systems in South Asia (e.g. coral mining, blast fishing, overfishing, pollution and sedimentation) to take immediate action. Unequivocal results are already at hand from the 3–4 decade long large-scale experiment on the effects of uncontrolled human activities on coastal ecosystems in South Asia.

CORDIO will maintain the support to long-term monitoring in the region, and continue to develop demonstration projects for reef management. Also, in 2004, CORDIO, together with IUCN Regional Marine Programme, assumed the role of the GCRMN node in South Asia. This increases CORDIO's emphasis on networking, dissemination of information, and influencing coral reef stakeholders at local as well as policy-making levels.

## ACKNOWLEDGEMENTS

CORDIO wishes to express gratitude to Global Coral Reef Monitoring Network (GCRMN) South Asia, the South Asia Co-operative Environment Programme (SACEP), the World Conservation Union (IUCN), the Ministry of Environment and Forests (MoEF), India, the Zoological Survey of India (ZSI), the Suganthi Devadason Marine Research Institute (SDMRI), India, the National Institute of Oceanography (NIO), India, the Marine Research Centre, Ministry of Fisheries, Agriculture and Marine Resources (MRC), Maldives, the National Aquatic Resources and Research Development Agency, Ministry of Fisheries and Aquatic Resources (NARA), Sri Lanka, the Turtle Conservation Project (TCP), Sri Lanka, Eastern University, Sri Lanka, and all the other people on whom the CORDIO work in South Asia has depended. The financial support from Sida is also acknowledged.

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# The Status of Coral Reefs in Sri Lanka in the Aftermath

## of the 1998 Coral Bleaching Event and the 2004 Tsunami

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*key words:* reef recovery, tsunami impacts, branching *Acropora*, Corallivorous butterfly fish

### ABSTRACT

Coral reefs were monitored in Sri Lanka to assess their recovery since the bleaching event in 1998 and the damage caused by the tsunami in 2004. Reef recovery after 1998 is slow except in some patch reefs in the Bar Reef Marine Sanctuary where *Acropora cytherea* and *Pocillopora damicornis* have shown rapid growth. The tsunami damage to coral reefs was variable; the major impact was seen both in the south and in the east, with extreme damage at two locations in the east coast. Hard coral cover has declined in a number of reef sites affected by the tsunami while there was no damage to the corals in the Bar Reef Marine Sanctuary and the Pigeon Islands National Park. The abundance and species diversity of butterfly fish was high where branching *Acropora* corals dominated the habitat. A combination of heavy resource exploitation, use of destructive fishing methods and lack of management continue to degrade reefs in Sri Lanka.

### INTRODUCTION

A progressive decline in reef condition in Sri Lanka has been observed and reported within the last 3 decades. Prior to 1998, the decline in reef condition was attributed primarily to human activities, sedimentation and crown-of-thorns starfish infestations (De Silva, 1981; 1985a; 1985b; Rajasuriya & White, 1995). In 1998, the El Niño induced coral bleaching event accelerated this decline and recovery has been low and variable (Rajasuriya, 2002). Many reefs affected by the 1998 bleaching event have undergone changes in the composition of coral communities, with previously dominant species being replaced by others (Rajasuriya, 2002), which is a pattern reported from elsewhere by Sprecher *et al*. (2003); Loch *et al*. (2002), Raymundo & Maypa (2002).

Butterfly fishes (Chaetodontidae) are among the most sensitive to severe reef damage; they are also easy to study because they are highly conspicuous within their habitats. The abundance of butterfly fish was studied in relation to percent cover and families of hard corals as they are closely associated with their habitats and the abundance of corallivorous butterfly fish correlates with live hard coral cover (Bell & Galzin, 1984; Bouchon-Navaro & Bouchon, 1989; Russ & Alcala, 1989). A previous study carried out in Sri Lanka showed a positive correlation between corallivorous butterfly fish and live hard coral cover (Öhman *et al*., 1998). A marked reduction in the abundance of butterfly fish on coral dominated habitats was reported by Rajasuriya and Karunarathna (2000) after the 1998 coral bleaching event and they have remained scarce due to poor reef recovery (Rajasuriya, 2002).

There have been sporadic attempts to manage reefs and resource exploitation, however, there has been little success due to lack of continuity in management efforts and inadequate resources to implement regulations. De-

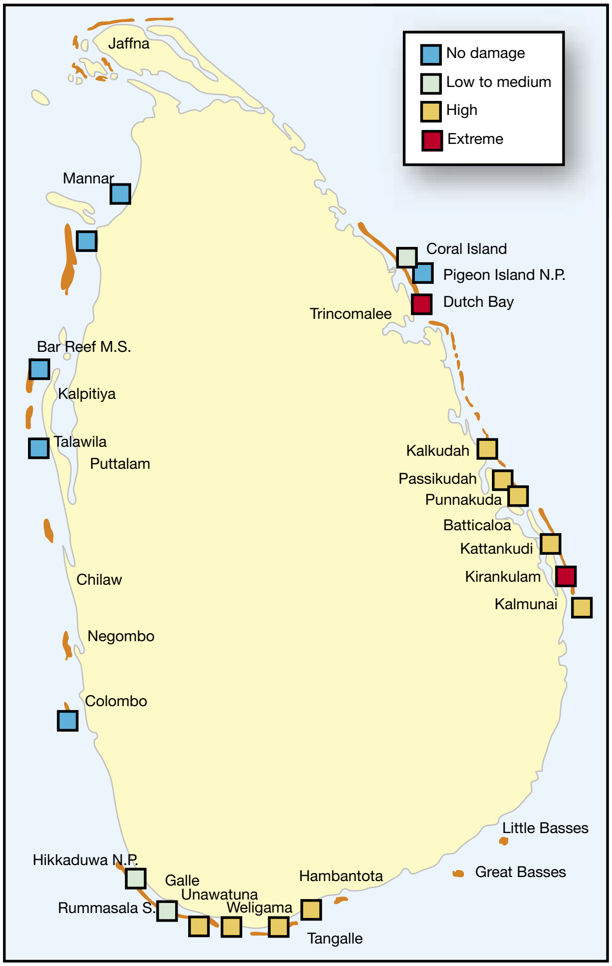


**Figure 1.** Map of Sri Lanka showing the reef sites surveyed and the level of impact from the tsunami on 26 December, 2004.

structive fishing and uncontrolled resource harvesting has increased rapidly; even within marine protected areas (Rajasuriya *et al.*, 2004). Most reef habitats remain degraded and heavily exploited (Rajasuriya *et al.*, 2004) even prior to the tsunami in December 2004. The tsunami caused further damage to many coral reefs (NARA, CORDIO/IUCN/GCRMN, SLSAC, 2005; IUCN-CORDIO, 2005). Preliminary observations indicated that it was the shallow coral habitats that suffered extensive damage (NARA, CORDIO/IUCN/GCRMN, SLSAC, 2005) and that it was difficult to recognize damage to other reef habitat types such as sandstone and rock reefs that do not support sizeable fragile coral communities. This report is based on results of pre and post tsunami reef monitoring on shallow coral reef habitats where damage to reef structures and the resulting loss of live corals can be recognized and quantified easily.

Shallow coral reef habitats were surveyed along the northwest, the south and the east coasts of Sri Lanka (figure 1). Data describing the cover of live coral and the pre and post tsunami reef status are presented for several monitoring sites.

## METHODS

The study sites were selected among shallow (1–5 m depth) coral reef habitats where changes in percent cover of live hard coral can be used to indicate reef condition. Study sites were at Mannar, Bar Reef Marine Sanctuary, Talawila, Colombo, Hikkaduwa National Park to Tangalle and Rekawa in the South, Pigeon Island, Coral Island and the Dutch Bay in Trincomalee and reefs from Punnakuda to Kalmunai in the Batticaloa District. Surveys were carried out between January and May 2005.

Benthic communities and substrate were assessed using 50 m line intercept transects (LIT) and reef fish censuses were carried out using 50 m x 5 m belt transects at the same locations as the LIT (English *et al.*, 1997). In order to be able to compare the results with post-tsunami condition of the reefs, transects were deployed on the same coral patches at previously monitored reef sites. Reefs in Trincomalee were surveyed previously using the ReefCheck methodology (Christoffelsz *et al.*, 2000) whilst the present study was conducted using the LIT and belt transect methods described in English *et al.* (1997). Benthic categories recorded were live hard coral (HC), soft coral (SC), dead hard coral (DC), coral rubble (CR), algae (ALG), substrate (SUB), rock (RK), sand (SA), silt (SI) and others (OT), which includes sponges, tunicates and corallimorpharians. Data were collected by snorkeling and scuba diving.

Qualitative reef assessments to determine the impact of the tsunami were also carried out at several locations using manta tow and timed swims (English *et al.*, 1997, Hill & Wilkinson, 2004).

## RESULTS

### Status of Reefs

#### *Bar Reef Marine Sanctuary*

Bar Reef was not affected by the tsunami. Recovery of shallow coral reef habitats was variable; some coral patches showed very good recovery whilst others had low recovery. The most serious impact in 1998 was among the shallow reef flats (SRF) (Rajasuriya & Karunarathna, 2000). The shallow reef flat (08 22.228 N, 079 44.805 E) had shown the fastest recovery and change since 1998. Prior to bleaching, this SRF had a high live hard coral cover (83.95%), comprising mainly of *Acropora* spp. both branching and tabulate (75.37%) and *Echinopora lamellosa* (8.58%) (Rajasuriya *et al.*, 1998). Since Bar Reef was not affected by the tsunami, this report contains the results of benthic components from surveys carried out in early 2003 and in the last quarter of 2004 (figure 2). By early 2003, hard coral cover was 18.64% (*Pocillopora damicornis* 6.91%, *Acropora cytherea* 6.78%, *Galaxea fascicularis* 2.28%, *Echinopora lamellosa* 0.75%, *Montipora* sp. 0.73% and others 1.19% (Faviidae & Siderastreidae). By end of 2004, the hard coral cover had increased to 40.76% due to very rapid growth of *Acropora cytherea* (*Acropora cytherea* 24.86%, *Pocillopora damicornis* 12.6%, *Montipora* sp 3% and others 0.26%).

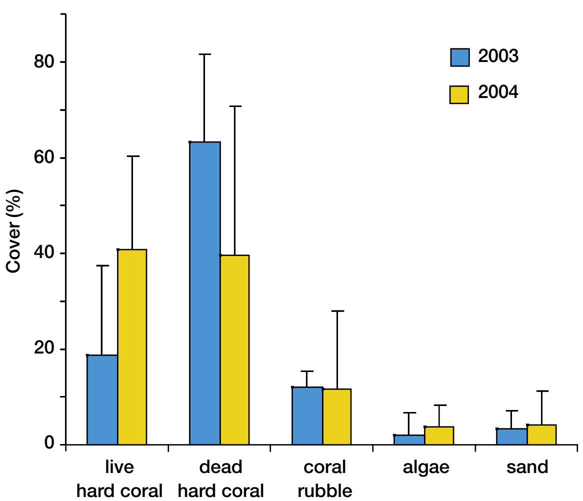


**Figure 2.** Comparison of the cover of the most abundant substrate types recorded on a shallow reef flat in Bar Reef Marine Sanctuary between 2003 and 2004.

The dead coral area has declined from more than 60% in 2003 to about 40% by the end of 2004 due to the rapid growth of live hard corals over the dead branching coral reef structure. There was little change in the amount of coral rubble as the reef structure composed of dead hard coral has been relatively stable since the bleaching in 1998.

#### *Hikkaduwa National Park*

Hikkaduwa National Park has a fringing coral reef. This reef was dominated by branching *Acropora* prior to bleaching in 1998 and since then the dominant coral species has been *Montipora aequituberculata* (Rajasuriya, 2002). By the end of 2004, the live hard coral cover was 15.55% (*Montipora* 10.77%, *Pocillopora* 0.24%, *Acropora* 0.10% and others 4.45%, which consisted of species belonging primarily to the families Faviidae, Poritidae and Siderastreidae).

The impact of the tsunami on Hikkaduwa National Park was relatively low. The live hard coral cover was reduced to 12.07% (figure 3 on next page). The percentage of dead coral has declined but coral rubble has increased from 17.28% (2004) to 29.78% (2005). Some corals at the base of the reef structure have been covered by sand due to shifting of sand within the reef lagoon and the percentage cover of sand had increased from 13.29% (2004) to 14.66% (2005).

#### *Kapparatota, Weligama*

The fringing coral reef at Kapparatota in Weligama was dominated by branching *Acropora* spp, foliose *Montipora* spp, *Millepora* and *Pocillopora* prior to bleaching. Except

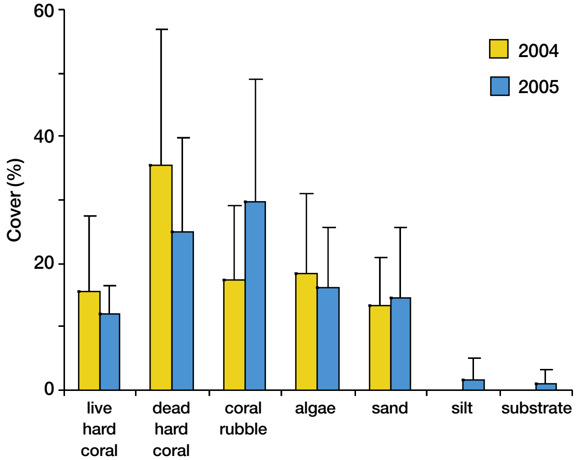


**Figure 3.** Comparison of the cover of the most abundant substrate types recorded pre and post tsunami at Hikkaduwa National Park.

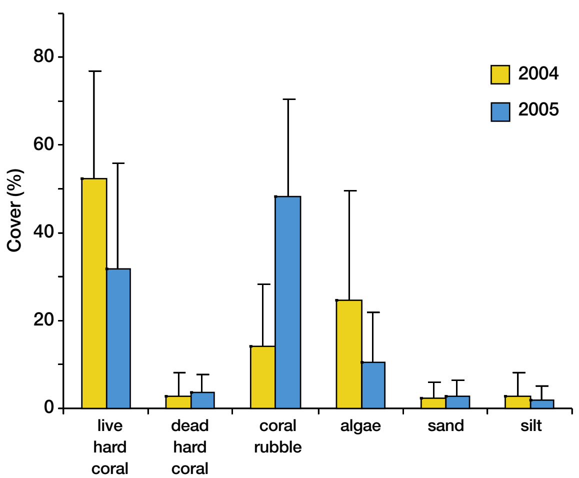


**Figure 4.** Comparison of the cover of the most abundant substrate types recorded pre and post tsunami at Kapparatota, Weligama.

for some branching *Acropora* and *Montipora* almost all other corals were destroyed. Some of the branching *Acropora* recovered relatively rapidly whilst most *Montipora* escaped bleaching (Rajasuriya & Karunarathna, 2000).

In 2004, the hard coral cover was 52.12% (branching *Acropora* 46.21% and *Montipora* 5.78% and *Pocillopora* 0.12% others, which were mainly faviids) (figure 4). The tsunami had caused damage to some of the branching *Acropora* by sweeping away parts of the reef and dumping coral rubble on live coral areas. In January 2005, the hard coral cover was 31.9% whilst the dead coral had increased from 2.95% (2004) to 3.44% (2005). The coral rubble had increased from 14.24% (2004) to 48.32% (2005). Much of the *Halimeda* had also been swept away and algal cover had declined from 24.73% (2004) to 10.49% (2005). Due to loss of live corals, the area of suitable habitat for reef fish such as damselfish (Pomacentridae) and butterfly fish (Chaetodontidae) has declined.

*Unawatuna*

The shallow coral reef habitat at Unawatuna was severely damaged during the 1998 bleaching event and recovery has been low (Rajasuriya, 2002). By 2004, hard coral cover had reached 15.74% (figure 5) and the dominant species were *Pocillopora eydouxi* and *Pocillopora verrucosa*. However, large amounts of dead coral (60.82%) were present. The dead coral was the result of the 1998 bleaching however, it had not yet broken down into coral rub-

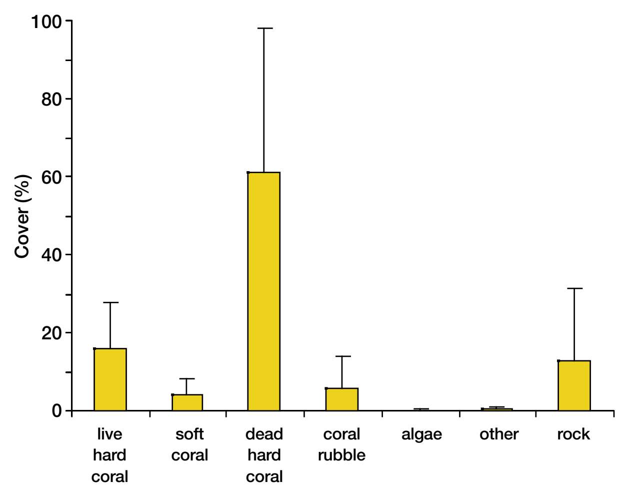


**Figure 5.** The cover of the most abundant substrate types recorded on the shallow coral reef habitat at Unawatuna.

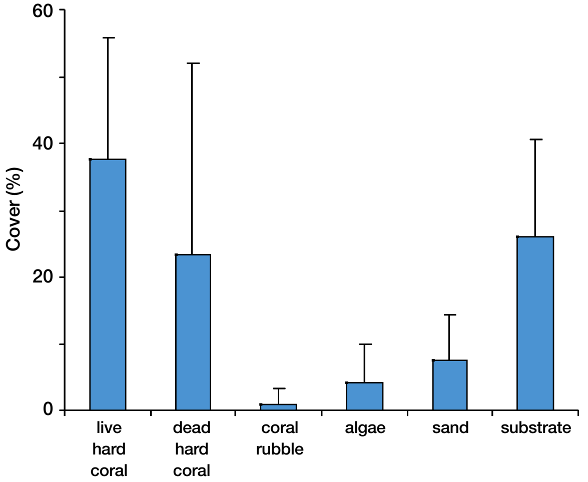


**Figure 6.** The cover of the most abundant substrate types recorded on the shallow coral reef habitat at Talawila.

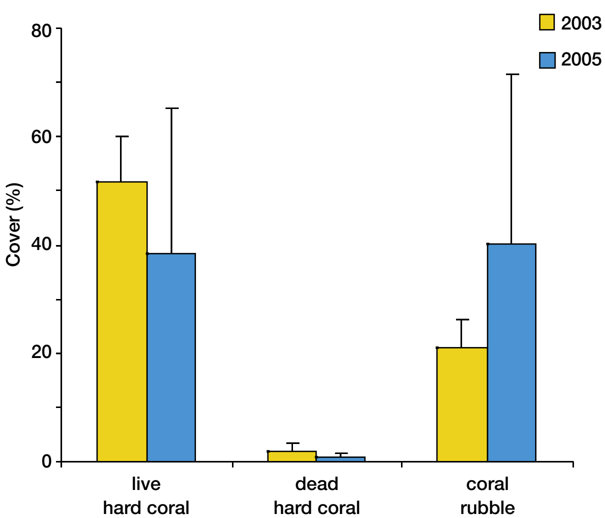


**Figure 7.** The cover of the most abundant substrate types recorded at Dutch Bay, Trincomalee.

ble and continues to provide substrate for new coral settlement.

The tsunami had caused extensive physical damage to sections of the reef slope due to the movement of large pieces of dead coral and coral rubble. The inner reef and the reef crest were also damaged by the movement of large amounts of coral rubble over the reef crest.

*Talawila*

The Talawila coral reef, which is located about 30 km south of the Bar Reef Marine Sanctuary, was in relatively good condition in 2005. The shallow reef habitat is about 500 m from the shore. It had a live hard coral cover of 37.73% (figure 6), which was dominated by several genera of the family Faviidae (*Favia, Favites, Montastrea, Leptoria, Platygyra*), and *Porites* spp. Many of these colonies were large, especially those on the reef slope. Most had a diameter of about 3 m and a height of 2 to 3 m. Sections of the reef had banks of dead branching and tabulate *Acropora* as a result of bleaching in 1998. The dead hard coral cover was 23.25%, whilst the substrate (limestone) was 26.06%. The tsunami had not damaged the reef at Talawila.

*Dutch Bay, Trincomalee*

The coral reef in Dutch Bay was in relatively good condition with sections of healthy branching *Acropora* spp., foliose *Montipora* and *Echinopora lamellosa*. This reef was previously monitored using ReefCheck methodology and had a cover of live hard coral of about 52% and 20% coral rubble. The reef sustained extensive damage due to the tsunami and the reef currently supports 38.30% live hard coral, while coral rubble covers 40.23% of the substrate (figure 7). A large section of the reef that contained foliose *Montipora* spp. has been completely destroyed by the tsunami.

*Pigeon Island National Park*

The Pigeon Island National Park is located about 15 km north of Trincomalee. It has a shallow coral reef, which is dominated by branching and tabulate *Acropora* species. In 2003, it had a live hard coral cover of 54.38%, dead coral 1.25% and coral rubble 31.88%. The tsunami did not damage this reef and the live coral cover had increased in 2005 to 74.25%, dead coral cover was less than 1% and coral rubble was 8.31% (figure 8 on next page).

The slightly higher percentage of dead coral at Pigeon

Island in 2005 appears to be the result of feeding by the crown-of-thorns starfish (*Acanthaster planci*); a total of 17 individuals were recorded in an area of about 2000 $m^2$ in the study area.

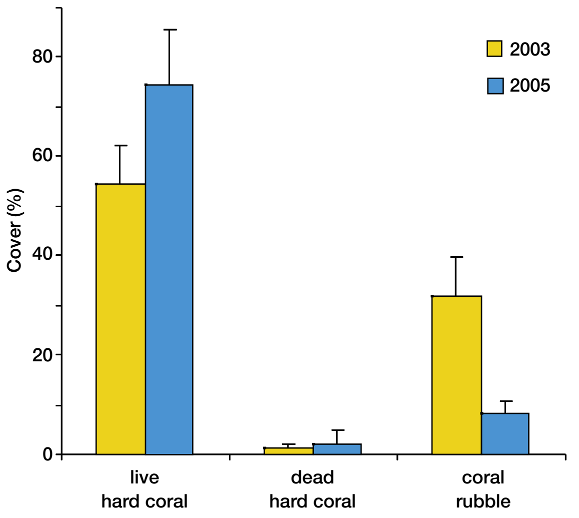


**Figure 8.** Comparison of the cover of the most abundant substrate types recorded at Pigeon Island National Park, Nilaveli pre and post tsunami.

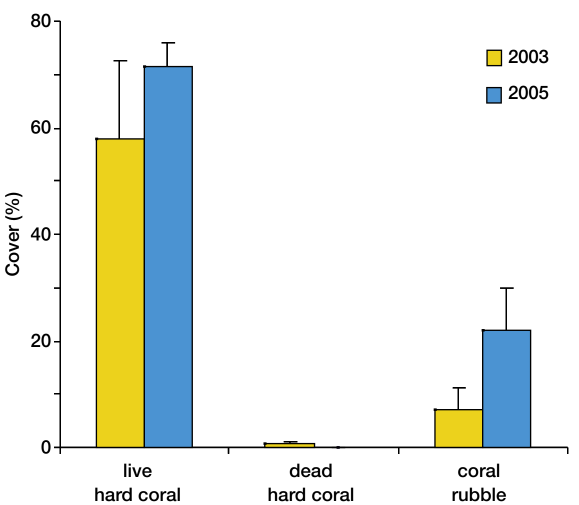


**Figure 9.** Comparison of the cover of the most abundant substrate types recorded at Coral Island, Nilaveli pre and post tsunami.

### *Coral Island*

Coral Island is located close to shore and about 1 km north of the Pigeon Island National Park. There are coral patches on the northern and southern flanks of the islet, which is a rocky outcrop in front of the Irrakkandy Lagoon at Nilaveli. The coral reef habitats are dominated by branching *Acropora* spp.. Other commonly occurring genera are *Montipora, Porites, Galaxea, Favia, Favites, Platygyra* and *Leptoria*.

The live hard coral cover in 2003 was 58.13%, dead coral was 0.63% and coral rubble was 7.19%. The live hard coral cover had increased to 71.25% and coral rubble was 22.08% (figure 9). The dead coral cover was negligible. The tsunami had caused partial damage to the reef slope by scraping off sections of the reef resulting in an increase in the amount of coral rubble. Although intense, this damage affected only a small area and much of the reef on the southern side remains intact.

### *Coral Reefs in Batticaloa, Matara and Hambantota District*

Fringing coral reef habitats were investigated in 2003 at Kalkudah, Passikudah and Punnakudah. The reef lagoons in the two former sites appeared to have been severely affected by the bleaching in 1998. The lagoon of Kalkudah Reef had very little live hard coral; *Sargassum* and filamentous algae were abundant on the dead coral. The lagoon of Passikudah Reef supported few live hard corals, which consisted mostly of *Goniastrea edwardsi*, *Platygyra pini* and *Porites* spp.. Large sections of many colonies were dead and there were large amounts of coral rubble in the reef lagoon (Rajasuriya *et al.*, 2003). Dharmaratnem and Ahamed (2004) carried out a detailed study of benthic communities in the lagoon of Passikudah Reef and reported that the live hard coral cover was 15.81%, dead coral was 26.06% and algae 15.69%. The seaward reef slope of Passikudah had comparatively high live hard coral cover; mainly *Porites* spp, *Psammacora digitata* and *Acropora microphthalma* (Rajasuriya *et al.*, 2003).

The healthiest coral reef among the three sites investigated in 2003 was at Punnakuda, about 10 km north of Batticaloa. This healthy fringing reef had banks of

**Figure 10.** Extreme tsunami damage to corals was seen at Kirankulam, eastern Sri Lanka where large *Porites* domes have been deposited on land up to a distance of about 150m from the shoreline. *Photo:* ARJAN RAJASURIYA.

branching and tabulate *Acropora* spp.. To the north of the fringing reef there was an area of about 2000 $m^2$ that had large *Porites* domes (Rajasuriya *et al.*, 2003). A survey conducted in May 2005 revealed that the *Acropora* banks at Punnakuda had died leaving very little living coral and much of the reef reduced to rubble with many coral colonies overturned. Although the tsunami had a severe impact on this fringing reef, it was evident from the presence of undisturbed dead coral banks that large-scale coral mortality had occurred prior to the tsunami.

IUCN-CORDIO (2005) reported that the tsunami had shifted large amounts of coral rubble in Passikudah Bay and that there was medium to high-level damage to inshore coral habitats at Kalmunai, Kalkudah and Sallithivu in the Batticaloa District. A survey by NARA in May 2005 revealed that the most extreme tsunami damage to corals was at Kirankulam, about 10 km south of Batticaloa where large *Porites* domes have been deposited on the foreshore about 150 m from the shoreline (figure 10).

In the south considerable damage was seen at Tangalle where the entire back reef area has been covered by coal rubble. At Rekawa, about 10 km east of Tangalle, the reef was mined for many years and the tsunami has dislodged many coral blocks already damaged due to mining. Much damage has been caused to a patch of *Montipora aequituberculata* close to shore. There was little live coral to be damaged at Kudawella, west of Tangalle; large amounts of coral rubble have been redistributed at this location. The impacts of the tsunami at Polhena east of Weligama were similar to Kudawella. Several other small fringing reefs in the south showed low to medium level damage from the tsunami.

## CORAL BLEACHING

Low to medium level coral bleaching in shallow coral reefs was observed at many locations from March to May 2005. The main sites were Bar Reef, Hikkaduwa, Dutch Bay, Pigeon Island, Coral Island, Punnakuda, Kattankudi and Kalmunai. The temperature recorded at these sites during late March until May 2005 was between 30° C and 32° C. A temperature gauge installed by the Oceanographic Division of the National Aquatic Resources Research and Development Agency (NARA) at Kirinda near Hambantota had recorded a temperature of 33° C in mid March 2005. The level of bleaching varied from paler than normal to total or partial bleaching. All colonies of those species affected within a given area were not bleached. For example, on Coral Island, several species of *Acropora* were paler than normal, while some faviids (*Favites chinensis* and *F. abdita*) appeared to be highly susceptible and were totally bleached. At all other sites, there was little impact on *Acropora* spp. while faviids (*Favia, Favites, Platygyra, Leptoria, Goniastrea*) and *Porites* seemed more susceptible to stress (table 1).

However, a survey on 22 June 2005 revealed that there was total bleaching of nearly all species of hard and soft corals in Batticaloa and surrounding areas to a depth of about 20 m. The sea surface temperature was in the area was about 32° C.

## THE ABUNDANCE AND DIVERSITY OF BUTTERFLY FISH AT STUDY SITES

The abundance and species of butterfly fish (Chaetodontidae) were recorded at selected reef sites as they may be indicators of reef health (Reese, 1989; Bouchon-Navaro & Bouchon, 1989; Öhman *et al.*, 1998). Fifteen species of chaetodontids were recorded within the belt transects conducted at 7 shallow coral reef sites (table 2).

The highest average number of butterfly fish per study site was recorded at Pigeon Island, which had the highest live hard coral cover. This was followed by Coral Island, Dutch Bay, Bar Reef, Talawila, Hikkaduwa and Kapparatota/Weligama (figure 11).

**Table 1.** Level of bleaching exhibited by different species of hard corals in March and April 2005

| Affected species | Level of bleaching |
|---|---|
| *Favia pallida* | Partial bleaching (mainly on upper surfaces of colonies) |
| *Favia favus* | Partial bleaching (mainly on upper surfaces of colonies) |
| *Favites abdita* | Partial to total bleaching |
| *Favites chinensis* | Partial to total bleaching |
| *Platygyra daedalea* | Partial bleaching (mainly on upper surfaces of colonies) |
| *Leptoria phrygia* | Partial bleaching (mainly on upper surfaces of colonies) |
| *Hydnophora microconos* | Partial bleaching (mainly on upper surfaces of colonies) |
| *Goniastrea retiformis* | Partial to total bleaching |
| *Symphyllia radians* | Partial bleaching |
| *Pocillopora damicornis* | Partial to total bleaching |
| *Pocillopora eydouxi* | Partially bleached |
| *Acropora muricata* | Partial and total. Only few small colonies affected |
| *Montipora foliosa* | Edges of whorls bleached on some colonies |
| *Montipora* sp. (encrusting) | Pale and bleached colonies |
| *Porites* sp. | Partial bleaching of large colonies. Total bleaching of some small colonies |

**Table 2.** Butterfly fish species recorded within belt transects

| Butterfly Fish Species | Bar Reef | Talawila | Hikkaduwa NP | Kapparatota | Coral Island | Pigeon Island | Dutch Bay |
|---|---|---|---|---|---|---|---|
| *Chaetodon auriga* | – | – | x | x | x | x | x |
| *Chaetodon citrinellus* | – | – | x | – | x | – | – |
| *Chaetodon collare* | x | x | x | – | – | – | – |
| *Chaetodon decussatus* | – | x | x | x | x | – | x |
| *Chaetodon falcula* | – | – | – | – | – | x | – |
| *Chaetodon guttatissimus* | – | – | – | – | – | x | x |
| *Chaetodon lunula* | – | x | x | – | – | – | – |
| *Chaetodon melannotus* | x | – | – | – | x | x | – |
| *Chaetodon meyeri* | – | – | – | – | x | x | x |
| *Chaetodon octofasciatus* | – | x | – | – | – | – | – |
| *Chaetodon plebeius* | x | – | – | – | x | x | x |
| *Chaetodon trifascialis* | x | – | – | – | x | x | x |
| *Chaetodon trifasciatus* | x | x | – | x | x | x | x |
| *Chaetodon vagabundus* | – | – | x | x | x | x | x |
| *Heniochus pleurotaenia* | – | x | – | – | – | – | – |

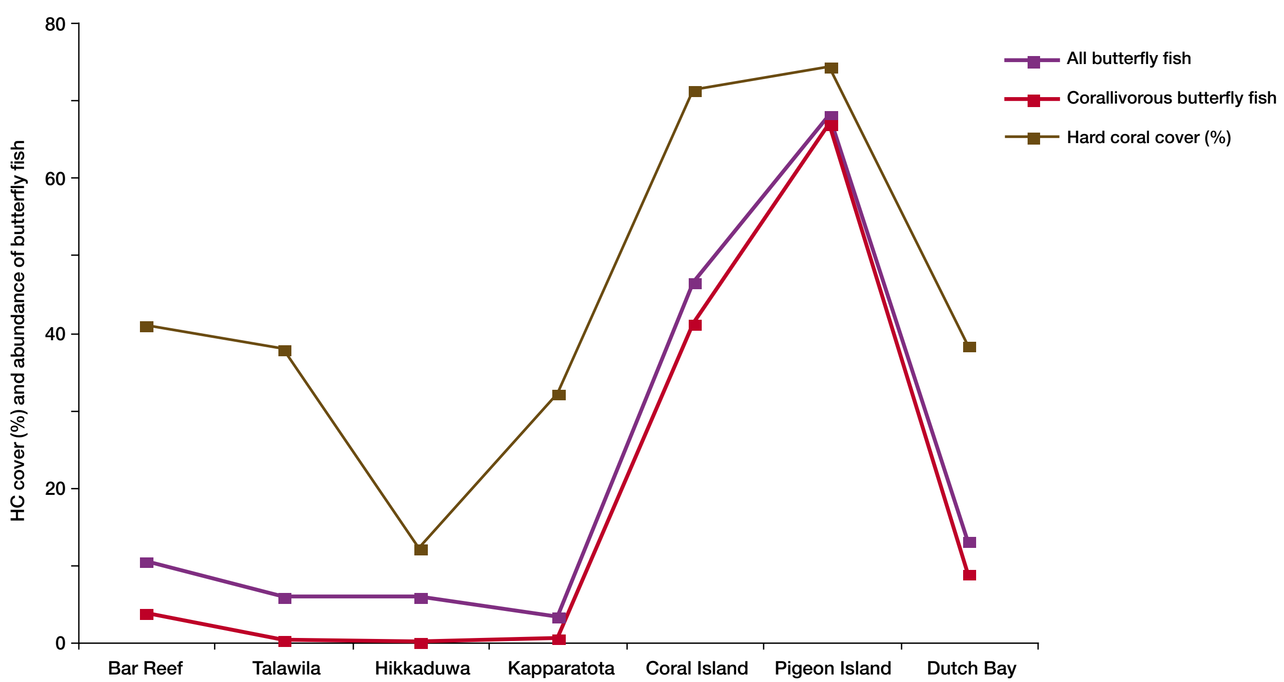


**Figure 11.** Hard coral cover, average number of butterfly fish and corallivorous butterfly fish recorded at each site.

**Figure 12.** Corallivorous butterfly fish were abundant at Pigeon Island National Park, eastern Sri Lanka. *Photo:* ARJAN RAJASURIYA.

Of the 15 species of butterfly fish recorded, only 6 (*Chaetodon melannotus, C. meyeri, C. octofasciatus, C. plebeius, C. trifascialis* and *C. trifasciatus*) are considered obligate corallivores, whilst the other 9 species feed on a variety of invertebrates including scleractinian polyps (Allen, 1985; Harmelin-Vivien, 1989). The highest abundance of butterfly fish recorded at Pigeon Island and Coral Island in April 2005 was due to a recruitment pulse of 4 obligate corallivore species (*Chaetodon trifasciatus*, *C. trifascialis, C. meyeri and C. plebeius*), of which the most abundant was *Chaetodon trifasciatus* (figure 12). The average number of individuals per 250 $m^2$ at Pigeon Island and Coral Island was 49 and 26 respectively.

## DISCUSSION

Tsunami damage to coral reefs varied from no visible damage in the northwest to extreme damage at two locations in the east. It was evident that the structural complexity of the reef and the seabed configuration in the surrounding area has directed the tsunami in inshore waters. The damage to reefs was patchy even within a single reef. The most extensive damage was seen in reef sections where fragile corals (foliose *Montipora* and branching *Acropora*) were exposed to the open sea such as in Dutch Bay at Trincomalee where about one third of the reef was wiped out.

At Kirankulam in the Batticaloa District, large *Porites* domes have been dumped on the foreshore indicating

## Human Impacts

Destructive fishing methods have increased in recent times. Blast fishing targeting reef and reef-associated species is widespread in Sri Lanka, including within marine protected areas, especially Pigeon Island National Park (east), Bar Reef Marine Sanctuary (northwest) and Rumassala Sanctuary (south). Furthermore, other banned fishing methods are used freely. Although the use of purse seine nets is banned within coastal waters, it is carried out in the Bar Reef Marine Sanctuary (BRMS) and is causing severe depletion of fish stocks. Entire schools of snappers (Lutjanids), emperors (Lethrinids) and jacks (Carangids) are targeted; however many other species such as surgeonfish (Acanthuridae) are also caught resulting in severe overfishing and destroying the breeding stocks in the area. Recently, the Ministry of Fisheries and Aquatic Resources apprehended some of the illegal fishers in the BRMS and the surrounding area. This resulted in some of the purse seine fishers switching over to the harvest of sea cucumber, which is a resource that is already overexploited (Rajasuriya et al., 2004). Ornamental fish collection using the banned 'moxy' nets (Ohman, et al., 1993; Rajasuriya et al., 1995) continues to cause severe damage to shallow coral habitats, especially in the south and in the east. Most of this damage occurs to the remaining branching Acroporid corals which are important for recruitment of juvenile butterfly fishes as indicated in this study.

Coral mining in the sea has not been stopped even after the tsunami. Various forms of pollution from land-based sources continue to degrade the coastal waters. Visitor pressure is relatively low at popular reef sites such as Hikkaduwa and Pigeon Island after the tsunami, but due to lack of management, it could increase to unsustainable levels in the near future.

that the force of the tsunami was highly variable at different points along the coast. The tsunami caused damage to live corals at many locations especially in the south at Tangalle, Kudawella, Polhena, Unawatuna and Kapparatota/Weligama by moving large amounts of coral rubble and dead coral blocks resulting from the 1998 bleaching event. The nearshore reef at Tangalle had been severely damaged and its reef lagoon has been completely filled with coral rubble. At Rekawa in the southeast, the tsunami had shifted and broken apart most of the coral blocks damaged by intense coral mining in recent times. The tsunami has not damaged the coral reef at Rumassala Sanctuary in Galle Bay as it is sheltered behind a headland. Overall, coral structures facing the open ocean had sustained more damage than those within reef lagoons. The tsunami had caused the greatest damage to reef structures where the underlying substrate was composed of dead fragile corals (e.g. branching, tabulate and foliose forms) and coral rubble. Similar impacts were reported from Belize, after a severe bleaching event 1998 and a hurricane that caused extensive damage to fragile corals (*Acropora cervicornis* and *Agaricia tenuifolia*) and to some massive corals (McField, 2000). Such fragile substrates are unstable and can be damaged easily by storm waves or other physical forces (Arthur, 2000), which could destroy the living corals above.

Sand and sediment accumulation due to the tsunami in reef lagoons on the south coast was high, although these fringing reefs regularly receive high loads of sand and sediment, especially during the southwest monsoon (Rajasuriya, 1991; Rajasuriya & Premaratne, 2000). The tsunami had caused erosion and redistribution of sand and sediment already present within inshore areas. Regular influxes of sediment and particle bound nutrients appear to be responsible for the overall low condition of southern coastal reefs. High sedimentation has been known to adversely affect coral recruitment (Hodgson, 1990; Wittenberg & Hunte, 1992; Babcock & Smith 2000) and may also contribute to increased algal growth, smothering and burial of corals (Nugues & Roberts, 2003). These conditions have been observed along the entire southern coast especially in Hikkaduwa National Park, Kapparatota/Weligama, Rumassala Sanctuary and Polhena.

The recovery of coral reefs after the 1998 bleaching event has been variable (Rajasuriya, 2002); the highest coral cover in relation to reef area was at Pigeon Island and Coral Island where both reefs were dominated by branching *Acropora* species. Some of the shallow coral patches at Bar Reef have shown good recovery with an abundance of *Acropora cytherea* and *Pocillopora damicornis* while other patches remain in poor condition. Patchy recovery of branching *Acropora* spp. was seen at Kapparatota/Weligama. Reef recovery was low at most other sites in the south, although among new recruits, foliose *Montipora* and massive corals of the families Faviidae and Poritidae were common. The reason for near total loss of live corals at Punnakuda in the east is unknown; however, large-scale coral mortality could be due to severe bleaching in 2004, although only minor bleaching was reported at several locations in the west and east coast (Rajasuriya *et al.*, 2004). Recurrent coral bleaching events may cause much greater damage to reefs than any other natural disaster.

The abundance of butterfly fish showed an increase where there was higher live hard coral cover. The highest abundance was at Pigeon Island followed by Coral Island and Dutch Bay where there were large numbers of juveniles of which the majority belonged to the corallivorous group. Such high densities of juveniles were observed only where there were extensive branching *Acropora* corals. Bouchon-Navaro and Bouchon (1989) discovered that the density of obligate corallivores was positively correlated with the abundance of branching corals but a significant relationship was demonstrated only with *Acropora*. The post settlement feeding of juvenile butterfly fish on benthic organisms is related to their dietary specialization as adults and that the diet of new recruits of obligate corallivores, such as *Chaetodon trifasciatus* and *C. trifascialis*, is comprised exclusively of scleractinian coral polyps (Harmelin-Vivien, 1989). Öhman *et al.* (1998) suggested that the availability of food might result in 'assemblage specific distribution patterns' among butterfly fish. These observations are similar to the results in the present study where highest densities of *Chaetodon trifasciatus* and *C. trifascialis* were present on Pigeon Island and Coral Island, which were dominated by branching *Acropora* species. Branching *Acropora* may also provide protection from predators in addition to a large surface area for feeding. Further studies are required to establish whether the large number of juvenile chaetodontids observed at Pigeon Island and Coral Island eventually control adult populations and whether they can be supported by small coral areas such as in those sites surveyed. The physiological state of the larvae and new recruits may also determine the population dynamics (Booth, 2000). Butterfly fish abundance was low at Kapparatota/Weligama due to heavy pressure from ornamental fish collection. Chaetodontid abundance was also low at Hikkaduwa National Park where branching *Acropora* had not recovered after bleaching in 1998 (Rajasuriya, 2002) and all the species recorded recently were omnivores. The abundance of chaetodontids at Talawila was similar to Hikkaduwa, where the habitat was dominated by massive corals (Faviidae and Poritidae). The relatively low number of butterfly fish, especially the corallivorous species at Bar Reef, could be due to the present dominance by tabulate *Acropora* and *Pocillopora damicornis* whereas previously, the coral habitats were dominated by branching and tabulate *Acropora* species (Rajasuriya *et al.*, 1998) which supported a large number of butterfly fish (Öhman *et al.*, 1997). Chaetodontids are important economically as they are a key species group sought after by the aquarium trade. The understand the long term impact of an overall decline of branching *Acropora* thickets due to repeated bleaching events on butterfly fish populations requires further investigations.

The future of coral reefs in Sri Lanka remains uncertain especially due to lack of management and increasing use of destructive fishing methods and impacts from land use. Although there are adequate laws and regulations, there is inadequate capacity to implement these (Rajasuriya *et al.*, 2004), especially with regard to reef mining and the use of destructive fishing methods. The absence of alternative employment for those who are engaged in activities that damage coral reefs has been identified as one of the main reasons for lack of success in management (Perera, 2003), however, lack of alternative employment should not be used as an excuse to delay implementation of existing regulations.

## ACKNOWLEDGEMENTS

I wish to thank Chaminda Karunarathna of NARA and Nishan Perera of the Sri Lanka Sub Aqua Club for field assistance and data collection. This study was carried out as an activity of the coral reef monitoring programme of NARA supplemented with funds from CORDIO (Coral Reef Degradation in the Indian Ocean) programme.

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