Coral Reef Degradation in the Indian Ocean

Status Report 2005

The coastal ecosystem of the Indian Ocean includes environments such as mangroves, seagrass beds and coral reefs. These habitats are some of the most productive and diverse environments on the planet. They form an essential link in the food webs that leads to fish and other seafood providing food security to the local human population. In addition coral reefs and mangrove forests protect the coastal areas against erosion. Unfortunately, due to a number of human activities, these valuable environments are now being degraded at an alarming rate. The use of destructive fishing techniques on reefs, coral mining and pollution are examples of some of these stresses from local sources on the coral reefs. Climate change is another stress factor which is causing additional destruction of the reefs.

CORDIO is a collaborative research and development program involving expert groups in 11 countries of the Indian Ocean. The focus of CORDIO is to mitigate the widespread degradation of the coral reefs and other coastal ecosystems by supporting research, providing knowledge, creating awareness, and assist in developing alternative livelihoods. The program receives core support from Sweden (Swedish International Development Cooperation Agency) and is also supported by IUCN and Finland. This report presents the results from the period 2003–2005 and summarizes the activities since the start of the program in 1999.

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Coral Reef Degradation in the Indian Ocean. Status Report 2005

CORDIO

KALMAR UNIVERSITY

Coral Reef Degradation in the Indian Ocean

Status Report 2005

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IUCN The World Conservation Union

Sida

Finland

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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 prebleaching 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.

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 1,000m^2 in early 2003, to 10 per 10m^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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Assessing the Status and Improving Management of Coral Reef Resources:

Experiences and Achievements in South Asia

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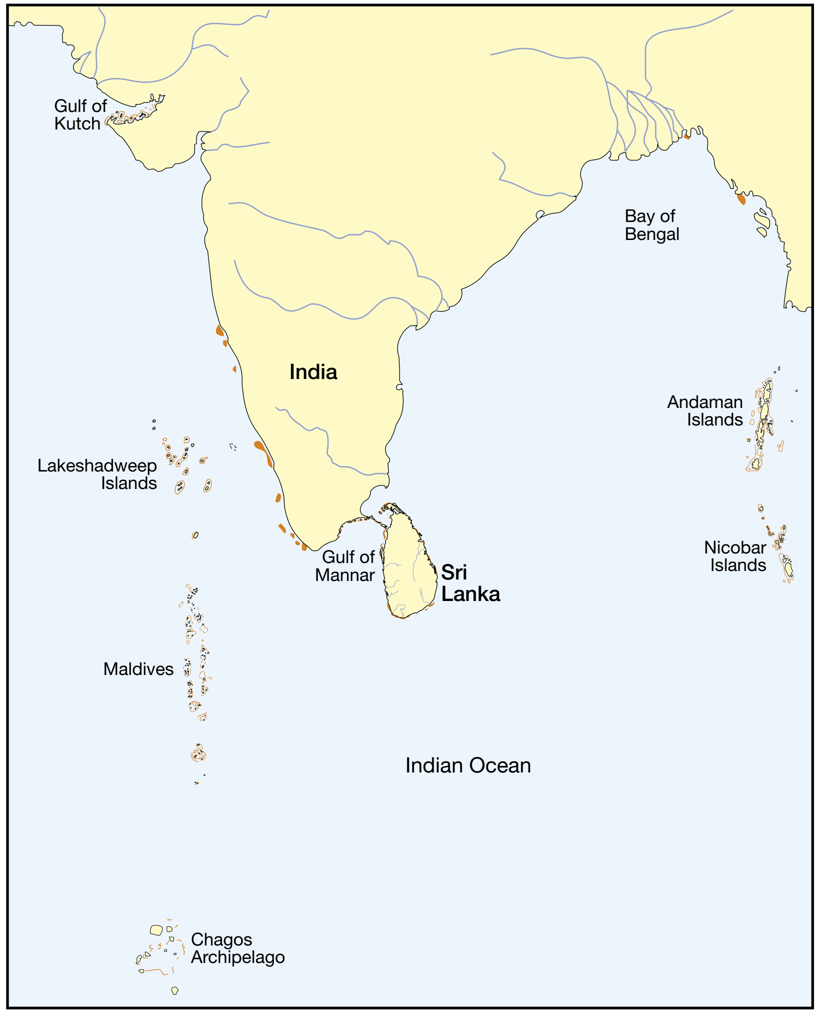
INTRODUCTION

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 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.

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

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.

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Indian Ocean Island – Summary

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INTRODUCTION

The Indian Ocean Islands CORDIO node consists of Comoros, Madagascar, Mauritius and Seychelles, all located within the western Indian Ocean. Although their combined total Exclusive Economic Zone (EEZ) exceed 4.1 million km², coral reefs cover only about 3 500 km², with the largest area being in Madagascar (see table 1).

Significant areas of coral reefs occur in the sub-region, in particular within the Seychelles archipelago, Madagascar, Mauritius, and Comoros. Madagascar has the largest area of coral reefs in the sub-region, mostly dominant along the eastern coast. Most of the granitic islands of the Seychelles are encircled by discontinuous, fringing reefs. Along the east coast of Mahé, reef flats reaching over 2 km in width and terminating in a high algal ridge which descends down a reef slope to a floor typically at 8 to 12 m are observed. In the coral islands, the types of reefs are highly varied from true atolls, raised atolls to submerged or partially submerged atolls and sand banks. Mauritius is almost completely encircled by fringing reefs, with substantial lagoon and barrier reef development on the east and southwest coasts (Salm, 1976). Rodrigues Island (Mauritus) is totally encircled by reefs, with wide shallow reef flats extending from the shore, with its widest extent reaching 10 km in the west (Spalding *et al.*, 2001). The main types of reefs in the Comoros are discontinuous fringing reefs, ranging from 15 m to several kilometres from the coastline. In Comoros, reef cover is most extensive on the island of Anjouan (Scetauroute, 1999).

There are a total of about 14 marine protected areas (MPAs) in the region, covering over 800 km² of ocean.

Table 1. Estimated coral cover in the Indian Ocean Islands

Countries	Land Area (km²)	Coastline (km)	Est. Coral Cover	No. of Species	No. of Genera
Comoros	2 230	469	432 km² (Anjouan)	N.A	N.A
Madagascar	581 540	9 935	~2 000 km²	112	57
Mauritius	2 030	496	~500 km²	133	47
Seychelles	450	747	~577 km²	174	55

Source: McClanahan *et al.*, 2000.

Table 2. Characteristics of marine protected areas in the sub-region

Country	Name	Year Est.	Size (km^2)
Comoros	Moheli Marine Park	2001	404
Madagascar	Nosy Atafana Marine Park	1989	10
	Masoala Marine Park	1997	100
Mauritius	Fishing Reserves (Port Louis, Grand Port, Black River, Poudre d'Or, Poste Lafayette, & Trou d'Eau Douce)	1983	63.2
	Blue Bay Marine Park	1997	3.5
	Balaclava Marine Park	1997	5
Seychelles	St Anne Marine National Park	1973	14
	Aride Island Special Reserve	1979	0.1
	Baie Ternay Marine National Park	1979	1
	Cousin Island Special Reserve	1979	1
	Curieuse Marine National Park	1979	16
	Port Launay Marine National Park	1979	1.5
	Aldabra Special Nature Reserve/World Heritage Site	1981	190
	Silhouette Marine National Park	1987	

Source: Francis *et al.*, 2002.

All of these MPAs include substantial areas of coral reefs, however, recent assessments indicate that there are still a number of important coral reefs areas which should be included in MPAs in all of these countries (Payet, 2004). Within its research programme CORDIO has assisted and supported monitoring within and outside MPA's.

STATUS OF THE REEFS

The status of coral reefs in the Indian Ocean is reported in the 'State of the Coral Reefs 2004' report, through the contribution of CORDIO experts (Ahamada *et al.*, 2004). This summary provides an update to that report.

Comoros

Monitoring of coral reefs in Comoros is undertaken at 20 sites on the three main islands in the group. Monitoring has been ongoing since the 1998 mass coral bleaching event, and in many areas coral recovery has been observed.

However, reported coral recovery has been modest. In some areas (Isandra Island), coral cover has increased from 36% in 2003 to 42% in 2004. Ouani (Ajounan Island) remains one of the most intact and diverse reef within the Comoros which deserves better management, although it was also affected by the 1998 bleaching. In some areas such as Bimbini reef (Anjouan Island), live coral cover has actually decreased from 24% in 2003 to 18% in 2004, primarily due to a proliferation of sea urchins and also pressure from trampling and anchor damage. Conservation efforts at the Moheli Marine Park (Moheli Island) indicate that coral reef recovery is enhanced when areas are protected and human intervention reduced.

Surveys undertaken in 2005 (Ahamada, 2005) indicate a 48.8% increase in coral cover in Isandra Island, a slight increase over 2004. However, in Ouani, the extent of recovery from 2003 to 2005 ranges up to 61%. Extensive stands of branching and tubular *Acropora* species which are currently unprotected at this site continue to be threatened by human intervention.

Madagascar

Due to its large coastline, coral reef monitoring sites around Madagascar are separated by large distances and also exposed to various local conditions which can influence recovery. For example, sites such as Dzamandjar (on the north-west coast) saw a decline in live hard coral cover (LHC) in 2004, whilst in Foulpointe (on the east coast) LHC has increased, despite high levels of sediment input in that region. At the 'Grand Recif' in Toliara (on the south-west coast), no significant change in coral cover has been reported. Overall human impacts on coral reefs in Madagascar include sediment discharge from unsustainable land-use practices and fishing pressure has not diminished and remains largely unmanaged. Natural events such as cyclones also impact on coral reefs, in particular unconsolidated ones.

Mauritius

Coral bleaching was also observed in the lagoons of Mauritius in 1998 during regular coral reef monitoring. However, the percentage of bleached corals was less than 5% at all the sites surveyed (7 sites). Follow up surveys in 1999 showed that the coral reefs exhibited marked recovery. In 2003, further bleaching of corals was observed in late February but by June, 97% of the bleached corals had recovered. Coral cover dropped by 11% to 37% in 2002. Likewise, in 2004 almost 60% of the corals were affected by bleaching during the warmest month (March) but by July most of these affected corals had recovered. Overall, Mauritius reported a higher coral mortality at all of the sites due to the 2004 bleaching episode than previous episodes.

Coral cover at the Blue Bay Marine Park remained stable at 91%. Substantial stand of *Acropora* sp. (59%) remain, primarily as a result of intensive conservation efforts by the Mauritius Government from human intervention, mainly from hotel and tourism development.

Seychelles

Most of the shallow reefs in the Seychelles archipelago were bleached in 1998. Seven years after the bleaching event, recovery of coral communities has been variable, although recovery has been hampered by recurring bleaching events in 2002 and 2003. In 2000, mean LHC was only 3% (surveys done at 22 sites), but in 2004 mean LHC was 10.2% (surveys done at 48 sites) a significant increase despite the recurring bleaching events.

Detailed coral reef surveys of Cosmoledo Atoll in 2002 showed that bleaching-related mortality had been quite severe, despite its remoteness from human population (Souter *et al.*, this volume). Coral mortality in the lagoon was very high, with 95% of the large colonies of *Acropora* completely decimated.

Recovery rates on carbonate reefs were found to be much slower than on granitic reefs. This may be due to the greater stability of granitic reefs compared with carbonate reefs (Payet *et al.*, this volume). The majority of reefs with high rates of recovery are found in MPAs.

ASSESSMENT OF TSUNAMI DAMAGE

Seychelles was the only country within this CORDIO node to have reported damage to its coral reefs as a result of the tsunami of 26 December 2004 that affected many countries in south-east Asia and the Indian Ocean. A rapid assessment of the damage was undertaken by CORDIO and IUCN in February 2005 (Obura & Abdullah, 2005). Coral reefs were found to be particularly vulnerable to physical damage from the tsunami waves due to the weakened reef structure and bio-erosion as a result of the recent bleaching events. The survey revealed little direct damage caused by the tsunami on coral reef habitats, with the majority experiencing 5% reduction in coral cover, especially in unconsolidated reef areas. However, greater than 50% substrate damage and greater than 25% of direct damage to corals was observed in northern and eastern-facing carbonate reef sites.

CLIMATE CHANGE IMPACTS

As a result of the 1998 coral bleaching due to elevated sea surface temperatures (SST), research aimed at predicting the occurrence of such bleaching events is being undertaken. Sheppard (2003) using mean historical SSTs (from 1871 to 1999) in combination with the HadCM3 climate model (IS92a climate scenario) generated forecast SST for the period 2010–2025. The results of this modelling work indicated that reefs found at latitudes between 10–15° south in the western Indian Ocean will be affected by elevated SST every 5 years. Although areas outside of this geographical range will also be affected, the model does not give clear results. Such predicted coral bleaching events will have serious impacts on ongoing conservation efforts and coral recovery.

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CORAL REEF DEGRADATION IN THE INDIAN OCEAN

Status Report 2005

Coral Reef Degradation in the Indian Ocean

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Finland

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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 1,000m^2 in early 2003, to 10 per 10m^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 31ºC during May 2001, which was only 1ºC 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

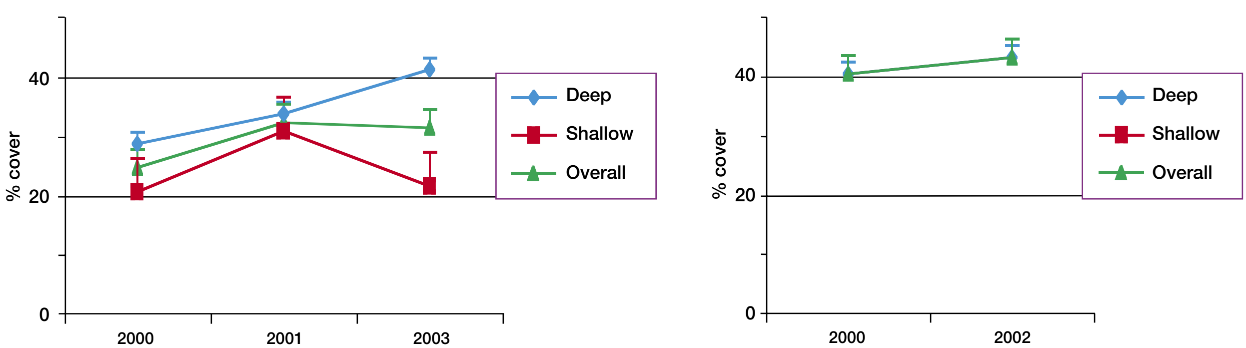

Figure 1. Mean percent cover (and s.d.) of hard corals at Socotra during 2000, 2001 and 2003 (left) and the Brothers Islands during 2000 and 2002 (right).

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.

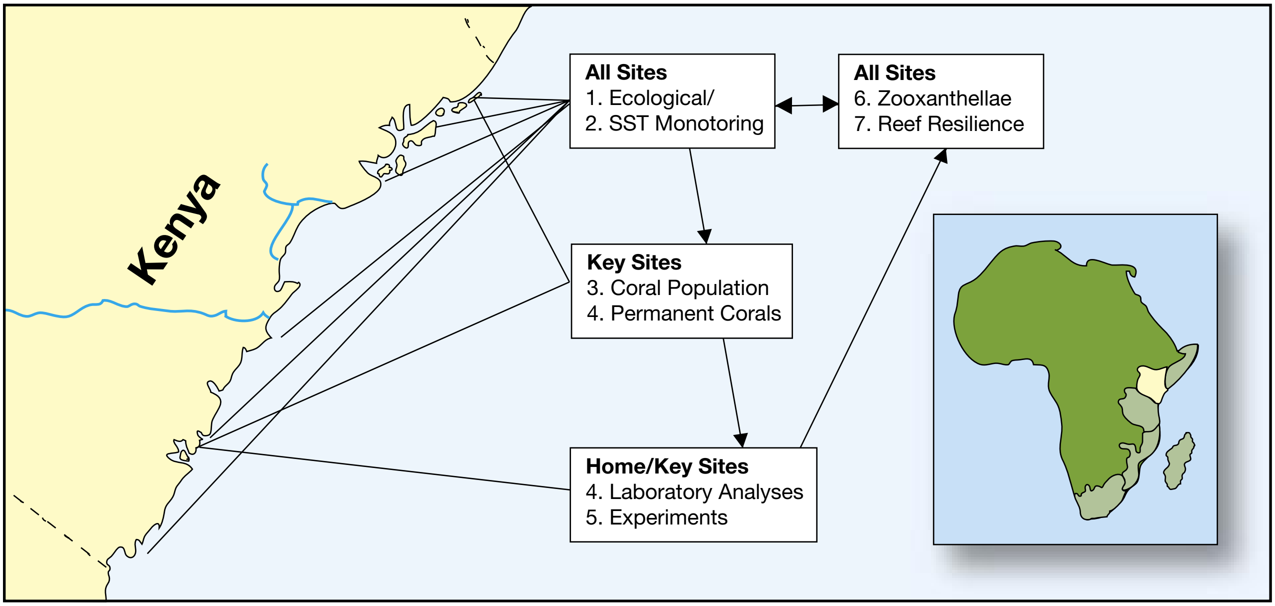

Figure 1. Schematic diagram of the hierarchical components of resilience studies of coral reefs in Kenya listed in table 1. Primary study sites are the Kiunga and Mombasa Marine Parks in the north and south, respectively, marked by stars.

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

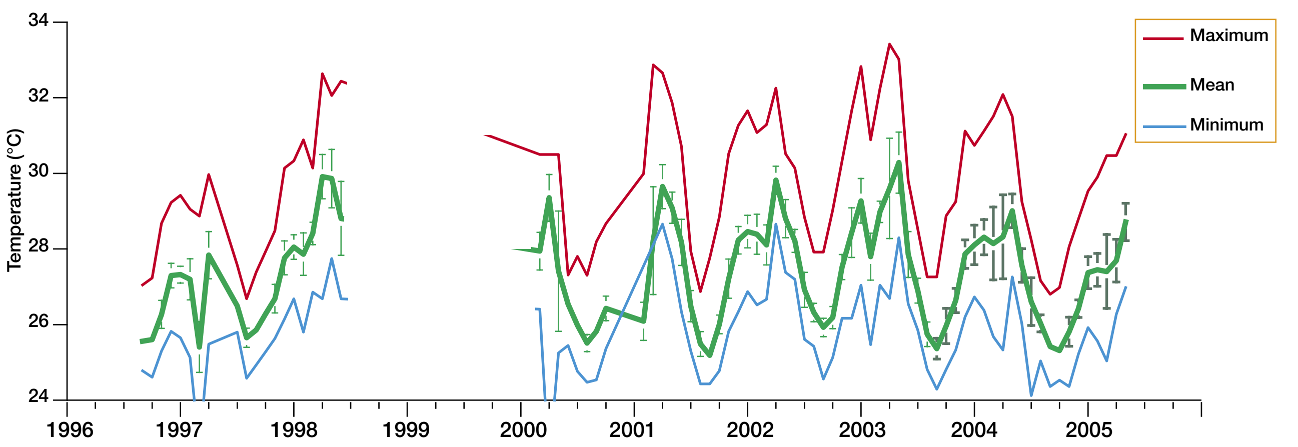

Figure 2. Long term sea temperature record for Mombasa Marine Park from 1996 to present, for depth <1 m at MLW. Data shown are monthly mean and standard deviation, minimum, maximum values. A data gap for May 1998–December 1999 was due to a faulty logger.

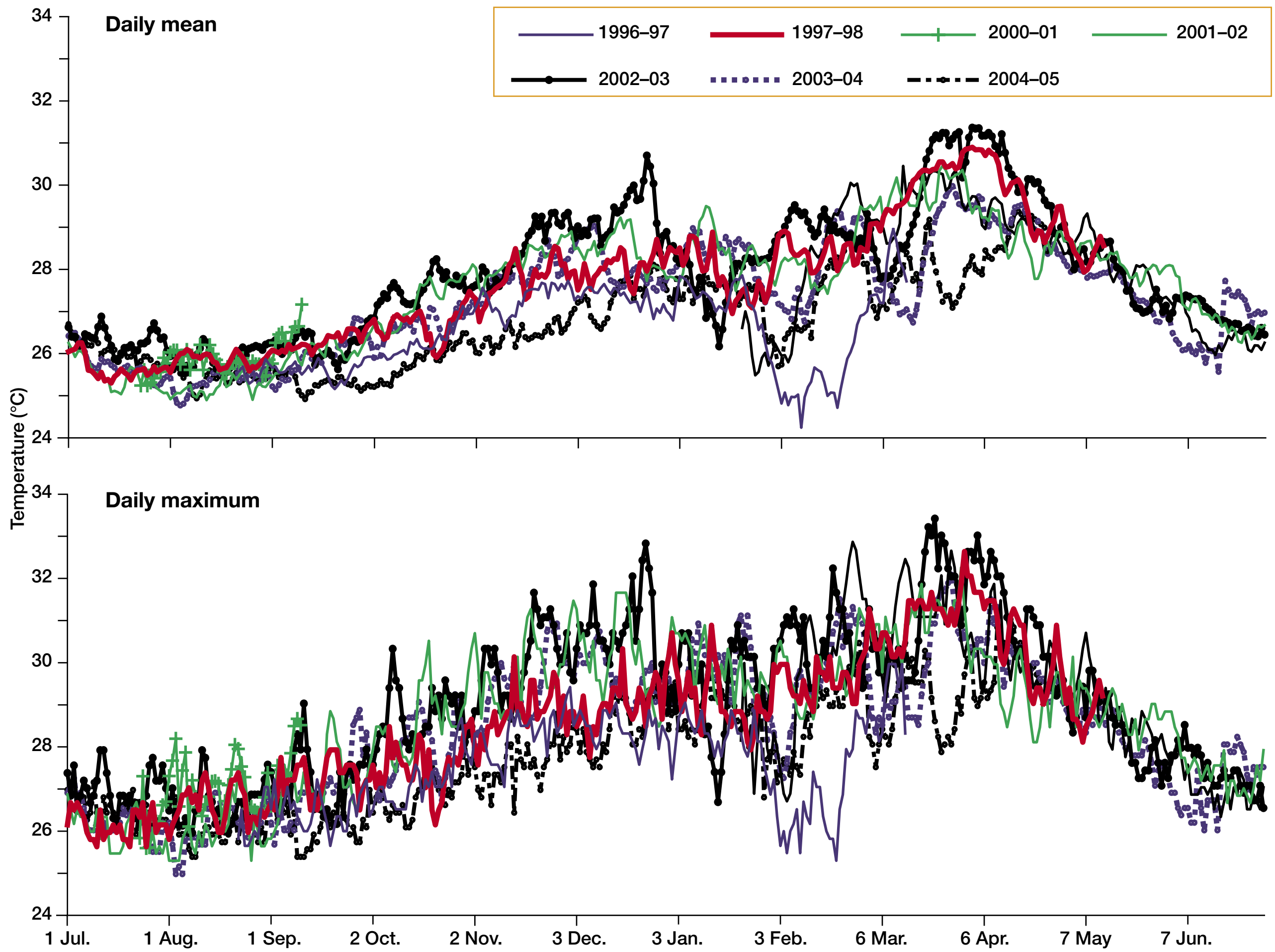

Figure 3. Annual daily temperature records (mean and maximum) for Mombasa Marine Park. The annual period is shown from July to June to show the increase in temperature from August to March. Same dataset as presented in figure 2. The dark red line shows the temperature profile for 1997–98 which culminated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

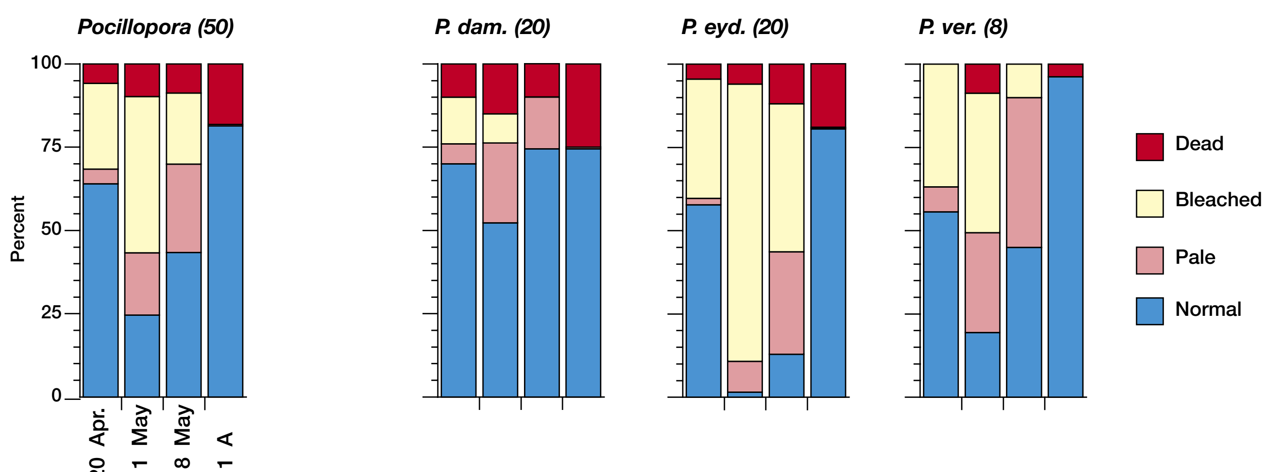

Figure 4. Differences in bleaching resistance between *Pocillopora damicornis*, *P. eydouxi* and *P. verrucosa* at Nyali Reef, Mombasa, April–August 2003. The y-axis shows the percentage of colonies showing normal, pale and bleached condition, and mortality.

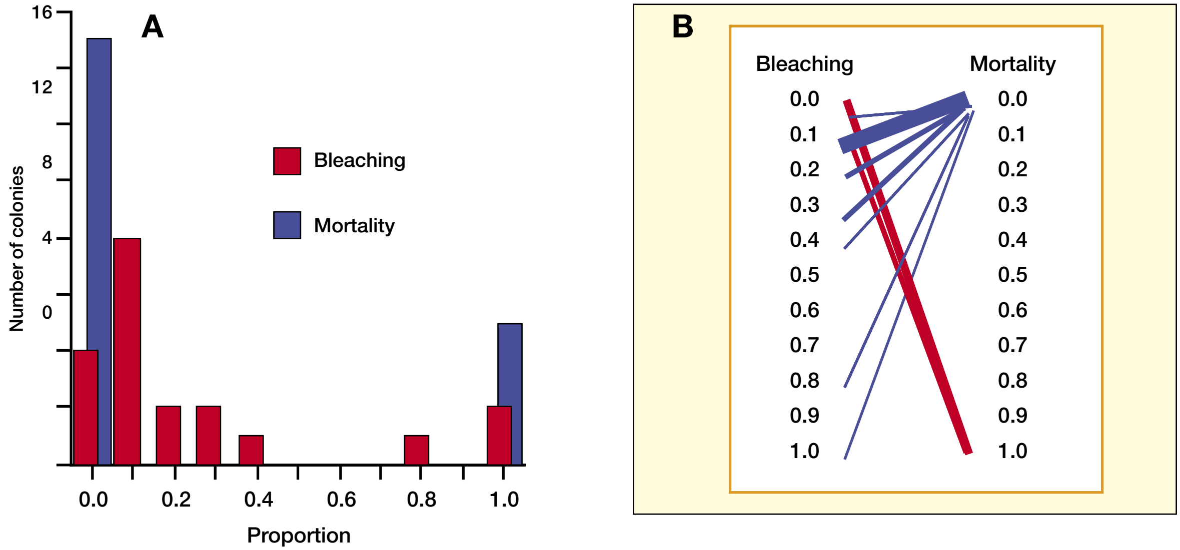

Figure 5. Maximum levels of bleaching and mortality of individual colonies of *Pocillopora damicornis* in Mombasa Marine National Park in 2003 (from figure 4). Bleaching was noted shortly after 20 April, 2003, and observations were recorded on 1 and 18 May, and after all bleaching had ceased on 11 August 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$\cdot$m^{-2} at Kichwani, Mnemba Atoll compared with only 0.04 and 0.16 individuals$\cdot$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 2. Bongoyo Marine Reserve 3. Pangavini Marine Reserve 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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BACKGROUND

Mozambique lies on the east coast of Africa between latitudes 10º 20' and 26º 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 km^2 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

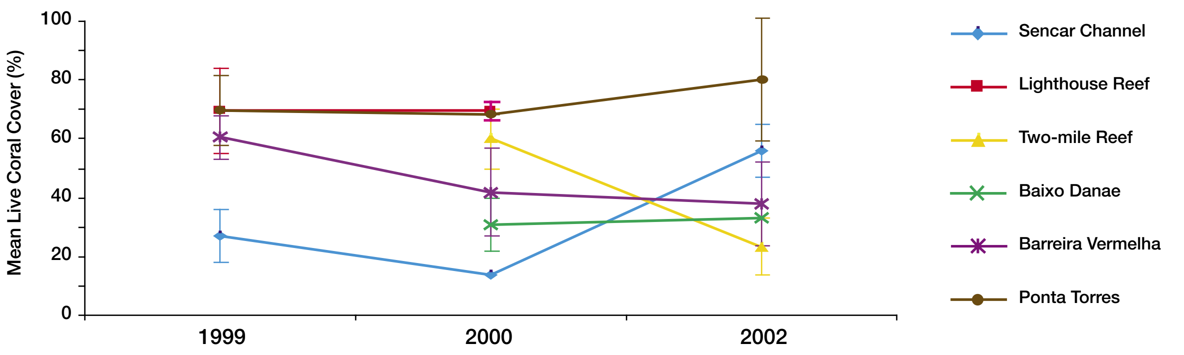

Figure 1. Trends in live hard coral cover at six protected reefs surveyed between 1999 to 2002.

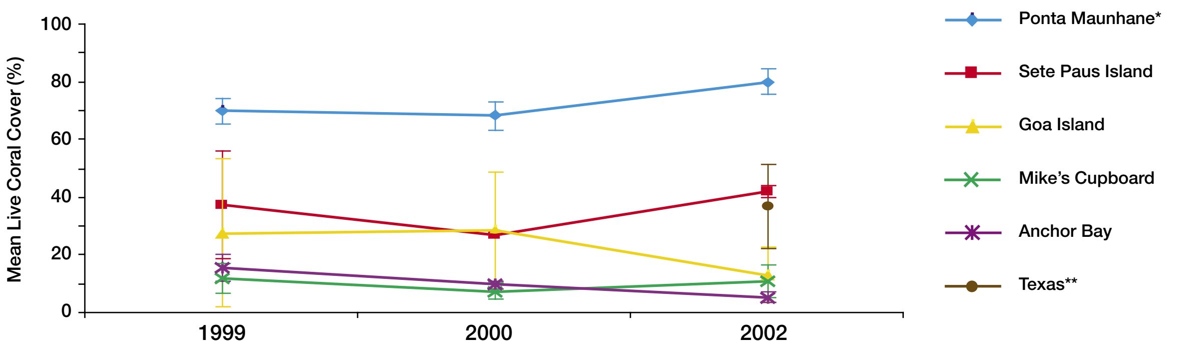

Figure 2. Trends in live hard coral cover at six unprotected reefs surveyed between 1999 and 2002. *This reef is not legally protected reef but is located deeper than 25 m and access is restricted to experienced divers only. **Monitoring station established in 2002.

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-

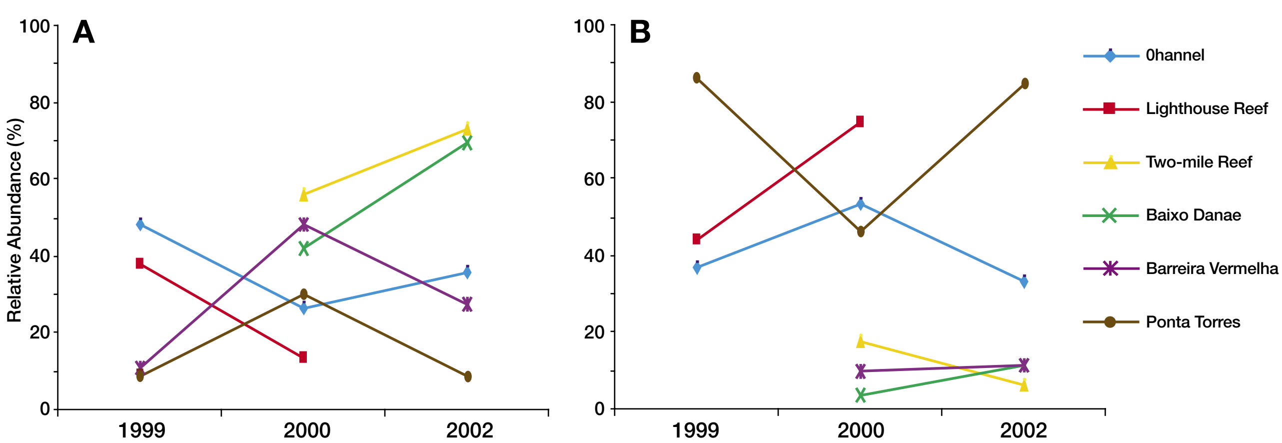

Figure 3. Trends in the relative abundance of (a) herbivorous and (b) carnivorous reef fish at six protected reefs surveyed between 1999 and 2002. Sencar Channel Reef has been protected since 2001.

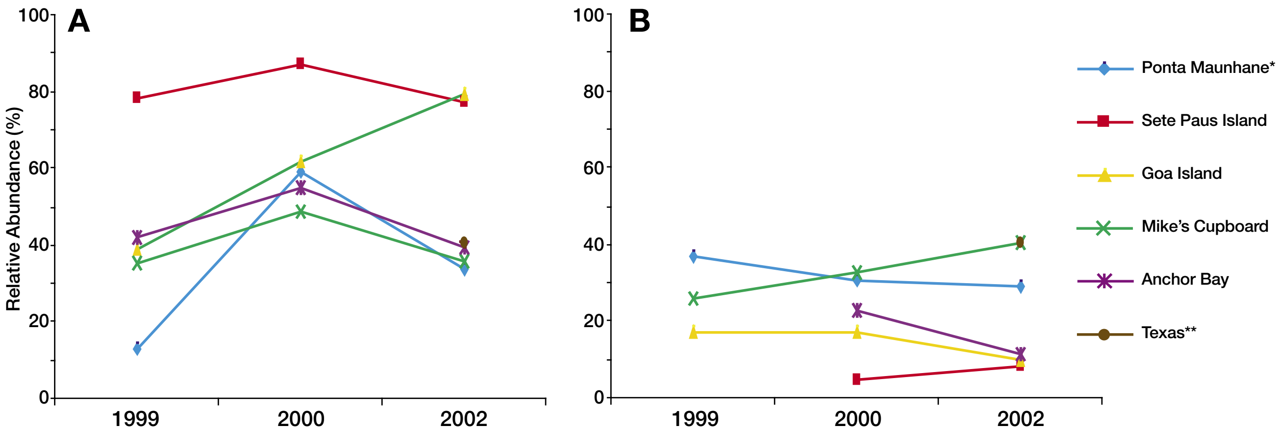

Figure 4. Trends in the relative abundance of (a) herbivorous and (b) carnivorous reef fish at six unprotected reefs surveyed between 1999 and 2002. *This reef is not legally protected reef but is located deeper than 25 m and access is restricted to experienced divers only. **Monitoring station established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

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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

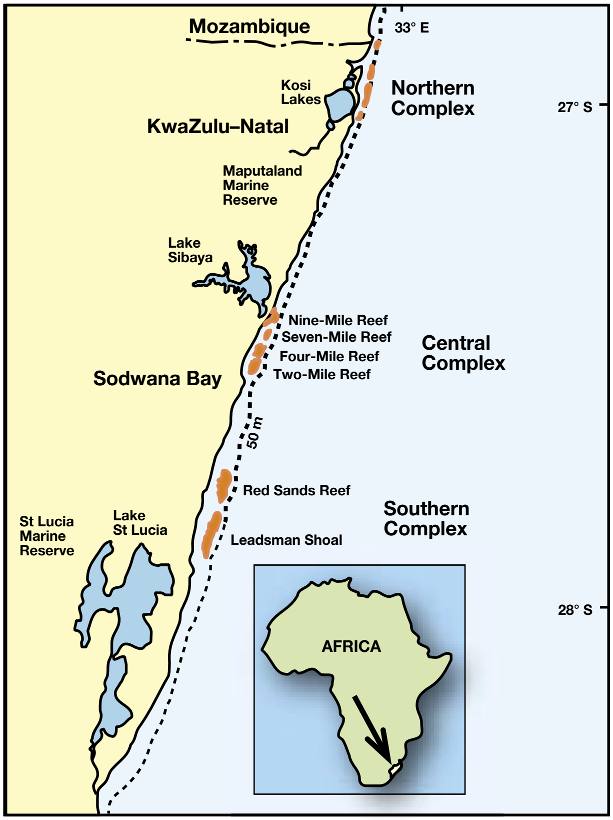

Figure 1. The northern, central and southern reef complexes of northern KwaZulu-Natal, South Africa (after Schleyer, 2000).

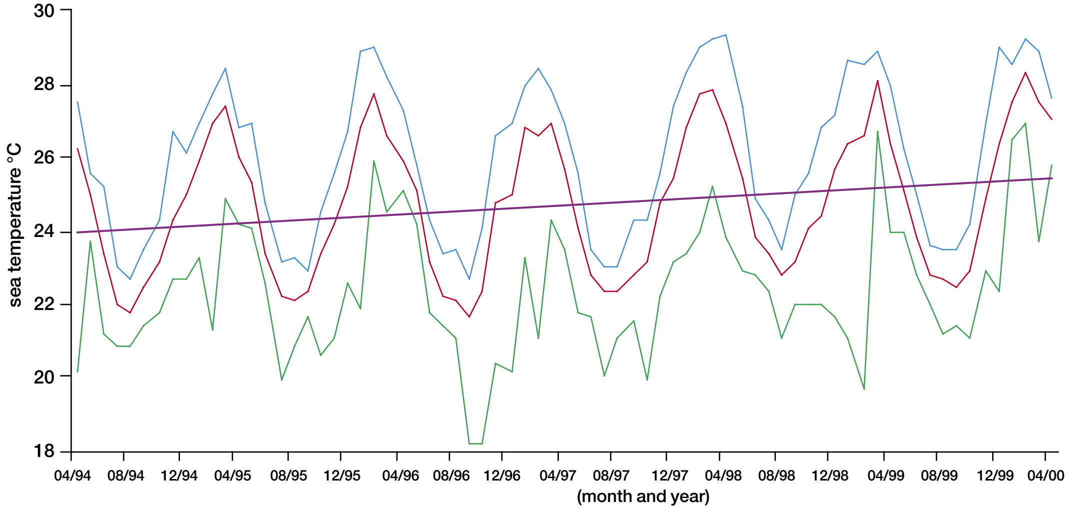

Figure 2 a. Monthly maximum, mean, and minimum sea temperatures recorded at a depth of 17 m (low tide) at a fixed monitoring station located at Sodwana Bay between May 1994 and April 2000. The regression line for the mean temperature data is included (temperature increase=0.27°C.y^{-1}).

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.

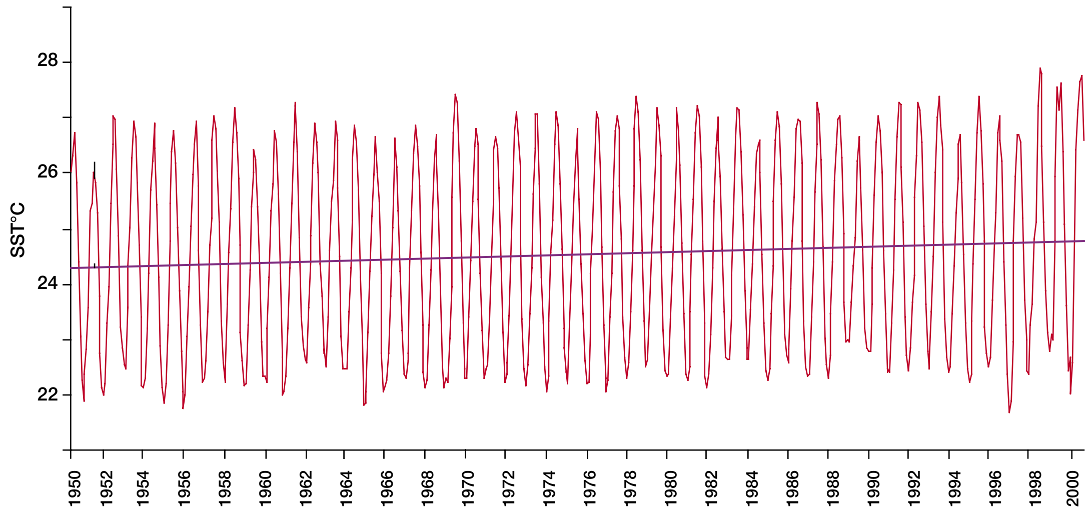

Figure 2 b. Monthly mean sea surface temperatures for the 2° latitude x longitude block incorporating Sodwana Bay. The regression line for all points is shown (reconstructed SST fields supplied by the South African Weather Service; temperature increase =0.01°C.y^{-1}).

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.

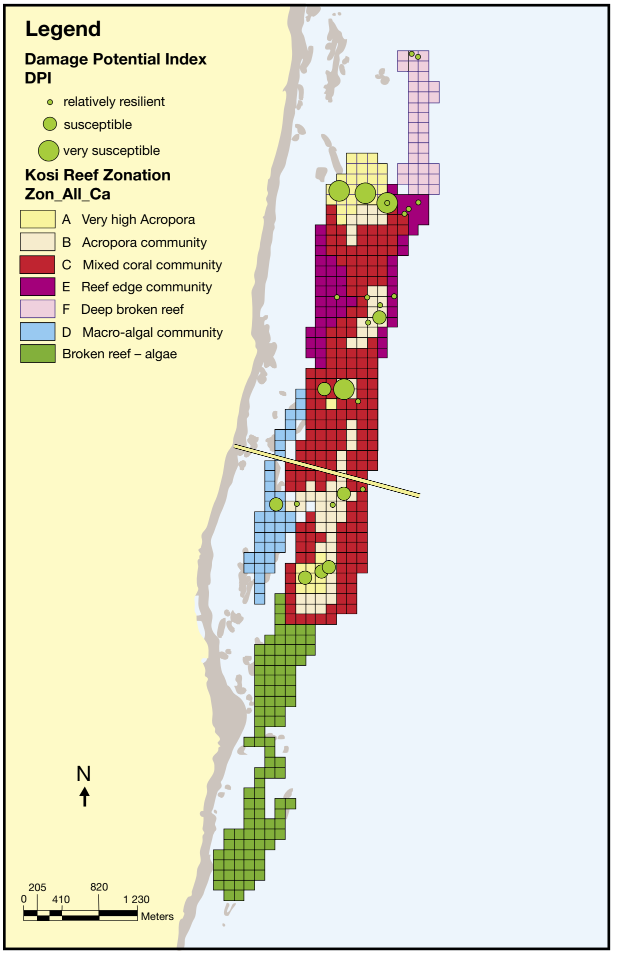

Figure 3. Biotic zonation of the Kosi reef system, showing the damage potential index (DPI) within the zones and recommended boundary between the Kosi Reef sanctuary in the north and diving concession area in the south (after Schleyer and Celliers, *in press*).

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

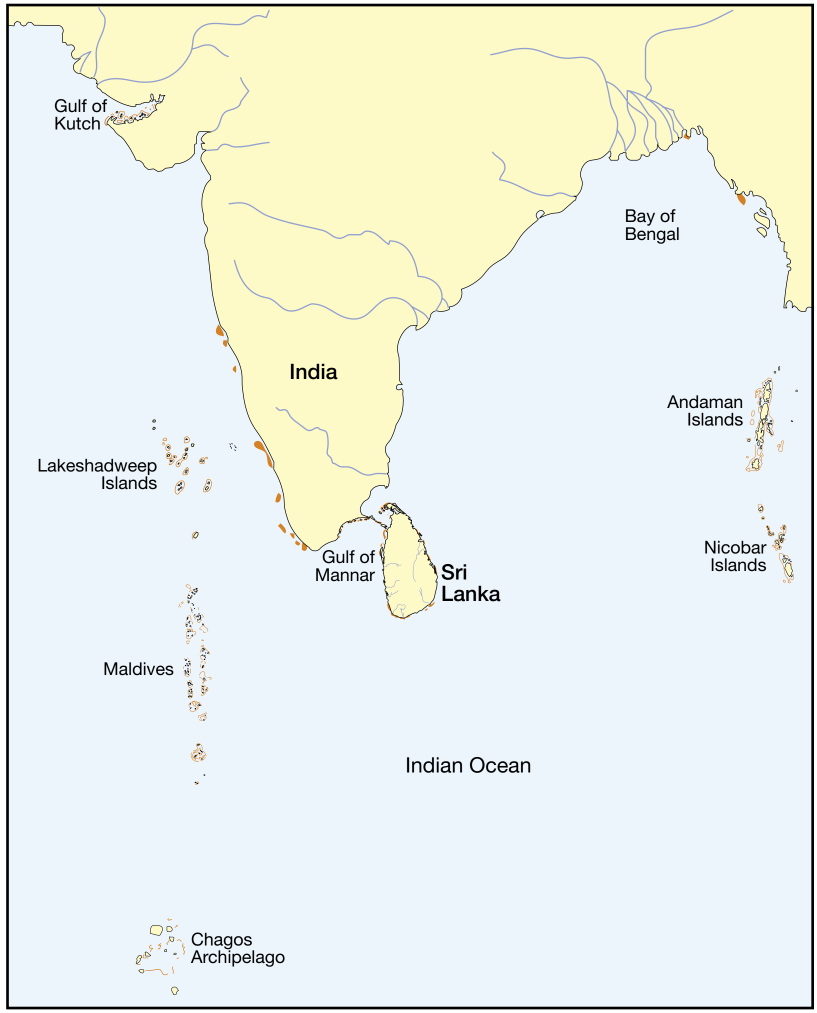
INTRODUCTION

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).

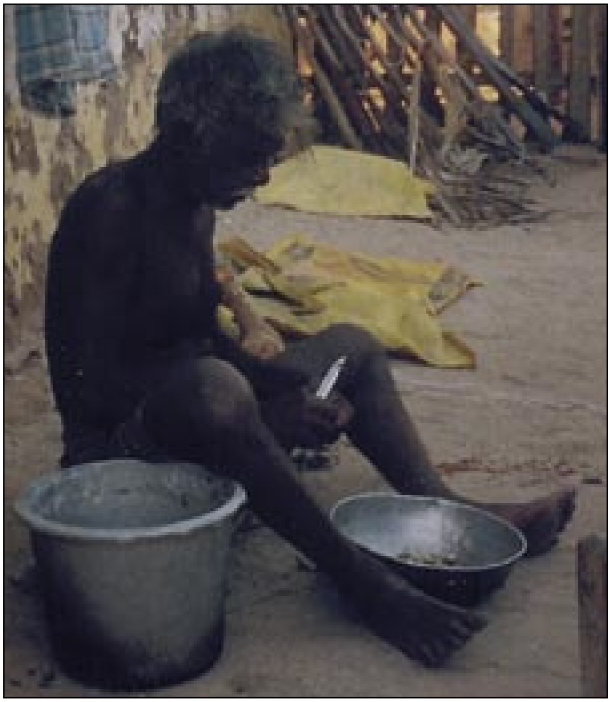


Figure 7. Fisherman in Vellapatti village preparing gastropods. *Photo:* DAN WILHELMSSON.

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 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.

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

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.

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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-

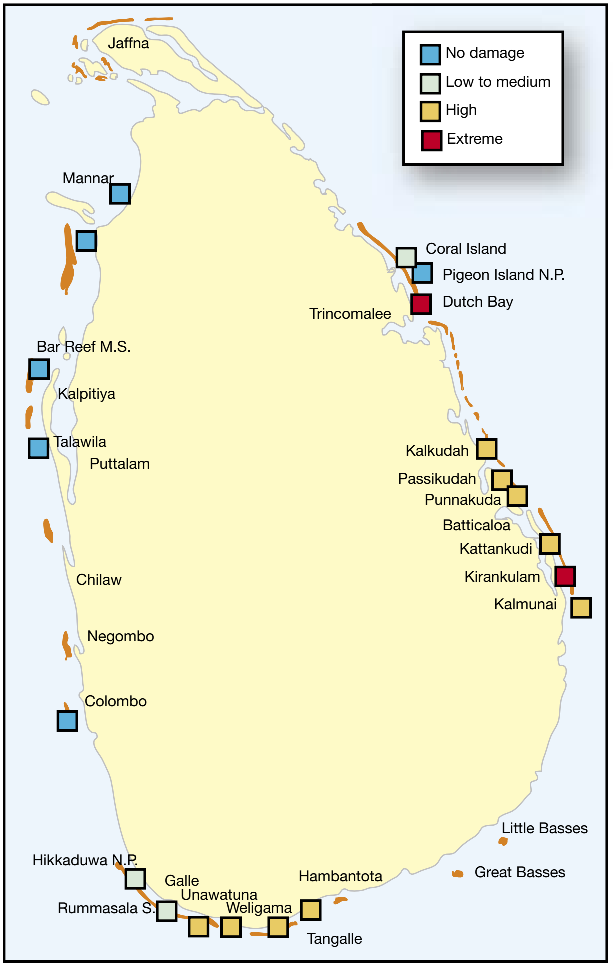

Figure 1. Map of Sri Lanka showing the reef sites surveyed and the level of impact from the tsunami on 26 December, 2004.

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%).

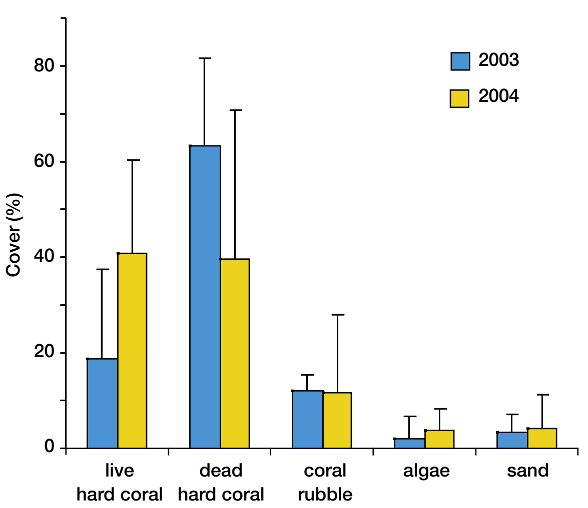

Figure 2. Comparison of the cover of the most abundant substrate types recorded on a shallow reef flat in Bar Reef Marine Sanctuary between 2003 and 2004.

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

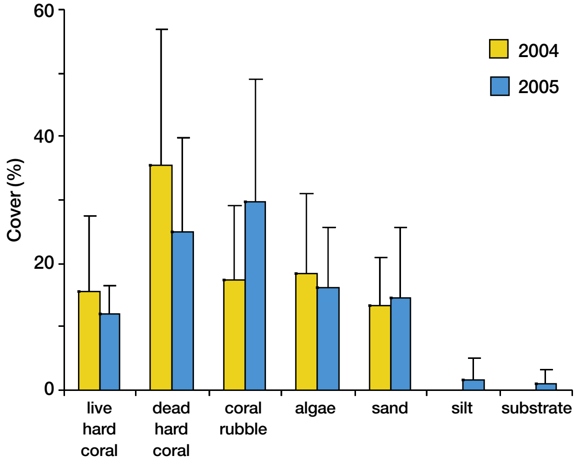

Figure 3. Comparison of the cover of the most abundant substrate types recorded pre and post tsunami at Hikkaduwa National Park.

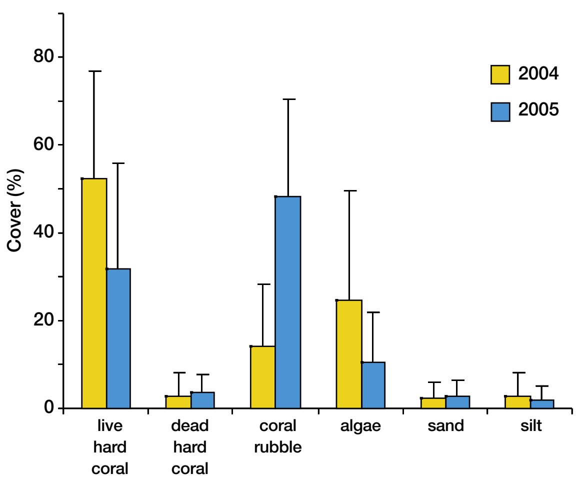

Figure 4. Comparison of the cover of the most abundant substrate types recorded pre and post tsunami at Kapparatota, Weligama.

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-

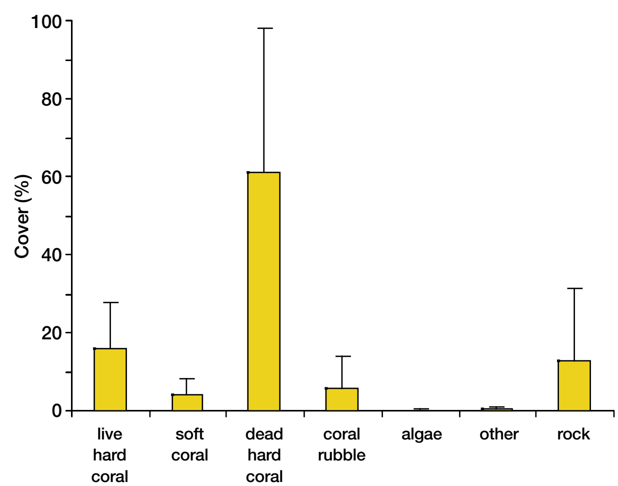

Figure 5. The cover of the most abundant substrate types recorded on the shallow coral reef habitat at Unawatuna.

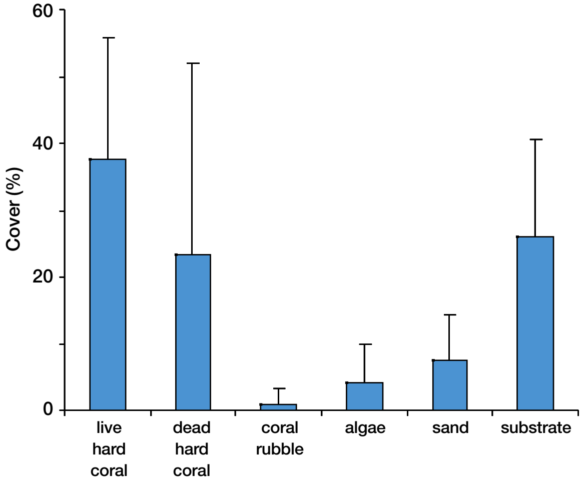

Figure 6. The cover of the most abundant substrate types recorded on the shallow coral reef habitat at Talawila.

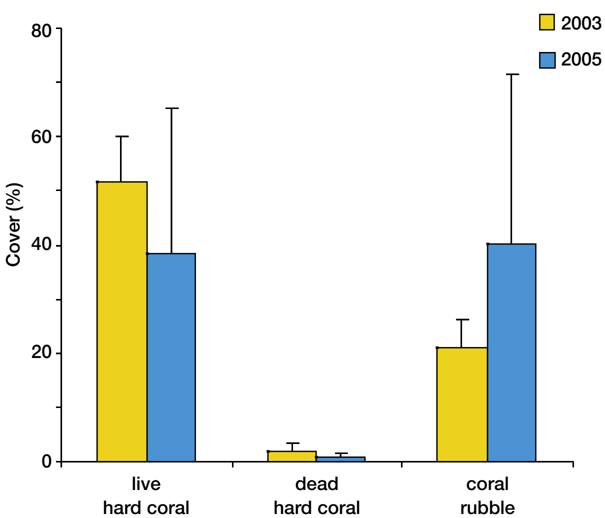

Figure 7. The cover of the most abundant substrate types recorded at Dutch Bay, Trincomalee.

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.

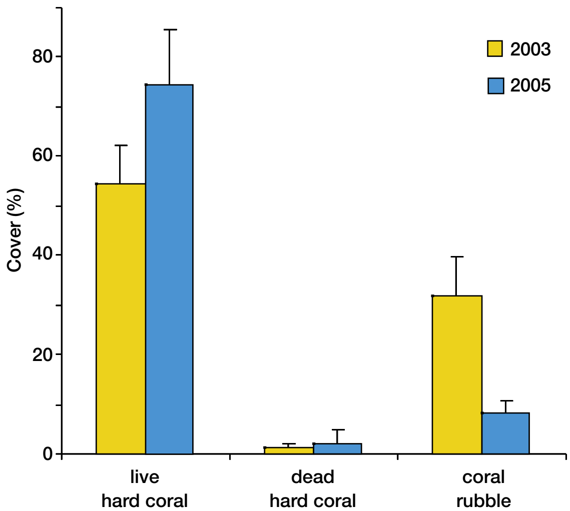

Figure 8. Comparison of the cover of the most abundant substrate types recorded at Pigeon Island National Park, Nilaveli pre and post tsunami.

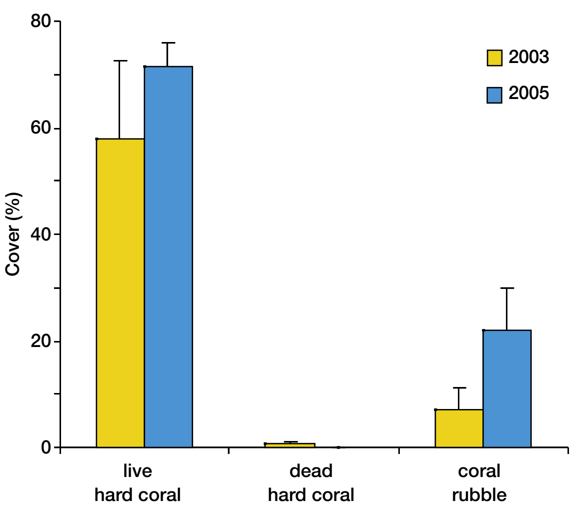

Figure 9. Comparison of the cover of the most abundant substrate types recorded at Coral Island, Nilaveli pre and post tsunami.

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	–	–	–	–	–

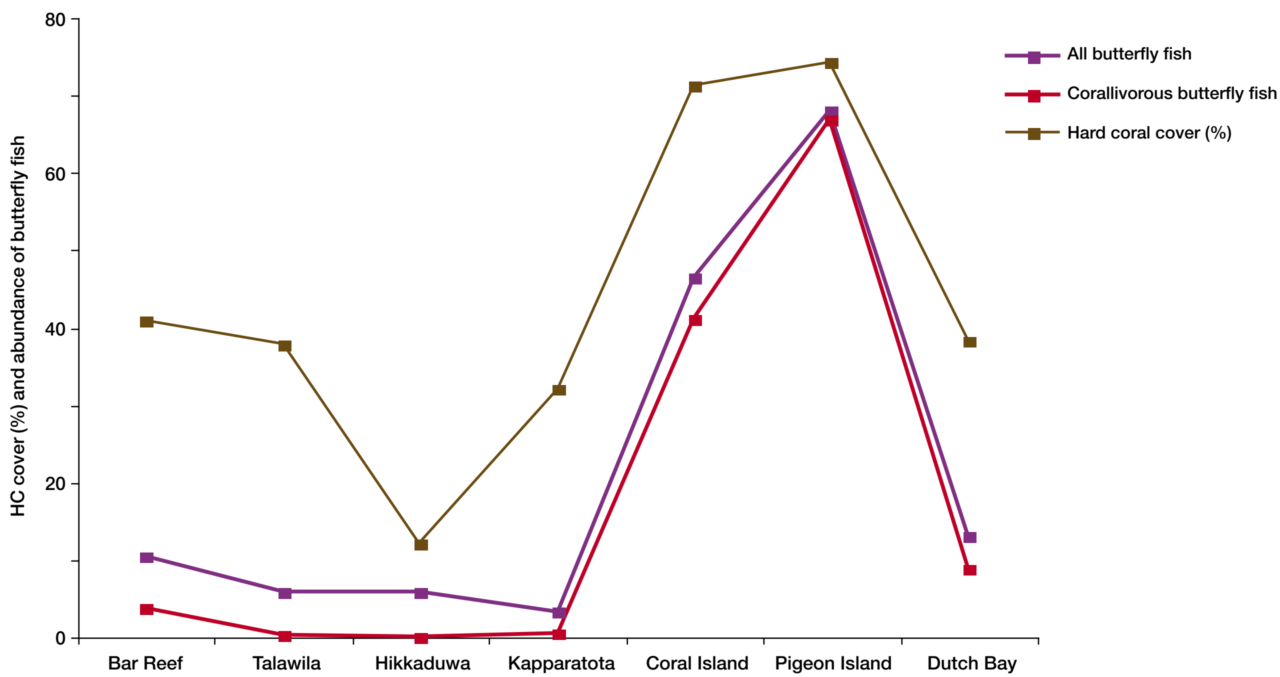

Figure 11. Hard coral cover, average number of butterfly fish and corallivorous butterfly fish recorded at each site.

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.

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Status of Coral Reefs in Trincomalee, Sri Lanka

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key words: reef status, Crown-of-Thorns starfish, blast fishing

INTRODUCTION

Trincomalee is located on the east coast of Sri Lanka. It is known for its deepwater natural harbour, abundant fish resources, and large marine fauna such as whales and dolphins. It is an important location for tourism and has many attractions on land as well as underwater. The rocky seabed of Trincomalee supports extensive reef habitats, the majority of which are large boulder type reefs of crystalline rock. Coral reefs are few and their distribution is patchy along the coast. The main coral reefs are located at Nilaveli, (Pigeon Island and Coral Island), Dutch Bay, Back Bay, Coral Cove and Foul Point, and along the coast south of Foul Point to Batticaloa (figure 1) (Swan, 1983; Rajasuriya & Premaratne, 2000). There are also some small coral patches within the Trincomalee Harbour and in embayments along the eastern coast outside the harbour. There are no coral reefs in Koddiyar Bay due to freshwater and sediment input from the Mahaweli River. A very deep canyon more than 1 000 m deep extends in a north-easterly direction from Koddiyar Bay.

There are extensive rock and sandstone reef habitats, both inshore and offshore. Narrow fringing coral reefs have developed on rock substrates, extending about 200 m from the coast to a depth of about 8 m, while offshore reef habitats are found to a depth of more than 50 m. To date, over 100 species of corals and more than 300 species of reef fish have been identified in Trincomalee and surrounding areas. Rajasuriya and Karunarathne (2000) reported that corals in Trincomalee were not af-

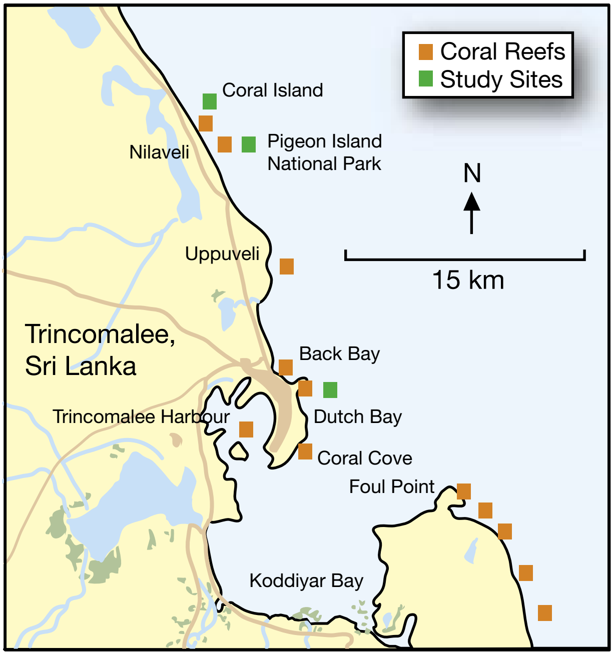

Figure 1. Map of Trincomalee, eastern Sri Lanka showing coral reef areas and study sites.

fected during the major coral bleaching event in 1998, whilst most reefs elsewhere in the country were severely damaged. However, the area experienced major reef degradation in the 1970s due to a crown-of-thorns starfish (*Acanthaster planci*; COTS) infestation (De Bruin, 1972; Rajasuriya & White, 1995).

Reef resources are utilised extensively. Fishing for edible species and ornamental fish collecting are the most common extractive reef uses in Trincomalee, while extensive harvesting of sea cucumber and chanks (*Turbinella pyrum*) is a relatively recent phenomenon that has evolved during the last 5 years. As elsewhere in Sri Lanka, reefs in the area are heavily affected by human activities, especially destructive fishing practices and over harvesting of resources (Rajasuriya *et al.*, 1995), and urban pollution affects reefs close to the town of Trincomalee. Pigeon Island is popular among tourists, both local and foreign, who damage the coral reef by trampling and collecting souvenirs. Visitors also dump refuse on the island.

Scientific studies of the reefs in Trincomalee are lacking because the past two decades of internal conflict in the country has rendered the area inaccessible. Thus the coral reefs were monitored only after the 1998 bleaching event, and due to the prevailing security concerns, reef surveys have been confined to the area between the Dutch Bay and Coral Island. The first survey was carried out at Pigeon Islands in 1999 (Christoffelsz *et al.*, 2000). Thereafter, two more surveys were conducted at this location, Dutch Bay and Coral Island were surveyed in 2003, and several other reef sites in the area were investigated without conducting detailed surveys. All surveys were carried out jointly by the National Aquatic Resources Research and Development Agency (NARA) and the Sri Lanka Sub-Aqua Club (SLSAC). In 2003 and 2004, the Hong Kong and Shanghai Banking Corporation also participated in investigating reefs at the study sites.

SITES

Pigeon Island National Park (N 8 43.198 E 81 12.101) is made up of two small islands (Large and Small Pigeon Island) located about 1 km offshore. There are several rock outcrops about 300–500 m to the south and south-east of Large Pigeon Island, the one on the southern side is called the 'Salabalas Rocks'. Large Pigeon Island has two small beaches on the south-western and northern flanks of the island. The main coral reef is in front of the south-western beach. It is about 200 m long and 100 m wide, with a depth of between 1 and 6 m. There are no large coral patches around Small Pigeon Island. Much of the surrounding area contains rocky reef habitats interspersed with old limestone reef structures and sandy patches. The two islands were declared a sanctuary in 1963 for the purpose of protecting birds. In 2003, Pigeon Island and the surrounding area within a one-mile radius, including its coral reefs, were declared a National Park under the Fauna and Flora Protection Ordinance of the Department of Wildlife Conservation.

Coral Island (N 8 44.200 E 81 10.590) is located about 500 m north of Pigeon Island and about 300 m offshore. It is a small rocky outcrop without sandy beaches. Fringing coral reefs have developed on the northern and southern sides, and small coral patches also occur around the island to a distance of about 200 m. Most of these coral areas are in very shallow water, the near shore fringing reef patches at depths of 2–4 m and the coral patches in the surrounding at depths of 4–6 m.

Dutch Bay contains a shallow coral patch at its northern end (N 8 34.404 E 81 14.373). The rest of the bay is made up of rocky substrate interspersed with patches of sand. In the centre of the bay, there are large *Porites* domes reaching a diameter of about 4 m.

SURVEY METHODS

The Reef Check method (Hodgson, 1999; 2003) was used for surveying the coral reefs as it is a rapid survey technique that allows coverage of large areas, and provides basic information about reef status and health. Point intercept transects 100 m in length were deployed between 3 and 7 m depth, and the following benthic cover categories recorded: hard coral (HC), dead coral

(DC), recently killed coral (RKC), soft coral (SC), sponge (SP), fleshy algae (FS), other organisms (OT) such as corallimorpharians and tunicates, coral rubble (RB), eroded dead coral blocks or rock (RC), sand (SD) and silt (SI). Brief visual surveys were also conducted on reef sites at Uppuveli and Back Bay in 2003.

The coral reefs around Pigeon Island were surveyed in 1999 and 2003 while Coral Island and Dutch Bay were surveyed only in 2003. Pigeon Island and Dutch Bay were also investigated in 2004 to record human influences, types of resource extraction and utilization of coral reefs for recreational purposes.

RESULTS

The surveys revealed that the investigated reef sites were relatively healthy. Surveys at Pigeon Islands indicated that there was little change in the status of live corals between 1999 and 2003, and the reefs that were degraded due to the COTS infestations in the 1970's (De Bruin, 1972) had recovered well. The benthic cover at each reef is presented separately below.

Pigeon Islands

Living hard coral cover on the shallow reef at Pigeon Islands was about 51.3% in 1999, increasing slightly to about 54.4% in 2003 (figure 2). The area is dominated by *Acropora* spp. (figure 3 on next page). The rock and limestone reef section between large Pigeon Island and the Salabalas Rocks was surveyed in 1999 only. Its living hard coral cover was about 24.4%, dominated by corals belonging to the families Faviidae, Mussidae and Poritidae. Notably, coral rubble constituted more than 30% of the benthic cover, while the cover of other organisms (e.g. corallimorpharians) was ~15% (figure 4 on next page).

Coral Island

The shallow fringing coral reefs on both the northern and southern sides of Coral Island were surveyed in 2003. The combined hard coral cover was 58%, mostly consisting of

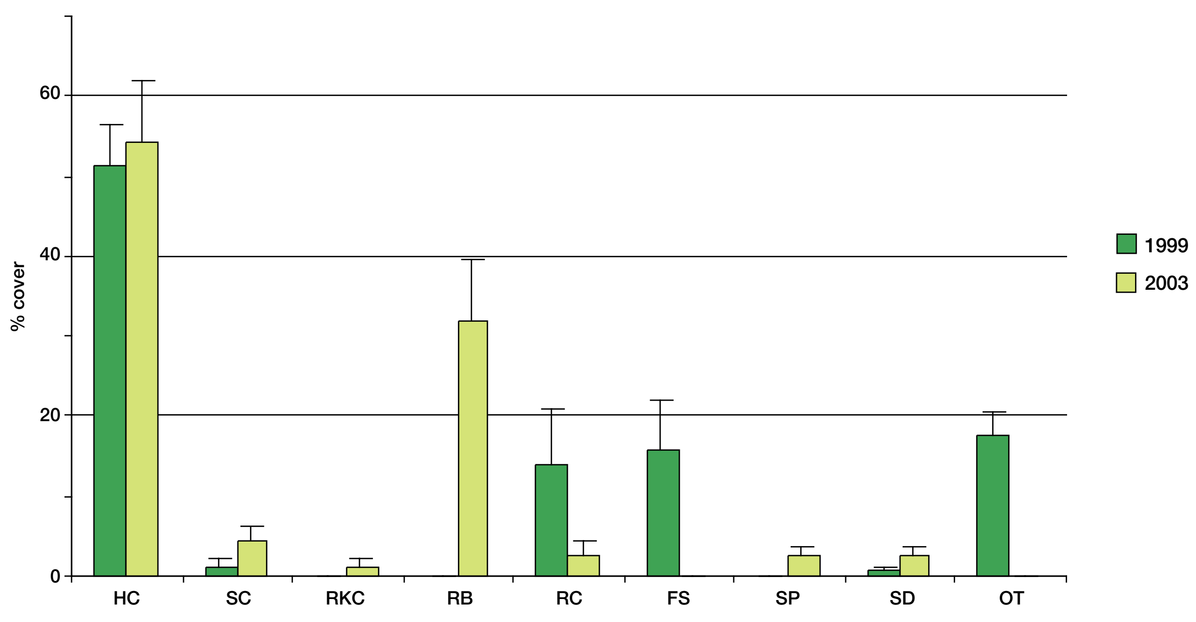

Figure 2. Percentage cover of each substrate category recorded at Pigeon Island during surveys conducted in 1999 and 2003.

Figure 3. *Acropora* dominated coral reef at Pigeon Island.

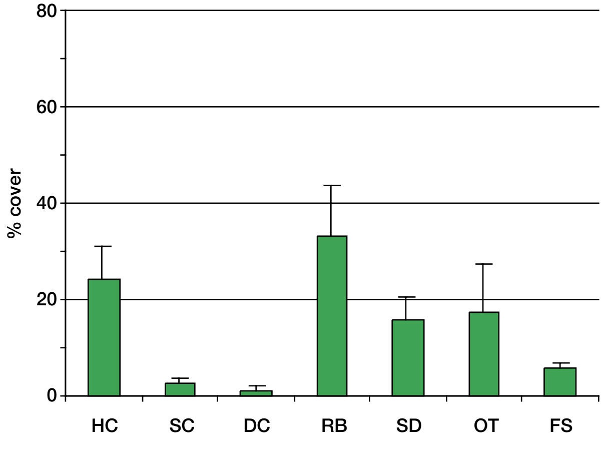

Figure 4. Percentage cover of each substrate category recorded between Pigeon Island and Slabalas Rocks during surveys conducted in 1999.

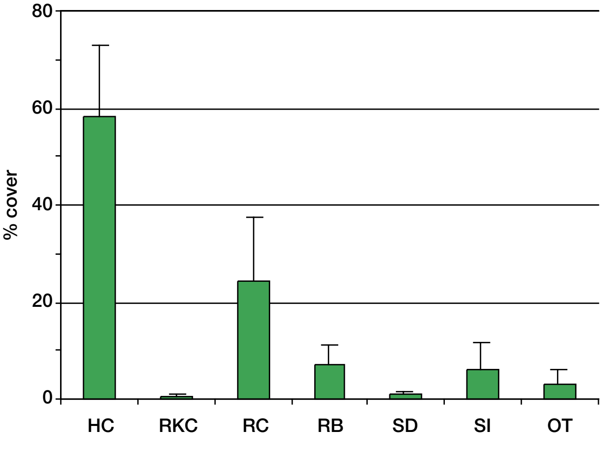

Figure 5. Percentage cover of each substrate category recorded at Coral Island during surveys conducted in 2003.

branching *Acropora* species, while ~24% consisted of rocky substrate devoid of corals (figure 5). Some dead coral and coral rubble was recorded. The northern side of the island exhibited higher coral cover, while rubble and non-coral benthic fauna cover was higher on the southern side.

Dutch Bay

The shallow coral patch was surveyed in 2003. Benthic cover was determined along two line intercept transects at an average depth of 3.5 m. Hard coral cover was 51.5%, with foliose *Montipora* the most abundant coral (figure 6).

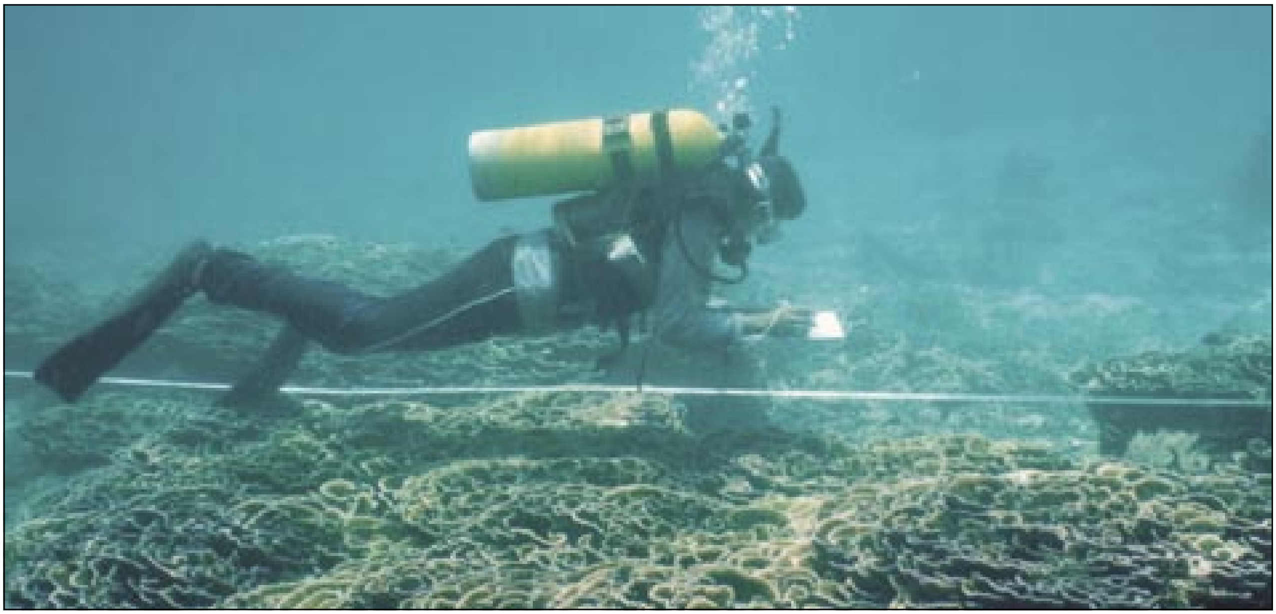

Figure 6. *Montipora* dominated habitat at Dutch Bay in 2003.

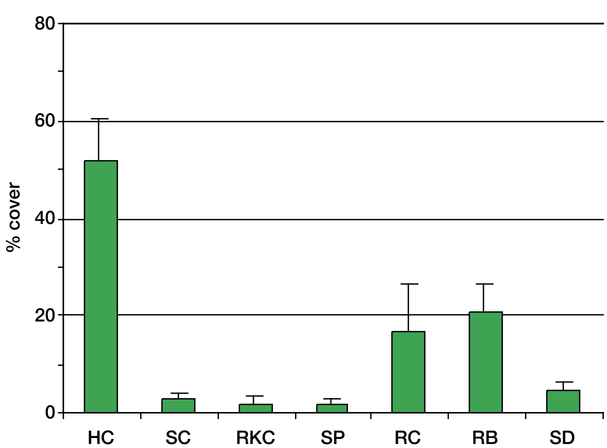

Figure 7. Percentage cover of each substrate category recorded at Dutch Bay during surveys conducted in 2003.

There were also many branching and digitate *Acropora* colonies. Coral rubble and rock substrates were 20.9% and 16.5% respectively (figure 7). The recently killed coral, making up about 1.8% of the total benthic cover, can be attributed to presence of *Acanthaster planci*.

RESOURCE USE

Fishing and ornamental fish collecting are the main extractive reef uses in Trincomalee. There is also widespread exploitation of sea cucumber particularly from the coral reefs in Nilaveli and Foul Point. Commonly used fishing gears are fish traps, rod and line, and a variety of nets including gill nets and bottom set nets. The damage caused by these nets in other areas of Sri Lanka have been highlighted previously (Rajasuriya *et al.*, 1995; Rajasuriya & Wood, 1997).

Major Causes of Reef Degradation in Trincomalee

- Blast fishing
- Use of banned fishing gears such as the bottom set nets used to harvest spiny lobsters and reef fishes and the use of *moxy* nets (a diver deployed underwater drop net) to collect aquarium fishes from shallow coral reef habitats.
- Uncontrolled resource exploitation
- Urban pollution
- Boat anchoring
- Visitor pressure on Pigeon Island and Coral Island (Trampling, souvenir collecting and pollution).

CONCLUSIONS

The coral reefs in Trincomalee have recovered from the COTS infestations that were first observed in the 1960s and reaching a peak in the early 1970s (De Bruin, 1972. This coincided with large scale COTS outbreaks on the Great Barrier Reef (Endean & Cameron, 1985). All the study sites showed healthy coral growth 20 years after the COTS infestation and they were dominated by fast growing species of *Acropora* and *Montipora*. Similar recovery has been observed elsewhere; on the mid-shelf reefs in the Great Barrier Reef, coral habitats damaged by COTS recovered to a level comparable with unaffected mid-shelf reefs after about 10–12 years (Moran *et al.*, 1985) due to the rapid growth of branching corals. A few COTS were present on all the sites surveyed, but no large-scale damage to any of the reef habitats was observed.

Coral reefs in Trincomalee are the only known reefs in Sri Lanka that escaped the major coral bleaching event in 1998 (Wilkinson, 1998; Rajasuriya *et al.*, 2000). Minor coral bleaching was observed at depths of about 1.5 m in the Dutch Bay and at a depth of about 3 m in the Trincomalee harbour in May 2004, which is the same time of year the mass coral bleaching occurred in 1998. Similar minor bleaching was also reported from the southern coast at Rumassala in Galle Bay in 2004.

However, despite recovering from COTS infestations

Blast Fishing in Trincomalee

Blast fishing is a widespread fishing method in Sri Lanka (Rajasuriya *et al.*, 2002), despite being banned under both the Fisheries Act and the Fauna and Flora Protection Ordinance. In Trincomalee too, this is the most damaging fishing practice at present, carried out daily especially north of Dutch Bay. It is most prevalent in the offshore area (2–5 km) from Uppuveli to north of Nilaveli, including in Pigeon Islands National Park.

Blast fishing destroys all forms of marine life and damages reef structures. It is also extremely harmful to divers. Today, all dive operators in Trincomalee have experienced the negative impact of blast fishing and have already lost business and potential revenue from tourists due to this practice.

There is also little interest in protecting and managing the marine environment other than to strengthen legislation periodically. Recently, the penalty for blast fishing was increased through an amendment to the Fisheries Act, but regulations are not enforced. A general lack of resources, manpower and equipment for management of fisheries and marine protected areas, and consequent inability to arrest blast fishermen at sea, means destructive practices continue to threaten coral reefs in Sri Lanka.

and escaping the bleaching in 1998, the area faces a severe threat. Pigeon Island has been declared a marine National Park, but there is no management plan nor are the park regulations implemented. At present, it is unguarded and visitors freely take corals and other souvenirs from the reef and pollute the island by discarding polythene bags and other non-biodegradable refuse. Nevertheless, the most serious threat to the health of biota in Trincomalee is rampant blast fishing. There is an urgent need to strengthen political will to implement and enforce existing fisheries regulations and provide Pigeon Island the protection its National Park status warrants, in order to prevent rapid decline of reef health and fish populations. Lastly, Trincomalee and the surrounding areas have not been studied in the same detail as some other locations in Sri Lanka, e.g. Bar Reef Marine Sanctuary. In order to strengthen and support management, long-term studies on coral reef health and resource use should be initiated in this area.

ACKNOWLEDGEMENTS

We thank the National Aquatic Resources Research and Development Agency (NARA) and the Coral Reef Degradation in the Indian Ocean (CORDIO) programme for financially supporting the reef surveys and the Hong Kong and Shanghai Banking Corporation for supporting its personnel to participate. We also thank Chaminda Karunarathne of NARA, members of the Sri Lanka Sub-Aqua Club, Terney Pradeep Kumara of the University of Ruhuna, participants from Hong Kong and Shanghai Banking Corporation for data collection and Claudio Trento for field support. Special thanks to Jerker Tamelander for reviewing the manuscript.

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A Preliminary Baseline Survey of
the Coral Reefs of Passikuda, Batticaloa

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key words: Passikudah, coral reef status, tourism impacts, solid waste

INTRODUCTION

Study area

Sri Lanka is situated between 5° and 10° north of the equator and south of the Indian subcontinent and has a total land area of 65 000 km^2. The coastline of the island, which is about 1 585 km, supports highly productive ecosystems such as coral reefs, mangroves, seagrass beds and marshy lands. The continental shelf of Sri Lanka is relatively narrow averaging only a few km in width (Rajasuriya *et al.*, 1995).

Well-developed coral reefs exist along much of the coast of Sri Lanka and, along the east coast, they occur between Vaharai and Valaichechenai and from Batticaloa to Kalmunai. These reefs are important sources of natural resources. For example, corals are mined to produce lime for the construction industry, the export of spiny lobsters, sea cucumber and ornamental fish have contributed significantly to the foreign exchange earnings of the country and tourism benefits from the aesthetic value of coral reefs. Despite their value, reef habitats are being degraded at an alarming rate due to unmanaged resource use. Unfortunately however, systematic baseline surveys of the condition of the reefs found along the north and east coast have not been conducted due to the civil conflicts during the last 20 years between the State and the LTTE.

Degradation of habitats at Passikudah

Passikudah Reef is located 28 km north of Batticaloa in a relatively calm bay which is a favoured spot for bathing. During the civil war that has been fought over the last two decades, the fisher families that comprise the civilian population at Passikudah were deprived of their main livelihood of fishing because of restrictions imposed by the military. In addition, tourism had virtually ceased further denying them of any supplementary income from the tourist industry. As a consequence, these people resorted to large scale coral mining of both extant and fossil coral reefs in the area in order to produce lime illegally. As there were severe restrictions in the southern part of the country on lime production, the lime produced at Passikudah was sent to the south in a surreptitious manner (Dharmaretnam & Kirupairajah, 2003). Large-scale live coral mining at Passikudah was stopped only recently.

With the recent cessation of hostilities between the LTTE and the State, local tourists have been arriving at Passikudah in increasing numbers. This large scale influx has had a negative impact on the environment as there were not adequate mechanisms to cope with the local tourists. Large quantities of polythene plastics and other solid wastes left by the tourists now litter the reefs in the bay.

The coral reefs of Sri Lanka were badly affected during the coral bleaching event of 1998. Coral bleaching was reported at sites in the west and south of Sri Lanka such as Bar Reef Marine Sanctuary, Hikkaduwa and Unawatuna (Rajasuriya, 2002). However, the reefs on the east coast at Trincomalee (Pigeon Island) did not seem to be affected by the coral bleaching event. To date, the reefs along the east coast south of Trincomalee have not been surveyed. Thus, the aim of the project was to conduct a baseline survey of the reef at Passikudah to determine its condition.

METHODOLOGY:

At Passikudah Reef, surveys were conducted between January and June 2004 to determine the condition of the reef. Beginning in the centre of the bay and moving eastwards towards Kalkudah, seven 50 m line intercept transects were laid perpendicular to the shore and separated by 100 m. The linear extent of each substrate type bisected by each transect was recorded by snorkel divers using the following codes from English *et al.*, 1997:

LC = Live Coral;
DC = Dead Coral (recently dead white to dirty white);
DCA = Dead Coral with Algae (this coral is standing, skeletal structure can still be seen);
R = Rubble (Unconsolidated coral fragments);
S = Sand;
SL = Silt;
AA = Algal Assemblage (consisting more than one species);
HA = *Halimeda*;
MA = Macro Algae (weedy/fleshy browns, reds, etc.);
TA = Turf Algae (lush filamentous algae, often found inside damselfish territories);
SP = Sponges;
OT = Others (Ascidians, anemones, gorgonians, giant calms).

The mean percent cover was calculated for each substrate type. The frequency with which different varieties of solid wastes occurred along each transect was also noted.

Salinity, temperature, turbidity and water depth were also measured at each transect using a refracto salinometer, a submersible thermometer, a secchi disc and a tape measure respectively.

RESULTS AND DISCUSSION

The overall cover of live coral was 15.81% (± 2.96 S.E.) (figure 1 on next page) and ranged from 8.88% to 29.6% (figure 2 on next page). The cover of dead coral, dead coral with algae and sand ranged between 10.6%–29.66%, 3.22%–8.6% and 6.2%–28.86% respectively and was generally greater towards the western boundary of the study site. The predominantly sandy substrate near the western most transects ensures that this area is the preferred site for bathing and where most tourist activities are concentrated. Coral rubble also occupies a considerable proportion of the substrate with the mean percent cover being 18.87% (± 1.57 S.E.) (figure 1) but is fairly evenly distributed between transects probably indicating skeletal breakdown following coral bleaching (figure 2). Despite the even distribution of coral rubble across the study site, the declining live coral cover and corresponding increases in dead coral with the concentration of tourist activities makes it quite evident that the abundance of live coral is being affected by trampling and siltation caused by the tourists. The impact of live coral mining would have also contributed to the status of the coral reefs of Passikudah.

The cover of *Halimeda* varied considerably between transects. In 3 transects, the cover exceeded 15% while in each of the remaining 4 transects, the cover was 5% or less (figure 2). There is a possibility that *Halimeda* is overgrowing new coral recruits at Passikudah, similar to that reported from the shallow waters of Kandakuliya in 2000 (Rajasuriya, 2002). Algal assemblages, macro-algae and turf algae comprised 6.1% of the substrate. Sponges and others consisted of 2.84% (figure 1).

The average salinity was 32‰ and visibility ranged from 75–88 cm. Water surface temperature was 28.6°C.

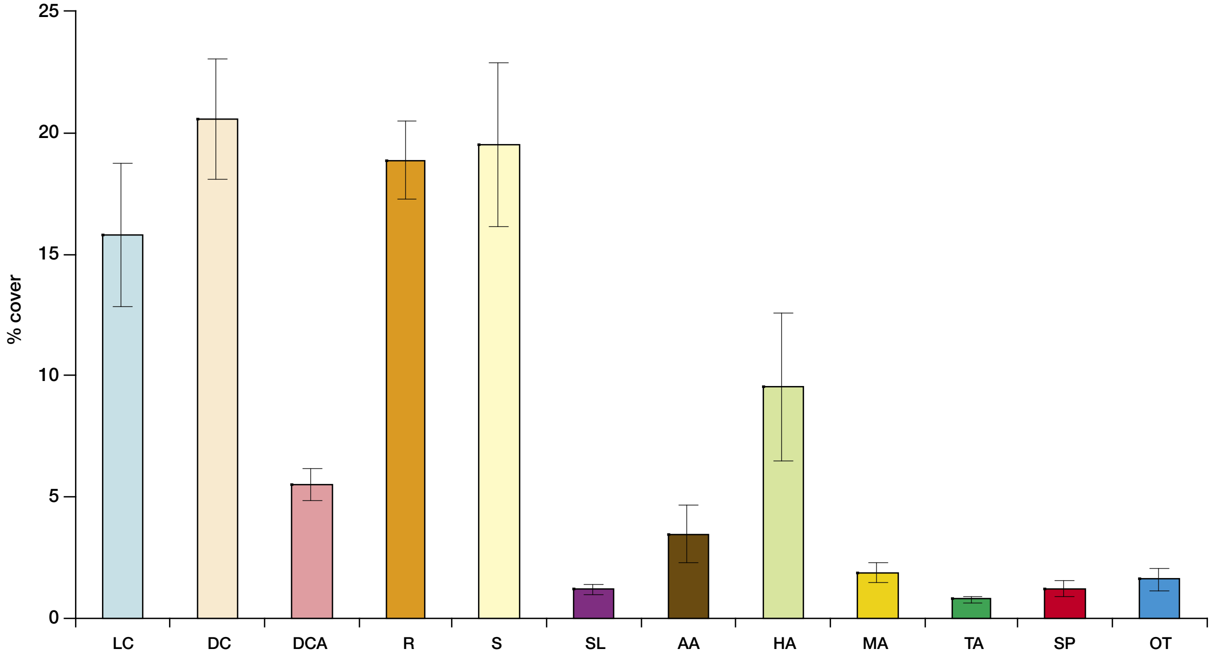

Figure 1. Mean percent cover (±S.E.) of each substrate type recorded from all transects conducted at Passikudah Reef.

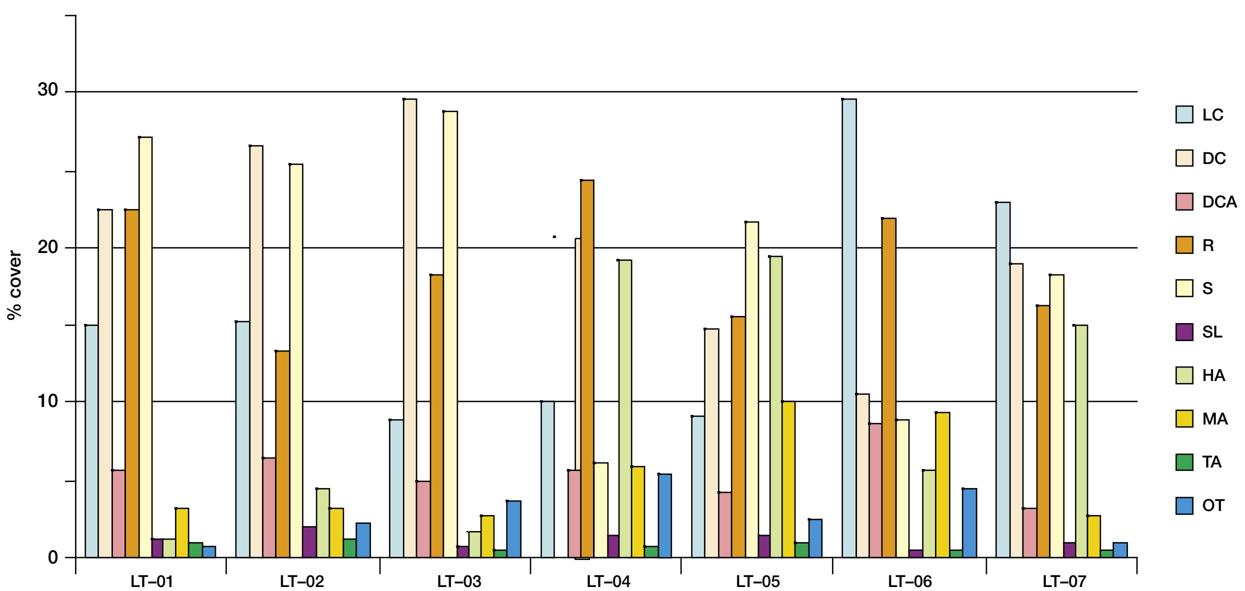

Figure 2. The percent cover of each substrate type recorded from each transect conducted at Passikudah Reef. Note: data for algal assemblages and macroalgae and for sponges and other have been combined and are presented as macroalgae and other respectively.

water depth ranged from 66–92 cm at the beginning of the transect and it was 90–151 cm at the end of the transect towards the sea.

The percentage cover of live coral at Passikudah in 2004 was similar to that of reefs in the southern part of the country that were damaged by coral bleaching. In 2000, live coral cover at Negambo Reef was 14%, while at Hikkaduwa in 2001, coral cover had increased from 7% immediately following the bleaching event in 1998 to 12% (Rajasuriya, 2002). Further systematic observations of Passikudah Reef are necessary to understand the dynamics of this reef.

Polythene plastics, including bags, papers and plastic bottles, were the most common solid wastes found on Passikudah Reef and, on average, were recorded approximately 5 times on each transect (figure 3). Although less frequent, wastes discarded from fishing activities such as longline filament, nets and anchors were the second most common pollutant occurring, on average, almost 4 times per transect. Bones, twigs, glass bottles and bricks comprised the remaining types of solid waste found on Passikudah Reef occurring 0.857, 2.286, 3.571 and 3.143 respectively.

CONCLUSION

The results of surveys presented in this paper are the first obtained from any coral reef along the east coast of Sri Lanka. It seems possible from comparisons with other studies done in southern part of Sri Lanka that the reef at Passikudah could have been damaged by the coral bleaching event. The impact on the live coral mining industry is also a factor to be considered.

Any recovery of these damaged reefs is currently threatened by activities of increasing local tourist population. The presence of discarded plastic material and bottles from tourists is very much higher than the material left by fishermen. The local authorities establish more

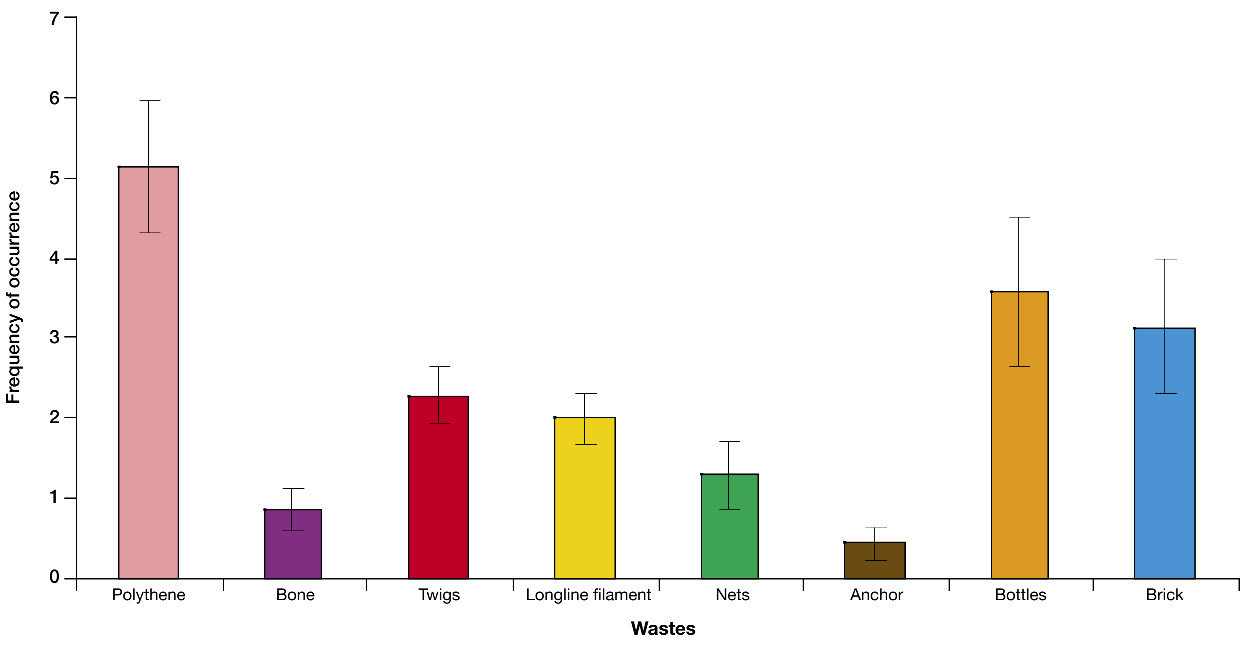

Figure 3. Mean frequency of occurrence (±S.E.) of solid waste material recorded from all transects conducted at Passikudah Reef.

stringent measures to ensure that the plastic material left by tourists does not reach the sea. The plastics are a threat to the growing corals.

Declaring Passikudah a marine sanctuary to protect the growth of the corals should be considered seriously by the authorities. Restricting the use of the beach for a period will no doubt contribute to the regeneration of the degraded coral reefs of Passikudah.

Almost all of the families in the village depend on fishing. There is no information regarding the impact of coral bleaching on fisheries. Studies revealing such impacts and the recruitment of corals are a necessity to conserve the beautiful coral reefs of Passikudah.

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Status of Coral Reefs of the Maldives:
Recovery Since the 1998 Mass Bleaching
and the Impacts of the Indian Ocean Tsunami 2004

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key words: coral bleaching, reef recovery, tsunami, Maldives

INTRODUCTION

The unprecedented magnitude of the coral bleaching event caused by the El Niño in 1998 affected several coral reef ecosystems throughout the world (Wilkinson *et al.*, 1999). Severe bleaching and subsequent mortality of large areas of coral reefs in the Indian Ocean have been reported (McClanahan, 2000; Edwards *et al.*, 2001; Sheppard *et al.*, 2002).

Coral reefs in the Maldives were severely affected by this El Niño event causing severe bleaching and mortality of more than 90% of the shallow water coral communities (Zahir, 2000; 2002). Reef recovery has been variable among several locations that have been monitored annually since the initial bleaching impact study in 1998. Re-colonisation of fast growing branching growth forms of corals has been reported (Edwards *et al.*, 2001; Zahir, 2002). It is likely the reefs may be modified as a result of the bleaching event changing the community structure. Preliminary findings indicate that the reefs are now being dominated by slow growing coral species such as agariciids and faviids rather than the branching acroporids and pocilloporids that were prevalent previously.

The long term objective of the monitoring program is to examine the processes of reef recovery in terms of coral cover and other benthic communities so that the ecological processes that influence the reef recovery and recolonisation are better understood for science and management needs.

This report describes the patterns of reef recovery since the bleaching event in 1998 over a period of 6 years. In addition, the impacts of tsunami of December 26th, 2004, on one of the regions included in this monitoring program are also described.

METHODS AND SURVEY LOCATIONS

Site Selection

Maldives comprised of 26 natural atolls stretching an area of over 8 000 km² in the northern and central Indian Ocean. The 15 sampling sites were chosen in the following 5 regions to cover a large spatial area (figure 1 on next page):

1 **Haa Dhaal** (north and a regional development target)
   Hondaafusi
   Finey
   Hirimaradhoo
2 **Male atoll** (east central with intensive tourism and other commercial activities)
   Emboodhoo
   Bandos
   Udhafush

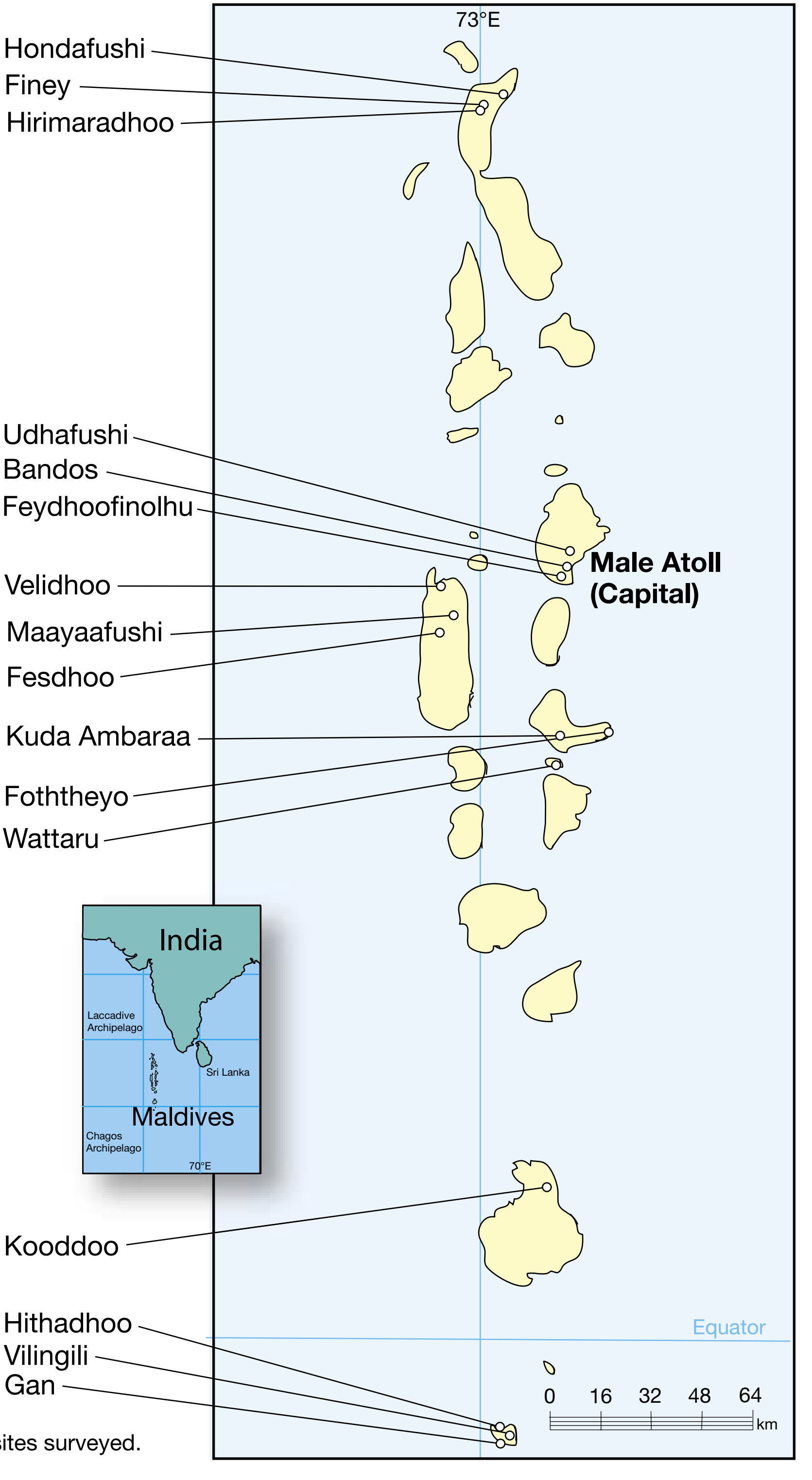


Figure 1. Map of Maldives illustrating the sites surveyed.

3 **Ari atoll** (east central with intensive existing tourism development)
Fesdhoo
Mayaafushi
Velidhoo

4 **Vaavu atoll** (figure 2; south central with a community-based integrated island resource management project underway)
Kuda Ambaraa
Wattaru
Foththeyo

5 **Addu-Gaaf Alif atoll** (south and a regional development target)
Gan
Villigili
Koddoo

These 15 sites were selected initially to ensure that reefs that had been surveyed prior to 1998 bleaching event were included thus providing baseline data against which monitoring data could be compared in order to assess the impacts of the bleaching event (Allison, 1999). In order to be comparable with all previous studies conducted on the coral reefs of Maldives and for logistical efficiency, all surveys were conducted on the reef tops. Surveys were also confined to inner reefs within the atolls because this is where past surveys had been conducted and also because the surge caused by oceanic swells ensures that working in shallow water on outer reefs is usually impossible.

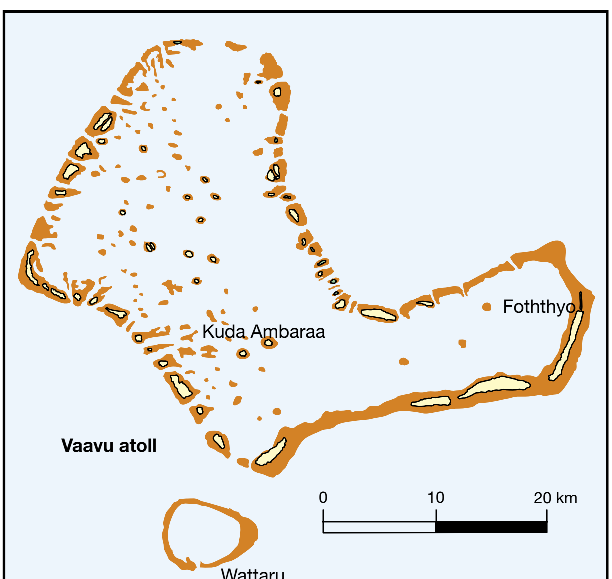


Figure 2. Reef monitoring sites in Vaavu atoll.

Survey Method

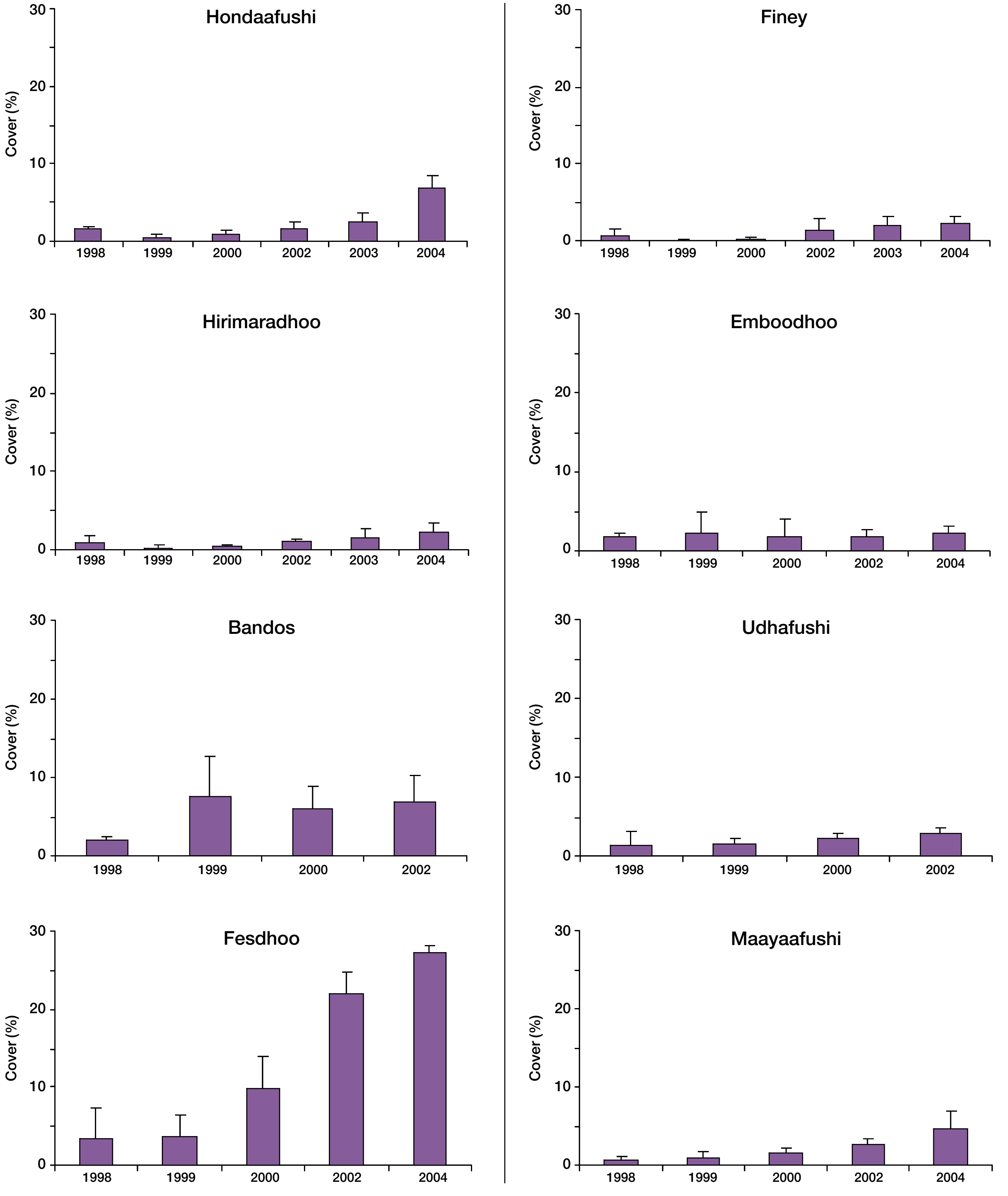
On each reef surveyed, data from three line intercept transects of 50 m (English *et al.*, 1997) were recorded in areas near the location of past survey sites and where physical conditions such as wave action permitted. Occasionally, when it was efficient to do so, a 50 m point intercept transect was used. Initial monitoring was done in 1998 soon after the bleaching, and surveys were repeated at the same sites in 1999, 2000, 2002, 2003 and 2004 to provide an insight into the processes of reef recovery, especially after the bleaching in 1998. Comparative surveys of three sites in Vaavu atoll (Kuda Ambaraa, Wattaru and Foththeyo) were carried out in January 2005 to assess the impact of tsunami of December 2004.

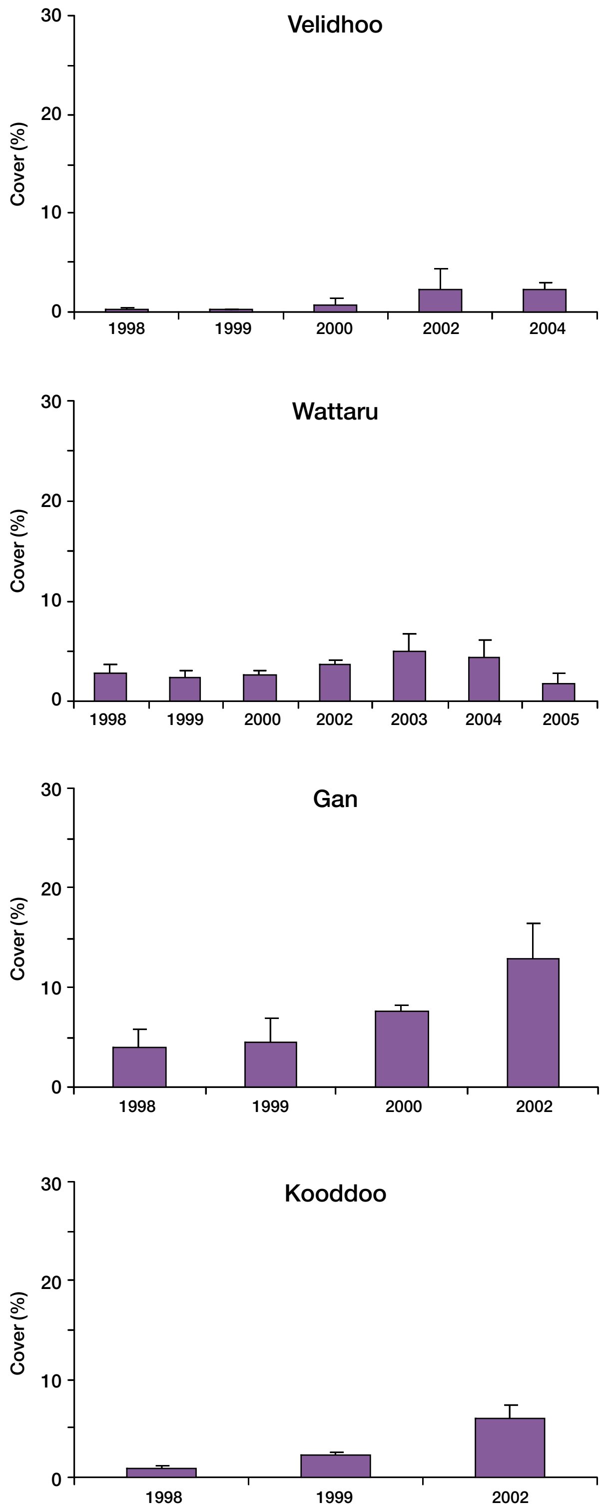
RESULTS

Reef Recovery Since 1998

Coral cover was variable among the 15 sites surveyed (figure 3 on next pages). The average percent cover of live coral for all sites surveyed was approximately 2%. The highest overall cover was recorded at the two southern sites, Gan and Villigili and a western central site, Fesdhoo. Overall coral cover increased approximately 7% in 2004 but the rates of increase varied between different sites. A 3–4 fold increase in coral cover was recorded at Gan, Villigili and Koddoo between 1998 and 2004. An 8 fold increase in coral cover from 3.34% to 27.16% was observed at Fesdhoo, between 1998 and 2004.

Overall, there was an increasing trend in the live coral cover at the 15 sites surveyed over the past 6 years since the 1998 bleaching event. In 1998, coral cover ranged be-


Hondaafushi
Finey
Hirimaradhoo
Emboodhoo
Bandos
Udhafushi
Fesdhoo
Maayaafushi
Cover (%)
0
10
20
30
1998
1999
2000
2002
2003
2004



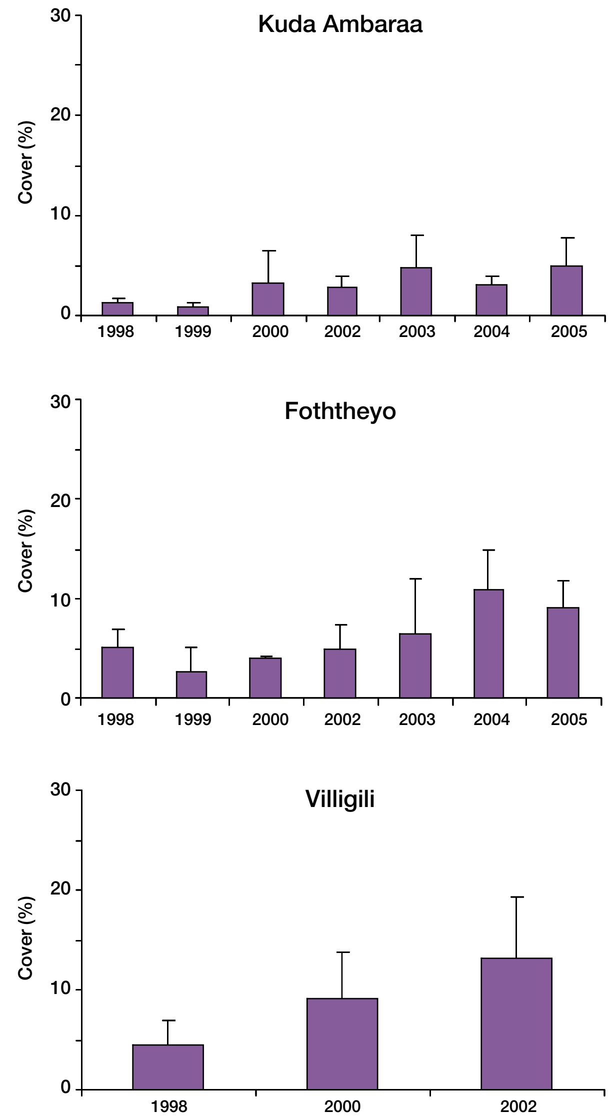


Figure 3. Coral reef recovery during the past 6 years (1998-2005) at the 15 permanent monitoring sites. Note the sampling frequency is not equal for all sites. Kuda Ambaraa, Wattaru and Foththeyo graphs include the coral cover of 2005 (Post tsunami). Figures are mean percent live coral cover and error bars illustrate the standard deviations.

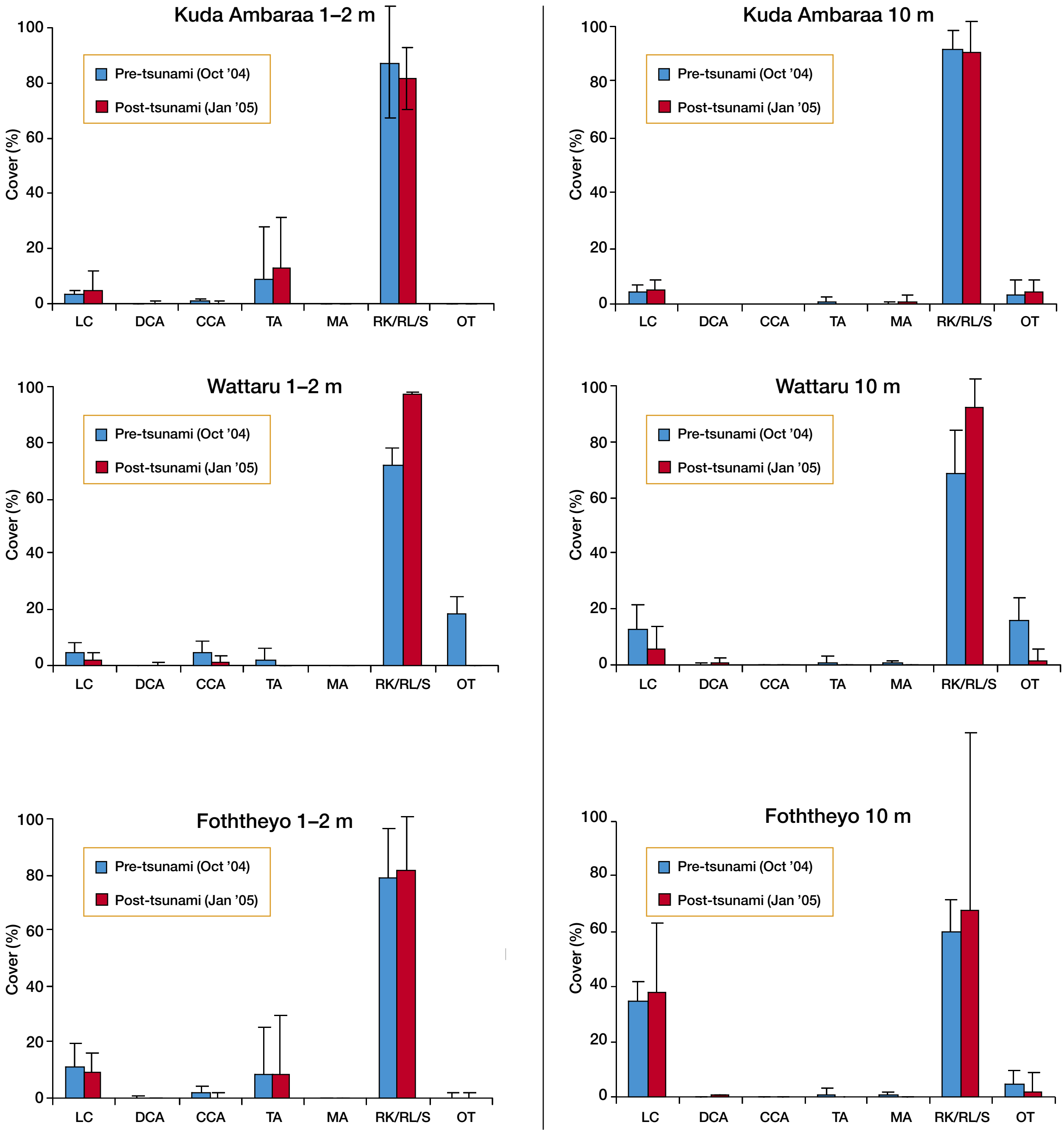


Figure 4. Comparison of the benthic community structure at three monitoring sites in Vaavu atoll before and after the tsunami of 26th December 2004. LC = Live coral, DCA = Dead coral algae, CCA = Crustose coralline algae, TA = Turf algae, MA = Macro algae, Rk/Rl/S = rock/rubble/sand and OT = Others. Values are mean percent cover. Error bars are 95% CL.

tween 0.2% at Velidhoo and 5% at Foththeyo. In 2004, the coral cover is still low at Emboodhoo (2.23%) but is moderate at Fesdhoo (27.16%).

The sites where the impacts of the tsunami were assessed, Kuda Ambaraa, Wattaru and Foththeyo at Vaavu atoll, showed variable coral cover in 2005 (post tsunami) compared with 2004 (pre tsunami). Kuda Ambaraa showed a slight increase in coral cover, from 3.09% ± 0.85 SD to 4.91% ± 2.80 SD and Foththeyo a slight decrease 10.81% ± 4.00 SD to 9.04% ± 2.77 SD. Wattaru suffered the most severe damage to the reef structure shown by the decrease in coral cover from 4.43% ± 1.75 SD in October 2004 (pre tsunami) to 1.80% ± 0.96 SD in January 2005 (post tsunami).

Tsunami Impact at Vaavu Atoll

Analysis of the LIT data obtained from the three sites surveyed at Vaavu atoll showed variable results among the sites. Pre and post tsunami surveys of these sites indicated an increase in live coral cover both at Kuda Ambraa and Foththeyo but a decrease in Wattaru (figure 4). Coral cover increased from 3.1% to 4.9% at 1–2 m and 4.0% to 5.2% at 10 m depth at Kuda Ambaraa. At Foththeyo, coral cover increased from 34.4% to 38.2% at 10 m but decreased from 11% to 9% at 1–2 m depth. In contrast, at Wattaru, coral cover decreased at both depths, from 4.4% to 1.8% at 1–2 m and from 13.2% to 6% at 10 m. The amount of bare substrate also increased at Wattaru compared with the other two sites.

The physical damage to the reef substrate varied significantly between the three sites. The number live coral colonies varied between sites; Kuda Ambaraa (32), Wattaru (27), Foththeyo (102) at 10 m and Kuda Ambaraa (63), Wattaru (22) and Foththeyo (164) at 1–2 m depth. The degree of the physical damage to the coral colonies was contrastingly different at the three sites. The reef at Wattaru exhibited considerably more damage than was observed at Kuda Ambaraa or Foththeyo (figure 5). The average number of live coral colonies also varied among the three sites; 10, 9, 34 at 10 m and 21, 7, 54 at 1–2 m for Kuda Ambaraa, Wattaru and Foththeyo respectively. The least number of live coral colonies was recorded at Wat-

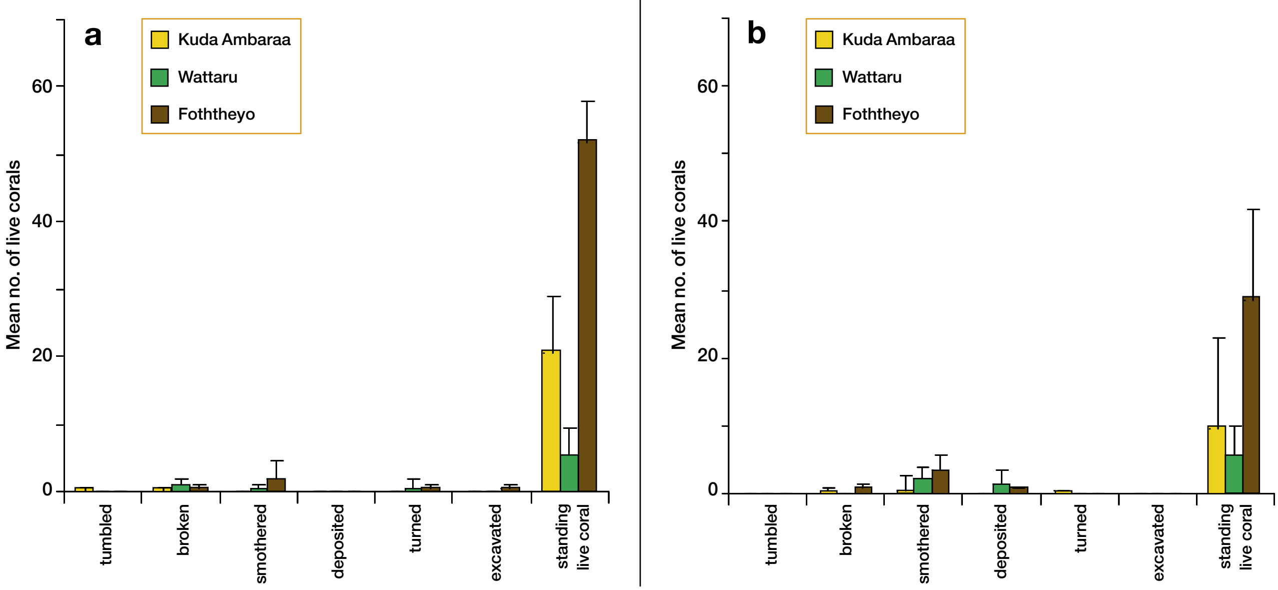


Figure 5. Proportion of the physical damage to the reef structure at three monitoring sites in Vaavu atoll. Depths are plotted separately, a = shallow (1–2m), b = deep (7–10meters).

taru. The percentage of damage to the coral substrate at Wattaru ranged from 27–37% for both depths (1–2 m and 10 m) compared with 3–9% for Kuda Ambaraa and 5–15% for Foththeyo.

The extent of mortality and physical damage to the live coral and reef substrate was also assessed for these three sites. A total of 410 coral colonies were used to assess the extent of mortality mainly due to smothering by sediments. Approximately 10% of the coral colonies were affected due to sedimentation inflicting varying levels of mortality. Among this 10%, only approximately 4% of the colonies sustained more than 50% mortality (partial death of coral colony, loss of tissue and colouration) whilst the remaining 6% exhibited less that 50% mortality. The extent of mortality was highest at Wattaru, moderate at Foththeyo and lowest at Kuda Ambaraa (figure 6).

DISCUSSION

The overall coral cover increased from approximately 2 to 28% between 1998 and 2005 among the 15 sites sur-

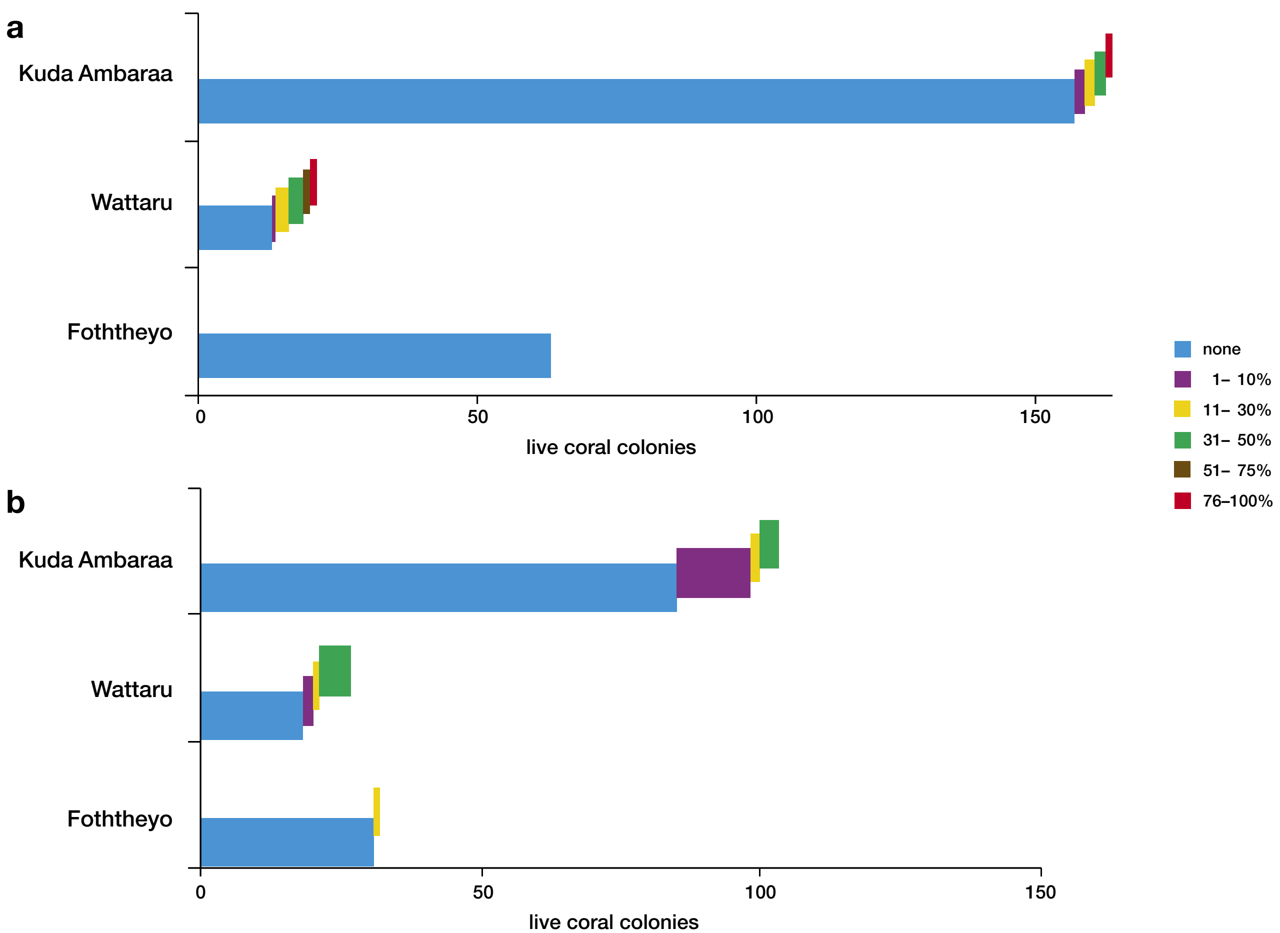


Figure 6. Coral mortality caused by smothering by sediment stirred up by the tsunami at three monitoring sites in Vaavu atoll. Coral mortality for each depth plotted separately, a = shallow (1–2m), b = deep (7–10m).

veyed. Reef recovery in terms of coral cover has been variable across the 15 sites. The 1999 survey indicated less live coral cover in several sites indicating subsequent mortality since the bleaching and the absence of measurable recovery at these sites. The subsequent decline in coral cover in 1999 and the variable recovery at several sites may be a good indication of the severity of the bleaching during the 1998 El Niño.

Strong recruitment of corals has been reported from a parallel study carried out to assess the reef recovery processes since the bleaching event in 1998 (Zahir *et al.*, 2002). Size frequency analysis of the recruits from this study indicated that the coral community is dominated by the influx of new and small recruits. Although the coral recruits are dominated by encrusting forms (e.g. agariciids, mostly *Pavona* spp.) indicating that a shift in coral community composition from the previously dominant branching and fast growing forms (e.g. acroporids), there is a good evidence that the reefs are recovering slowly. The recruitment success at these study sites also indicates that the reefs are not recruitment limited and a source of larvae is in the vicinity, although variable environmental factors are likely to affect the rate of reef recovery, especially on reefs recovering from severe disturbance.

The overall physical damage caused by the tsunami of 2004 was negligible (AusAID and MMRC, 2005). Broad-scale assessment of the damage of the tsunami to reefs showed similar patterns of coral cover through out the Maldives that are comparable to the results of this long- term monitoring program (figure 7).

One hundred and twenty four reef sites were surveyed in seven atolls, covering about 170 km of reef margin. Although there was damage to coral and movement of sediments in all regions these perturbations varied in extent and intensity. Even so, surveys generally indicated that direct damage to reefs from the tsunami was minor. However, the reefs of the Maldives are in the early stages of recovery from the massive bleaching in 1998 and the most significant consequence of the tsunami may be to hamper this process. Many survey sites had a light coating of sand. Small coral recruits are most vulnerable to smothering by sand and rubble and even a light coating of sand may make reef surfaces unsuitable for future settlement. This powdering effect imposes a considerable concern that may hamper the survival of coral and other benthic recruits in these locations. A recruitment failure due to recurring environmental perturbation would have a significant impact on the reef recovery process.

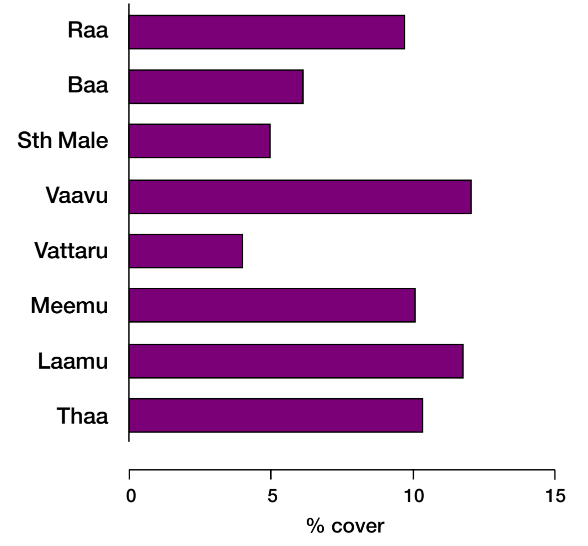


Figure 7. Live coral cover at each of the atolls surveyed by AusAID/ MRC to assess the impacts of the tsunami.

In general, little is known of the biodiversity or prior ecosystem status and past changes on coral reefs of the Maldives, especially after the tsunami. The results presented here provide important information with regard to the damage caused by the tsunami where the sites are directly compared before and after the tsunami.

ACKNOWLEDGEMENTS

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Status of Coral Reefs of the Tuticorin Coast,

Gulf of Mannar, Southeast Coast of India

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key words: Tuticorin coast, coral status, coral diversity

INTRODUCTION

The coral reefs of the Gulf of Mannar along the Indian coast are mainly found scattered around the 21 islands that are distributed in an 8 km wide band between Pamban and Tuticorin (figure 1 on next page). Tuticorin (Lat. 8° 45' N, Long. 78° 10' E) is located at the southern end of the Gulf of Mannar. The floral components comprises of economically viable species of seaweeds such as *Gracilaria* sp., *Gelidiella* sp., *Caulerpa* sp., *Sargassum* sp. and *Turbinaria* sp. The sea grass communities of this region are the most diverse in India with the highest number of sea grass species recorded, providing important feeding grounds for the endangered *Dugong dugon.* The Tuticorin group includes four islands namely, Vaan (Lat 8° 50' N, Long. 78° 13' E), Koswari (Lat. 8° 52' N, Long.78° 13' E), Kariyachalli (Lat. 8° 57' N, Long. 78° 15' E) and Vilanguchalli (Lat. 8° 56' N, Long. 78° 15' E). As a result of soil erosion caused by excessive coral mining, Vilanguchalli now lies 1 m below mean low tide level. The islands have fringing and patch reefs around them. Narrow fringing reefs are located mostly at a distance of 100–150 m from the islands. Patch reefs rise from depths of 2–9 m and extend to 1–2 km in length with widths as much as 50 m.

There are five important fishing villages depending on the Tuticorin coast namely, Pudhukadarkarai (Inico Nagar), Thirespuram, Siluvaipatti, Vellapatti and Tharuvaikulam. There are 42 551 registered fishermen from these villages who depend solely on fishing around these four islands and along the coast for their livelihood. Fishing is carried out mainly in and around Tuticorin. The main fishery targets finfishes and shellfishes.

Fishing is mainly done by trawling or using gillnets or traps. The reef fishery is not very important in terms of total landings or earnings when compared with other fisheries, such as the demersal fishery in the shallow coastal areas or the tuna fishery. Many commercially exploited shoaling fishes, like sardines, mackerels, anchovies, snappers, and fast swimming pelagic forms, like tuna, billfish and sailfishes, are abundant in this region, forming a major fishery. However, it is expected that the focus on the Tuticorin fisheries is likely to change due to increasing demand from foreign markets, for high quality reef fishes, such as grouper, snapper, and shellfishes, like lobsters and crabs.

The reefs of Tuticorin are under severe threat due to natural and human interference. The local fisherfolk of this region have traditionally had a close relationship with the sea resulting in strong cultural and economic links with maritime activities such as fishing, pearl (*Pinctata fucata*) and chank (*Xancus pyrum*) diving. The over-exploitation of seaweeds, sacred chanks, pearl oysters and seahorses by the locals has made them commercially threatened. Coral mining and the use of destruc-

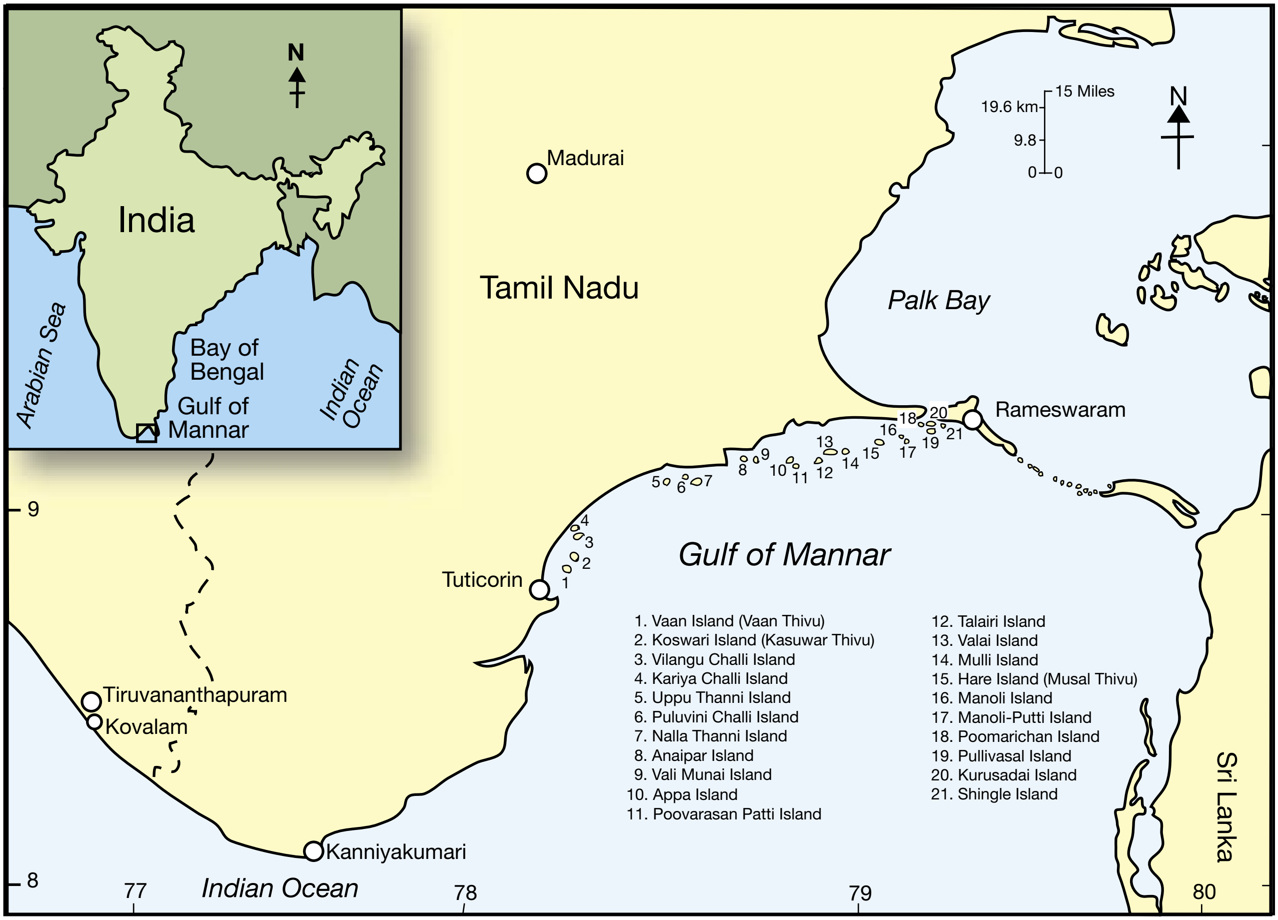

Figure 1.

tive fishing methods are prevalent in the area (Patterson, 2002).

In this present survey, the status of corals reefs along the Tuticorin coast was assessed, as an initiation of a longer-term monitoring effort, mainly around the islands and mainland areas

METHODS

Study Area

The Tuticorin region consists of 7 islands, which are categorized into two groups namely, the Tuticorin Group (4 islands) and the Vembar Group (3 islands). The Tuticorin Group includes two patch reefs, one found near Tharuvaikulam fishing village, which is approximately 300 m offshore and 3 km long, and another found near the Tuticorin harbour area, which is 1.2 km offshore and 5 km long. Each patch reef is found at different depths.

Surveys were conducted between January 2003 and February 2004 at each of the four islands of the Tuticorin group and the two patch reefs, Harbour and Tharuvaikulam.

Line Intercept Transect Method

The surveys were initiated by mapping the patch reefs and island reef areas, using manta tows (Done *et al.*, 1982).

After confirming the positions of the coral reef areas, the sessile benthic community were surveyed using the line intercept transect (LIT) (English *et al.*, 1997). Transects of 30 m in length were laid along the reef area, parallel to the depth contours of the reefs, using a flexible fibreglass measuring tape. The tape was laid at depths ranging between 1 m and 6 m. Depending on the size of the reefs, between 8 and 20 transects were laid on each of the four islands and the two patch reefs. Divers using SCUBA recorded each change of life-form category (table 1),

Table 1. Lifeform categories and codes.

Categories		Code	Notes/Remarks
Hard Coral			
Dead Coral		DC	recently dead, white to dirty white
Dead Coral with Algae		DCA	this coral is standing, skeletal structure can still be seen
Acropora	Branching	ACB	at least 2° branching, e.g. *Acropora palmate*, *A. formosa*
	Encrusting	ACE	usually the base-plate of immature *Acropora* forms, e.g. *A. palifera* and *A. cuneata*
	Sub massive	ACS	robust with knob or wedge-like form e.g. *A. palifera*
	Digitate	ACD	no 2° branching, typically includes *A. humilis*, *A. digitifera* and *A. gemmifera*
	Tabular	ACT	horizontal flattened plates e.g. *A. hyacinthus*
Non – *Acropora*	Branching	CB	at least 2° branching e.g. *Seriatopora hystrix*
	Encrusting	CE	major portion attached to substratum as a laminar plate e.g. *Porites vaughani*, *Montipora undata*
	Foliose	CF	Coral attached at one or more points, leaf-like, or plate-like appearance e.g. *Merulina ampliata*, *Montipora aequituberculata*
Submassive		CS	tends to form small columns, knobs, or wedges e.g. *Porites lichen*, *Psammocora digitata*
	Mushroom	CMR	solitary, free-living corals of the *Fungia*
	Heliopora	CHL	blue coral
	Millepora	CME	fire coral
	Tubipora	CTU	organ-pipe coral, *Tubipora musica*
Other Fauna			
Soft Coral		SC	soft bodied coral
Sponge		SP	
Zoanthids		ZO	examples are *Platythoa*, *Protopalythoa*
Others		OT	Ascidians, anemones, gorgonians, giant clams etc.
Algae	Algal Assemblage	AA	consists of more than one species
	Coralline Algae	CA	
	Halimeda	HA	
	Macroalgae	MA	weedy/fleshy browns, reds, etc.
	Turf Algae	TA	lush filamentous algae, often found inside damselfish territories
Abiotic	Sand	S	
	Rubble	R	unconsolidated coral fragments
	Silt	SI	
	Water	WA	fissures deeper than 50 cm
	Rock	RCK	
Other		DDD	Missing data

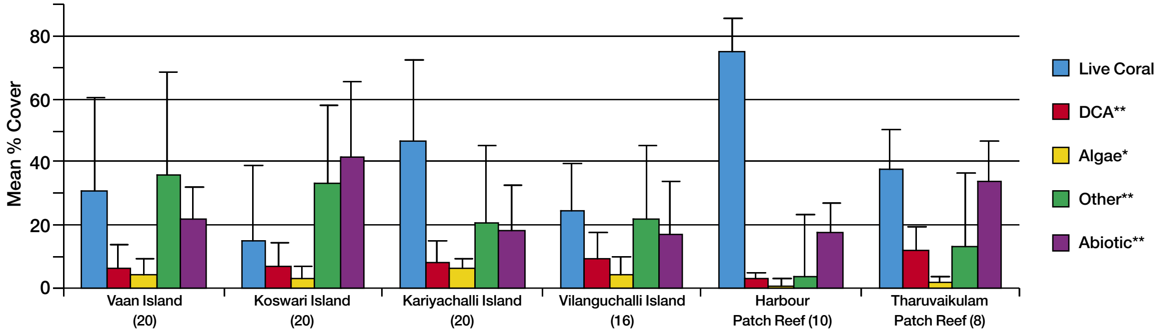

Figure 2. Mean percent cover (±SD) of each of the main habitat components at each site surveyed along the coast of Tuticorin. Differences in the cover of each substrate type between sites was tested using Kruskal-Wallis rank test (** indicates a significance level of $p<0.01$, while * indicates $p<0.05$). Numerals in parentheses indicate the number of transects recorded at each site.

along the transect. When *in situ* identification of coral genera was not possible, samples were collected for analysis in the laboratory. The percent cover of each life-form category was then calculated following the method of English *et al.* (1997). Differences in percent cover of the main benthic categories between the reef areas were tested using Mann-Whitney U-tests. Further, to compare the similarity of the benthic composition between the reef areas, a multivariate analysis was used. Multi Dimensional Scaling (MDS), based on rank similarity matrices using Euclidian Distance measure (Clarke, 1993) was performed on square root transformed data. The variables Halimeda (HA), Zoanthids (ZO) and Coralline algae (CA) were excluded from the analysis due to their low abundances. Differences between groups of samples were subsequently tested using the ANOSIM permutation test (Analysis of Similarities) (Clarke & Green, 1998).

RESULTS

Current Status of the Reefs

The total cover of each benthic life form recorded from each site surveyed is presented in figure 2. The multivariate analysis showed significant differences in the composition of the benthic community ($p>0.05$, Global Rho>0.3) between sites. The greatest differences occurred between the patch reefs and the island sites ($p<0.05$, Rho>0,0,4–0,8), and were caused by relatively small areas on each patch reef occupied by mono-specific stands of *Turbinaria mesenterina* and *T. peltata*. The differences between sites are clearly illustrated in figure 3 by the distinct grouping of the samples from these reefs.

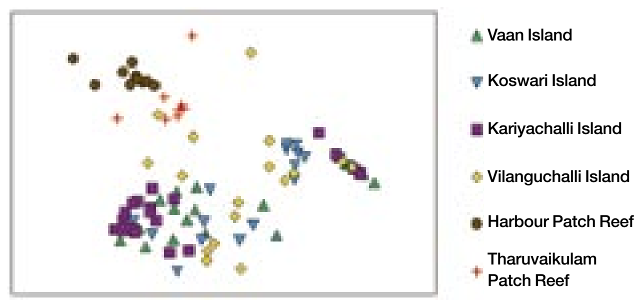

Figure 3. MDS plot illustrating the relative similarity between the benthic communities of each site, based on Euclidian distance similarities and square root transformed data. Each point represents one sample. The distances between the points display the relative similarities between the different samples. The closer the points are to each other, the more similar the samples.

The Harbour patch reef had significantly greater live coral cover ($p<0.001$) than all other sites, while the reef at Koswari Island had significantly less live coral than all other reefs except Vaan Island ($p<0.05$, Mann-Whitney U-test; figure 2).

The coral communities of the four island sites were dominated by massive corals (CM) followed by foliose (CF) forms and tabulate acroporids (ACT) (figure 4). The two patch reefs, on the other hand, were totally dominated by foliose *Turbinaria* spp. Branching acroporids (ACB) and other branching (CB) and encrusting (CE) forms contributed least to the cover of live coral suggesting that these corals are the worst affected by environmental stress.

Massive corals contributed the greatest cover of live coral at Kariyachalli Island, Vaan Island and Koswari Island. Foliose corals were the dominant life form at both patch reefs and Vilanguchalli Island. The highest cover of encrusting corals occurred at Koswari Island. The greatest percent cover of branching and tabulate acroporids occurred at Kariyachalli Island, while the greatest cover of branching non-acroporid corals was recorded at Vaan Island. Sub-massive corals were totally absent in the Tuticorin group of islands. Tabulate acroporids were only absent at Koswari Island.

The Scleractinian Fauna of Tuticorin

Pillai (1998) provided a comprehensive account of the coral fauna of the Gulf of Mannar in which 94 species belonging to 37 genera were reported. The scleractinian corals of the Tuticorin have been very little studied in the past. The first mention of corals from this area is that of Pillai (1972) who reported 21 species. During the past 30 years, little work has been conducted on the coral diversity of the region. The latest report is that of Patterson (2002) who reported 22 species from many localities in the Tuticorin region. However, the species composition of both reports shows little coincidence.

The present survey recorded 53 species of coral belonging to 22 genera (table 2 on next pages), of which 50 species from 19 genera were hermatypic and the remainder were ahermatypic. Among the 53 species, 42 were recorded for the first time in Tuticorin region and, of these, 10 species were recorded in the Gulf of Mannar for the first time.

DISCUSSION

Island Reefs

Among the islands, Kariyachalli exhibited the greatest live coral cover (46.6%) while Koswari exhibited the least

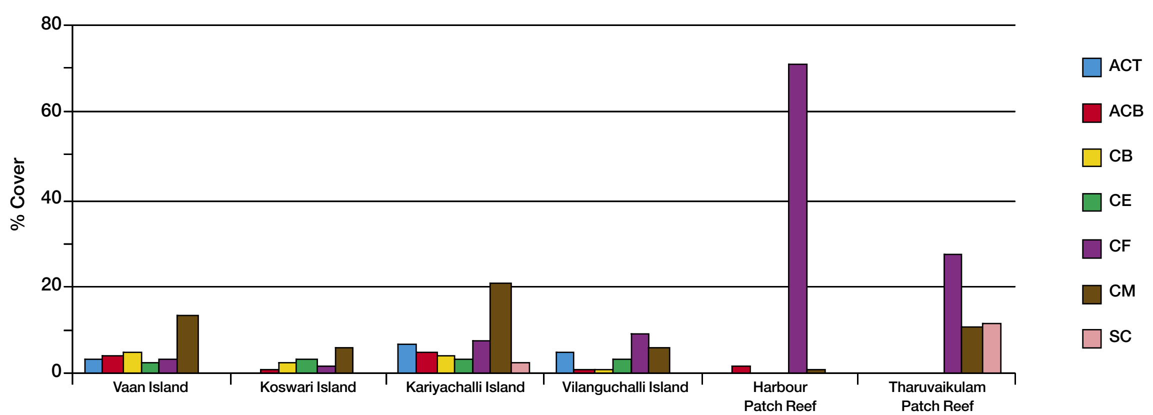

Figure 4. Percent cover of each live coral category, including soft coral, recorded from the Tuticorin group of islands and patch reefs in the Gulf of Mannar.

(15.29%). Generally, massive corals (11.32%) dominated the reefs of the Tuticorin Group of islands.

According to Venkataraman (2000), the bleaching event in 1998 destroyed most shallow water corals in the Gulf of Mannar, causing a significant reduction in the live coral cover, particularly among branching *Acropora* species of Tuticorin which declined to less than 1% of the total cover, and the local extinction of other branching species. Contrary to his report, the present survey, recorded 6.35% branching *Acropora* (ACB) and 3.26% cover of non-acroporid branching corals (CB) in this region and no signs of any mass mortality might have occurred when sea surface temperatures were elevated across the Indian Ocean in 1998.

Our results clearly demonstrate that, among the reefs of the four islands surveyed, only Koswari Island exhibited a low percentage cover of live coral (15.29 %). Coral mining around this island during the past two decades has reduced both the live cover and diversity of coral. At present, only the southwest corner of the island has live coral. Bleaching has not been noticed in Tuticorin Group of islands and, as a result, the damage to reefs in the re-

Table 2. List of scleractinian corals found along the Tuticorin coast

Species Name	Vaan Island	Koswari Island	Kariyachalli Island	Vilanguchalli Island	Harbour Patch reef	Tharuvaikulam Patch reef
Family: Pocilloporidae						
Pocillopora damicornis	–	+	+	+	–	–
Family: Acroporidae						
Acropora formosa	+	+	+	+	+	–
Acropora intermedia	–	–	–	–	+	–
Acropora valenciennesi	–	–	–	–	+	–
Acropora microphthalma	–	–	–	–	+	–
Acropora sp. novo	–	–	–	–	+	–
Acropora corymbosa	–	–	+	–	–	–
Acropora nobilis	+	–	+	+	+	–
Acropora humilis	+	–	–	–	+	–
Acropora valida	+	–	+	–	+	–
Acropora hemprichi	+	–	+	–	–	–
Acropora stoddarti	–	–	–	–	+	–
Acropora diversa	–	–	+	–	–	–
Acropora cytherea	+	+	+	+	+	–
Acropora Pillai sp.nov	–	–	–	–	+	–
Montipora subtilis	–	–	+	–	+	–
Montipora digitata	+	+	+	+	–	–
Montipora divaricata	+	+	+	+	–	–
Montipora jonesi	+	–	+	–	–	–
Montipora hispida	+	+	+	+	+	–
Montipora foliosa	+	–	+	+	–	–
Family: Siderastreidae						
Coscinaraea monile	+	–	+	–	+	+

Species Name	Vaan Island	Koswari Island	Kariyachalli Island	Vilanguchalli Island	Harbour Patch reef	Tharuvaikulam Patch reef
Family: Fungiidae						
Cycloseris cyclolites	+	–	–	–	–	–
Family: Poritidae						
Goniopora minor	–	–	+	–	–	+
Goniopora stutchburyi	+	+	+	+	+	+
Porites solida	+	–	+	+	+	–
Porites lutea	+	+	+	+	+	+
Porites lichen	–	–	+	–	–	–
Family: Faviidae						
Favia pallida	+	+	+	+	+	+
Favia favus	+	–	+	+	+	+
Favia matthaii	–	–	+	–	–	–
Favites abdita	+	+	+	+	+	–
Favites complanata	–	–	+	–	–	–
Favites flexuosa	+	–	+	–	–	–
Goniastrea pectinata	+	+	+	+	+	+
Goniastrea retiformis	+	+	+	+	+	–
Platygyra daedalea	+	+	+	+	+	–
Platygyra sinensis	–	–	+	–	–	–
Leptoria phrygia	+	–	+	+	–	–
Hydnophora microconos	+	–	+	+	–	–
Hydnophora exesa	+	+	+	+	–	–
Leptastrea transversa	–	–	+	–	–	–
Leptastrea purpurea	+	–	+	–	–	–
Cyphastrea serailia	+	+	+	+	+	–
Echinopora lamellosaa	+	–	–	–	–	–
Plesiastrea versipora	–	–	+	–	+	–
Family: Oculinidae						
Galaxea fascicularis	–	–	+	–	–	–
Family: Mussidae						
Symphyllia radians	–	–	+	–	–	–
Family: Caryophylliidae						
Polycyathus verrilli	–	+	–	–	–	–
Family: Dendrophylliidae						
Dendrophyllia indica	+	–	–	–	–	–
Turbinaria crater	+	+	+	+	+	+
Turbinaria peltata	+	+	+	+	+	+
Turbinaria mesenterina	+	+	+	+	+	+

+ Recorded. – Not recorded.

gion is attributable to mining and destructive fishing particularly bottom trawling in the reef area.

Patch Reefs

The results of surveys of the coral fauna conducted in this study are the first obtained from the patch reefs of Tuticorin. The two patch reefs, Tharuvaikulam and Harbour, appear to be healthy and the latter supports 10 species that have not previously been recorded in the region. There was no sign of impacts attributable to the 1998 bleaching event on these patch reefs, which are mostly covered with cup-shaped coral such as *Turbinaria mesenterina* and *T. peltata* and some massive and branching corals. However, sediment accumulating in the cup-shaped structures of colonies of *Turbinaria* seem reduce their growth rates resulting in a slow death.

Branching corals were totally absent from the patch reef of the Harbour area while encrusting corals were poorly represented. On the Tharuvaikulam patch reef, encrusting corals, branching and tabulate forms of *Acropora*, and non-acroporid branching corals were absent.

The commercially important seaweeds are found growing on the surface of the dead coral beds. Sea grass beds are common near all the islands and support a number of associated fauna such as sea anemones, the bivalve *Pinna* sp., and a number of species of starfish, sea cucumbers and sea urchins. Other life forms such as sponges, soft corals and reef fishes were also recorded.

Management Issues

The Gulf of Mannar is one of the most heavily stressed coral reef regions in India, with impacts from destructive fishing, pollution, coral mining, industrial effluent discharges, and domestic sewage pollution. Local fishermen complain that fish catches have declined both on the near shore and offshore coral banks and islands. The islands of Tuticorin have been affected by industrial pollution released by large number of factories that are located along the coast. Sewage has also resulted in the overgrowth by mats of green algae on the dead corals. Bottom trawling is also a major threat to the reefs. Trawlers are now fitted with a wheel at the footrope (Roller madi), which aids in jumping over coral reefs thereby causing destruction to the entire reef. Coral collection for the production of lime and the damage by trawlers continue to degrade the coastal reefs. Black, white and yellow band coral diseases have also been observed.

The live export of lobsters and fishes from this area in the recent years is also causing damage to corals. Fishermen set lobster and fish traps on all available coral areas. The setting and retrieving of cages causes damage to live corals. Ola valai, a type of beach seine, is not intrinsically destructive while the process of shore seine operation is largely responsible for the destruction of new colonies of corals.

It is evident that some of the islands, which are close to the mainland, have fewer live corals. Banning illegal coral mining and destructive fishing practices is the only way to protect coral diversity.

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Indian Ocean Island – Summary

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INTRODUCTION

The Indian Ocean Islands CORDIO node consists of Comoros, Madagascar, Mauritius and Seychelles, all located within the western Indian Ocean. Although their combined total Exclusive Economic Zone (EEZ) exceed 4.1 million km², coral reefs cover only about 3 500 km², with the largest area being in Madagascar (see table 1).

Significant areas of coral reefs occur in the sub-region, in particular within the Seychelles archipelago, Madagascar, Mauritius, and Comoros. Madagascar has the largest area of coral reefs in the sub-region, mostly dominant along the eastern coast. Most of the granitic islands of the Seychelles are encircled by discontinuous, fringing reefs. Along the east coast of Mahé, reef flats reaching over 2 km in width and terminating in a high algal ridge which descends down a reef slope to a floor typically at 8 to 12 m are observed. In the coral islands, the types of reefs are highly varied from true atolls, raised atolls to submerged or partially submerged atolls and sand banks. Mauritius is almost completely encircled by fringing reefs, with substantial lagoon and barrier reef development on the east and southwest coasts (Salm, 1976). Rodrigues Island (Mauritus) is totally encircled by reefs, with wide shallow reef flats extending from the shore, with its widest extent reaching 10 km in the west (Spalding *et al.*, 2001). The main types of reefs in the Comoros are discontinuous fringing reefs, ranging from 15 m to several kilometres from the coastline. In Comoros, reef cover is most extensive on the island of Anjouan (Scetauroute, 1999).

There are a total of about 14 marine protected areas (MPAs) in the region, covering over 800 km² of ocean.

Table 1. Estimated coral cover in the Indian Ocean Islands

Countries	Land Area (km²)	Coastline (km)	Est. Coral Cover	No. of Species	No. of Genera
Comoros	2 230	469	432 km² (Anjouan)	N.A	N.A
Madagascar	581 540	9 935	~2 000 km²	112	57
Mauritius	2 030	496	~500 km²	133	47
Seychelles	450	747	~577 km²	174	55

Source: McClanahan *et al.*, 2000.

Table 2. Characteristics of marine protected areas in the sub-region

Country	Name	Year Est.	Size (km²)
Comoros	Moheli Marine Park	2001	404
Madagascar	Nosy Atafana Marine Park	1989	10
	Masoala Marine Park	1997	100
Mauritius	Fishing Reserves (Port Louis, Grand Port, Black River, Poudre d'Or, Poste Lafayette, & Trou d'Eau Douce)	1983	63.2
	Blue Bay Marine Park	1997	3.5
	Balaclava Marine Park	1997	5
Seychelles	St Anne Marine National Park	1973	14
	Aride Island Special Reserve	1979	0.1
	Baie Ternay Marine National Park	1979	1
	Cousin Island Special Reserve	1979	1
	Curieuse Marine National Park	1979	16
	Port Launay Marine National Park	1979	1.5
	Aldabra Special Nature Reserve/World Heritage Site	1981	190
	Silhouette Marine National Park	1987	

Source: Francis *et al.*, 2002.

All of these MPAs include substantial areas of coral reefs, however, recent assessments indicate that there are still a number of important coral reefs areas which should be included in MPAs in all of these countries (Payet, 2004). Within its research programme CORDIO has assisted and supported monitoring within and outside MPA's.

STATUS OF THE REEFS

The status of coral reefs in the Indian Ocean is reported in the 'State of the Coral Reefs 2004' report, through the contribution of CORDIO experts (Ahamada *et al.*, 2004). This summary provides an update to that report.

Comoros

Monitoring of coral reefs in Comoros is undertaken at 20 sites on the three main islands in the group. Monitoring has been ongoing since the 1998 mass coral bleaching event, and in many areas coral recovery has been observed.

However, reported coral recovery has been modest. In some areas (Isandra Island), coral cover has increased from 36% in 2003 to 42% in 2004. Ouani (Ajounan Island) remains one of the most intact and diverse reef within the Comoros which deserves better management, although it was also affected by the 1998 bleaching. In some areas such as Bimbini reef (Anjouan Island), live coral cover has actually decreased from 24% in 2003 to 18% in 2004, primarily due to a proliferation of sea urchins and also pressure from trampling and anchor damage. Conservation efforts at the Moheli Marine Park (Moheli Island) indicate that coral reef recovery is enhanced when areas are protected and human intervention reduced.

Surveys undertaken in 2005 (Ahamada, 2005) indicate a 48.8% increase in coral cover in Isandra Island, a slight increase over 2004. However, in Ouani, the extent of recovery from 2003 to 2005 ranges up to 61%. Extensive stands of branching and tubular *Acropora* species which are currently unprotected at this site continue to be threatened by human intervention.

Madagascar

Due to its large coastline, coral reef monitoring sites around Madagascar are separated by large distances and also exposed to various local conditions which can influence recovery. For example, sites such as Dzamandjar (on the north-west coast) saw a decline in live hard coral cover (LHC) in 2004, whilst in Foulpointe (on the east coast) LHC has increased, despite high levels of sediment input in that region. At the 'Grand Recif' in Toliara (on the south-west coast), no significant change in coral cover has been reported. Overall human impacts on coral reefs in Madagascar include sediment discharge from unsustainable land-use practices and fishing pressure has not diminished and remains largely unmanaged. Natural events such as cyclones also impact on coral reefs, in particular unconsolidated ones.

Mauritius

Coral bleaching was also observed in the lagoons of Mauritius in 1998 during regular coral reef monitoring. However, the percentage of bleached corals was less than 5% at all the sites surveyed (7 sites). Follow up surveys in 1999 showed that the coral reefs exhibited marked recovery. In 2003, further bleaching of corals was observed in late February but by June, 97% of the bleached corals had recovered. Coral cover dropped by 11% to 37% in 2002. Likewise, in 2004 almost 60% of the corals were affected by bleaching during the warmest month (March) but by July most of these affected corals had recovered. Overall, Mauritius reported a higher coral mortality at all of the sites due to the 2004 bleaching episode than previous episodes.

Coral cover at the Blue Bay Marine Park remained stable at 91%. Substantial stand of *Acropora* sp. (59%) remain, primarily as a result of intensive conservation efforts by the Mauritius Government from human intervention, mainly from hotel and tourism development.

Seychelles

Most of the shallow reefs in the Seychelles archipelago were bleached in 1998. Seven years after the bleaching event, recovery of coral communities has been variable, although recovery has been hampered by recurring bleaching events in 2002 and 2003. In 2000, mean LHC was only 3% (surveys done at 22 sites), but in 2004 mean LHC was 10.2% (surveys done at 48 sites) a significant increase despite the recurring bleaching events.

Detailed coral reef surveys of Cosmoledo Atoll in 2002 showed that bleaching-related mortality had been quite severe, despite its remoteness from human population (Souter *et al.*, this volume). Coral mortality in the lagoon was very high, with 95% of the large colonies of *Acropora* completely decimated.

Recovery rates on carbonate reefs were found to be much slower than on granitic reefs. This may be due to the greater stability of granitic reefs compared with carbonate reefs (Payet *et al.*, this volume). The majority of reefs with high rates of recovery are found in MPAs.

ASSESSMENT OF TSUNAMI DAMAGE

Seychelles was the only country within this CORDIO node to have reported damage to its coral reefs as a result of the tsunami of 26 December 2004 that affected many countries in south-east Asia and the Indian Ocean. A rapid assessment of the damage was undertaken by CORDIO and IUCN in February 2005 (Obura & Abdullah, 2005). Coral reefs were found to be particularly vulnerable to physical damage from the tsunami waves due to the weakened reef structure and bio-erosion as a result of the recent bleaching events. The survey revealed little direct damage caused by the tsunami on coral reef habitats, with the majority experiencing 5% reduction in coral cover, especially in unconsolidated reef areas. However, greater than 50% substrate damage and greater than 25% of direct damage to corals was observed in northern and eastern-facing carbonate reef sites.

CLIMATE CHANGE IMPACTS

As a result of the 1998 coral bleaching due to elevated sea surface temperatures (SST), research aimed at predicting the occurrence of such bleaching events is being undertaken. Sheppard (2003) using mean historical SSTs (from 1871 to 1999) in combination with the HadCM3 climate model (IS92a climate scenario) generated forecast SST for the period 2010–2025. The results of this modelling work indicated that reefs found at latitudes between 10–15° south in the western Indian Ocean will be affected by elevated SST every 5 years. Although areas outside of this geographical range will also be affected, the model does not give clear results. Such predicted coral bleaching events will have serious impacts on ongoing conservation efforts and coral recovery.

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Status and Recovery of Carbonate and Granitic Reefs

in the Seychelles Inner Islands and Implications for Management

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key words: Seychelles, reef, carbonate, granitic, recovery, resilience, management

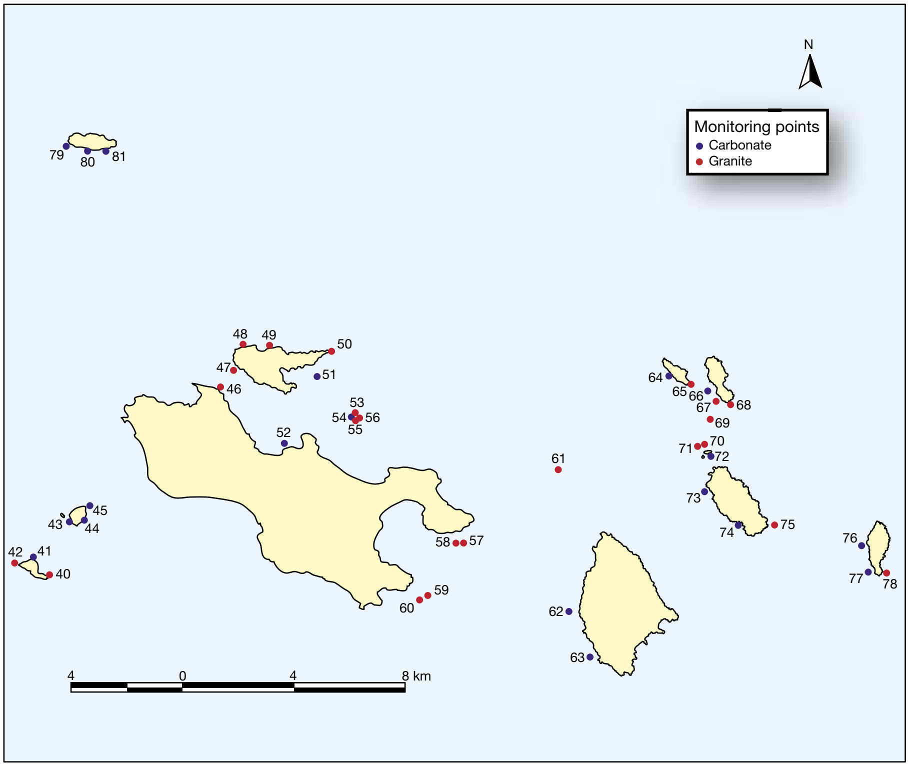
ABSTRACT

The majority of shallow reefs in the Seychelles suffered extensive damage as a result of the 1998 mass coral bleaching event, despite low levels of direct human impacts. This paper explores the historical status of coral reefs of Seychelles and considers the nature and future trends in factors that will affect recovery of coral reefs in the Seychelles inner islands. We have used data obtained from several coral reef monitoring programmes undertaken after the 1998 bleaching event to examine recovery rates on granitic and carbonate reefs and in protected and unprotected areas. Seven years after the bleaching event, recovery of coral communities has been variable. Recovery rates on carbonate reefs were much slower than on granitic reefs, which might be attributable to the greater stability of granitic reefs compared with carbonate reefs. The majority of reefs with high rates of recovery are found in Marine Protected Areas (MPAs). These findings have serious implications for management and also require further studies. Subsequent phases of the CORDIO project will investigate how and why these recovery rates are being observed, and what management options can be considered to maintain or increase those rates of recovery.

INTRODUCTION

The coral reefs of the Seychelles have been described as being one of the most extensive networks in the Western Indian Ocean (Jennings *et al.*, 2000). However, most historical studies and monitoring, as early as 1820, have primarily focused on the granitic islands and Aldabra (Stoddart, 1970). This is probably due to the accessibility of these islands. Recently, studies have also focused on Cosmoledo (Sheppard & Obura, 2005), several atolls in the Amirantes group (Wendling *et al.*, 2003) and Alphonse (Hagan, 2004) in order to better understand the impacts of the 1998 mass coral bleaching and the subsequent recovery of coral reef communities. The most comprehensive assessment of the coral reefs within the inner granitic islands was done through the Global Environment Facility (GEF) funded Seychelles Marine Ecosystem Management Programme (SEYMEMP) from 2000-2004, where 81 coral reef sites (figure 1, table 1 on page 134–135) were monitored using fine-scale monitoring techniques. The Regional Coral Reef Monitoring Programme of the Indian Ocean Commission (COI) also monitored several sites in the Seychelles, especially in the marine parks, and formed the basis for the production of reports to the Global Coral Reef Monitoring Network (GCRMN) (Ahamada *et al.*, 2002, 2004). The CORDIO programme in Seychelles focussed its work on socio-economic aspects and an expedition to Cosmoledo atoll in 2002. The current focus of CORDIO in Seychelles is to study coral reef recovery, management approaches to enhance recovery and the socio-economic

Figure 1. Location of the coral reef monitoring sites between 2000 and 2004.



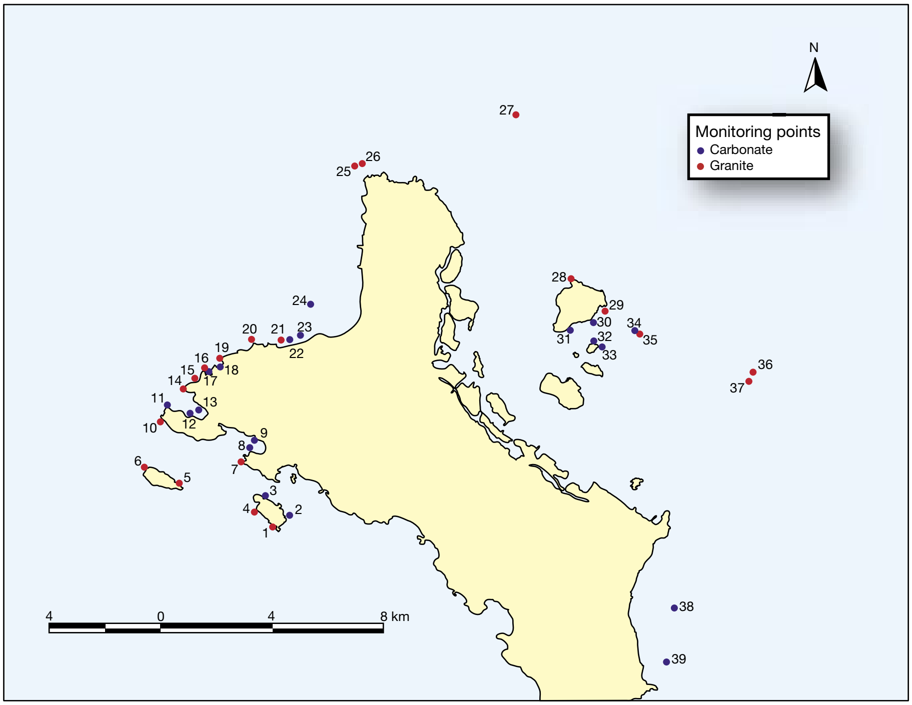


Table 1. Location and geological base of the coral reef sites monitored between 2000 and 2004. Under 'Type' C represents carbonate reefs and G represents Granitic reefs

Number	Name	Type	Latitude (UTM)	Longitude (UTM)
1	Ile Therese South point	G	322781.15	9482596.07
2	Ile Therese South East reef	C	323407.21	9483025.23
3	Ile Therese north East reef	C	322528.98	9483762.70
4	Ile Therese North rocks	G	322125.53	9483134.42
5	Conception North East point	G	319326.27	9484210.40
6	Conception North West rocks	G	318057.61	9484803.72
7	Port Launay South West point	G	321615.17	9485006.30
8	Port Launay South reef	C	321954.00	9485526.00
9	Port Launay South East reef	C	322125.00	9485802.00
10	Cap Matoopa North West point	G	318638.38	9486480.60
11	Baie Ternay North West reef	C	318906.08	9487091.73
12	Baie Ternay South West reef	C	319738.70	9486801.64
13	Baie Ternay Central reef	C	320081.35	9486913.92
14	Baie Ternay North East rock	G	319489.28	9487699.72
15	Rays point	G	319919.73	9488093.54
16	Willie's bay point	G	320272.39	9488465.73
17	Willie's bay reef	C	320429.00	9488352.00
18	Anse Major reef	C	320869.46	9488527.60
19	Anse Major point	G	320832.64	9488836.86
20	Black Rock	G	321999.14	9489510.04
21	White House rock	G	323100.22	9489487.56
22	Auberge reef	C	323414.81	9489510.04
23	Corsaire reef	C	323819.29	9489644.86
24	Aquarium reef	C	324192.87	9490810.55
25	L'ilot West rock	G	325819.07	9495914.53
26	L'Ilot North West rocks	G	326085.07	9496019.53
27	Brissare North rock	G	331776.85	9497832.75
28	Ste Anne North point	G	333793.92	9491777.09
29	Ste Anne South East point	G	335060.71	9490572.41
30	Ste Anne South Central reef	C	334627.86	9490161.70
31	Ste Anne South reef	C	333796.43	9489869.57
32	Moyenne North East reef	C	334650.00	9489468.00
33	Moyenne East reef	C	334950.88	9489237.57
34	Beacon North West reef	C	336147.00	9489862.00
35	Beacon South West rock	G	336335.66	9489734.75
36	Harrisson East rock	G	340521.00	9488311.00
37	Harrisson South rock	G	340345.00	9487985.00
38	Anse Aux Pins Central reef	C	337622.00	9479602.00
39	Anse Aux Pins South reef	C	337326.00	9477607.00
40	Cousine South East point	G	350550.73	9518981.49
41	Cousine North East reef	C	349976.03	9519607.23

Number	Name	Type	Latitude (UTM)	Longitude (UTM)
42	Cousine North West point	G	349311.49	9519416.35
43	Cousin South West reef	C	351271.91	9520863.19
44	Cousin East reef	C	351823.00	9520935.00
45	Cousin North East reef	C	352015.00	9521450.00
46	Praslin North East rock	G	356675.39	9525727.00
47	Curieuse West rock	G	357165.33	9526318.64
48	Curieuse North West rock	G	357495.61	9527247.89
49	Curieuse North Central rock	G	358453.00	9527210.18
50	Curieuse Point Rouge	G	360670.00	9526976.00
51	Coral Garden	C	360150.00	9526094.00
52	Anse Petit Cours	C	358977.00	9523699.00
53	St Pierre North East rock	G	361528.00	9524783.00
54	St Pierre North West reef	C	361386.43	9524636.61
55	St Pierre South East rock	G	361544.04	9524517.36
56	St Pierre East rock	G	361684.00	9524612.00
57	Round island South East rock	G	365404.96	9520123.88
58	Round island South West rock	G	365149.35	9520123.88
59	Ave Maria South rock	G	364114.00	9518234.00
60	Ave Maria South West rock	G	363836.50	9518080.07
61	Roches Boquet	G	368812.00	9522764.00
62	La Digue Central West reef	C	369188.75	9517665.05
63	La Digue South West reef	C	369957.07	9516046.90
64	Petite Soeur Central West reef	C	372791.00	9526100.00
65	Petite Soeur South East rock	G	373569.02	9525806.52
66	Grand Soeur South West reef	C	374176.00	9525558.00
67	Grand Soeur South West rock	G	374467.25	9525181.71
68	Grand Soeur South East rock	G	374985.65	9525086.05
69	Albatross rock	G	374269.91	9524542.55
70	Ile La Fouche North East rock	G	374049.00	9523638.00
71	Ile La Fouche South East rock	G	373827.00	9523566.00
72	Coco Island South East reef	C	374272.00	9523244.00
73	Felicite North West reef	C	374063.00	9521954.00
74	Felicite South West reef	C	375274.00	9520728.00
75	Felicte South East rock	G	376575.59	9520759.34
76	Marianne Central West reef	C	379696.00	9520037.00
77	Marianne South West reef	C	379938.00	9519087.00
78	Marianne South East rock	G	380571.00	9519026.00
79	Aride South West reef	C	351175.67	9534363.61
80	Aride South Central reef	C	351915.73	9534170.47
81	Aride South East reef	C	352596.00	9534149.48

impact of coral bleaching on local communities, especially fishermen, as well as supporting basic monitoring and capacity building.

This paper presents an overview of the historical status of coral reefs in Seychelles, and how this has changed as a result of local impacts and also the effects of mass bleaching. Using data collected since the bleaching event, recovery rates of coral reefs around the granitic Seychelles was computed and analysed against future trends and likely scenarios of elevated sea-surface temperature extremes.

THE STATUS OF CORAL REEFS IN THE SEYCHELLES

Coral reefs in Seychelles can be classified into three main groups: fringing reefs – characteristic of the granitic islands, atolls (e.g. Aldabra and Cosmoledo) and platform reefs (e.g. around islands of the Amirantes). The coral reef areas of the Seychelles have an estimated cover of about 1 690km² (Spalding *et al.*, 2001) of which 40 km² are in the granitics (Jennings *et al.*, 2000). There are more than 300 known species of corals from the Seychelles (Veron & Stafford-Smith, 2000). A recent expedition to the southern Seychelles atoll of Aldabra and Cosmoledo recorded 201 of these species (Sheppard & Obura, 2005). Table 2 summarises the characteristics of those reefs.

Prior to the 1998 coral bleaching event the coral reefs of the Seychelles was described as supporting a growing artisanal fisheries sector and to have remained relatively undamaged except for a certain amount of anchor damage, land reclamation on the east coast of Mahe and land based sources of pollution (Salm *et al.*, 1998). The most

Table 2. Reef characteristics around some of the main islands of the Seychelles

Island	Reef Type	Total area (km²)	Total area of island (km²)	Area of reef (km²)	Reef width (m)	Lagoon area (km²)
Mahe	Fringing	173.91	156.88	17.03	75– 1 400	–
Praslin	Fringing	66.02	37.85	28.17	135– 3 100	–
La Digue	Fringing	12.75	9.82	2.93	50– 630	–
Curieuse	Fringing	3.47	2.74	0.73	40– 275	–
St.Anne	Fringing	2.85	2.19	0.66	45– 440	–
Cousine	Fringing	0.74	0.24	0.50	70– 440	–
Cousin	Fringing	0.78	0.29	0.49	110– 305	–
African Banks	Platform	4.14	4.12	0.02	300– 1 050	–
Coetivy	Platform	15.44	6.50	8.94	230– 600	–
D’Arros	Platform	3.81	2.21	1.60	100– 750	–
Platte	Platform	10.36	9.91	0.45	230– 1 630	–
Providence-Cerf	Platform	138.07	135.75	2.32	Not Available	–
Aldabra	Raised platform	371.89	152.55	28.94	60– 660	190.40
Assumption	Raised platform	14.43	11.01	3.42	100– 390	–
Astove	Raised platform	16.16	5.36	4.20	135– 440	6.60
Cosmoledo	Raised platform	139.17	4.44	70.36	600– 5 000	64.37
St Pierre	Raised platform	1.71	1.71	–	– –	
Alphonse	Raised platform	19.26	1.60	12.79	100– 2 100	4.87
Farquhar	Raised platform	268.48	7.37	160.55	4 400–11 000	100.56
St Francois	Raised platform	48.73	0.32	34.45	200– 3 500	13.96
St Joseph	Raised platform	23.09	1.35	17.34	220– 2 700	4.40

significant impact on coral reefs occurred in 1998 when a widespread bleaching event resulting from globally elevated sea surface temperatures caused extensive mortality among corals affecting as much as 90% of the coral cover down to depths exceeding 15m in some areas of the Seychelles (Lindén & Sporrong, 1999).

Due to the recent bleaching event in 1998, the status of Seychelles reefs has significantly changed. Long-term analysis of sea surface temperature data extracted from the Hadley Centre in UK suggests that the 1997–1998 warming was the highest during the last 37 years (Spencer *et al.*, 2000), and seems to be closely associated with El Niño years, although Webster *et al.* (1999) has argued that ocean warming in the Indian Ocean may occur even in the absence of El Niño.

The status of coral reefs around Mahe was assessed in late 1999 by Turner *et al.* (2000) and Engelhardt (2000), which was focussed on the east coast and Ste Anne Marine Park and the north-west coast respectively. They concluded that the living hard coral cover (LHCC) on most of the shallow coral reefs of the granitic islands had declined to less than 10%, which in effect constituted a loss of between 15% and 70% of the coral cover in many areas. It was found that the branching and tabular *Acropora*, and branching *Pocillopora* species suffered the most while *Porites* was more resilient. Similar observations were reported by the Regional Coral Reef Monitoring Programme of the Indian Ocean Commission (COI) which recorded 95% bleaching-related mortality of *Acropora* (Bigot *et al.*, 2000). However, massive corals from the genus *Porites* and *Goniopora* were observed to have survived throughout the inner islands.

Although mortality among corals was extensive and the diversity at most sites surveyed was low following the 1998 mass bleaching event, no extinctions have been reported, rather the abundance and distribution of species have reduced. This finding has important implications for recovery and the probability of future recruitment from within the region (Engelhardt, 2000; Lindén & Sporrong, 1999).

CURRENT AND FUTURE THREATS TO CORAL REEFS

The quality of coral reefs in the Seychelles, particularly in the granitic islands, has declined significantly as a result of the 1998 coral bleaching event and growing human impacts (Engelhardt, 2004). Whilst the majority of threats act directly on coral reefs, the threat of global warming and further elevation of the sea surface temperature for sustained periods is the sole threat that could virtually eliminate viable coral populations in the Western Indian Ocean region (Sheppard, 2003). It is also feared that further development of coastal fisheries and tourism could result in considerable degradation of the remaining and more resilient reefs. At least five important threats to the coral reefs of the Seychelles are emphasized here:

1. Reclamation, Mining and Sedimentation

Extensive reclamation has occurred on the east coast of Mahe, and small areas have also been reclaimed on the other granitic islands to meet demand for land, since land is extremely scarce in the Seychelles (Payet, 2003). Reclamation on shallow reef flats completely eliminates coral reef ecosystems, and associated impacts such as silt from dredging can affect adjoining reef areas for many years if proper mitigation measures are not implemented. The Ste Anne Marine Park, for example, shows evidence of such sediment-related stress following chronic sedimentation from dredging activities on the east coast of Mahe since the early 1980s (Robinson, 1999).

Sedimentation from land-based activities further inland is also of concern as this fine silt is carried by rivers during periods of heavy rainfall. A red colouration due to erosion of the lateritic soils is also observed within several kilometres of the coast following intense rainfall on the granitic islands. Such sedimentation is mainly a result of heightened development and construction on the steep slopes, as opposed to deforestation which leads to similar effects in other countries. Strict guidelines for minor works and rainy season restrictions have been implemented to reduce the impacts of these types of developments.

2. Impacts from Tourism Activities

Tourism activities have several impacts on coral reefs in Seychelles. These include direct damage from anchors and trampling during snorkelling and diving, and indirectly during hotel construction and operation. Whilst a series of mooring buoys are currently being installed in the critical coral reef areas, there are still reports of anchor damage (Bijoux, J., *pers. obs.*). Trampling through poor visitor management at coral sites is a common problem caused by tour operators who wish to bring the maximum number of passengers to a particular site. Tourism can also affect coral reefs through the discharge of untreated sewage and sediments. This was the case with hotels that were built before the 1990s in the Seychelles. Today, it is a legal requirement that all hotels have to meet stringent effluent water quality standards and offshore outfalls are not encouraged. The environment impact assessment (EIA) process is mandatory for all such large developments and many of these threats are addressed in such a process (Payet, 2003).

3. Fishing Pressure

Reef fisheries have shown a considerable decline in catch per unit effort (CPUE) over the last 10 years (Grandcourt & Cesar, 2003). This is related to increased fishing pressure but also to the overall degradation of coral reef health. There is also evidence of trampling by fishermen when laying and removing their traps. All forms of destructive fishing, including spear guns, are banned in the Seychelles, and there are few records of historical use of such destructive practices. Recently, inhabitants of Praslin have used the argument of declining fish catches to lobby the Government of Seychelles for fishing rights to be granted within marine parks. The Government refused on the basis that the particular marine park in question protected highly resilient reefs that supported high coral cover and species diversity and were recovering rapidly from the 1998 mass bleaching event and that marine parks, in general, play an important role in fisheries.

4. Disease and Invasive Species

Disease and other invasive species have not been observed in any significant abundance on the reefs of the Seychelles. Localised outbreaks of the crown-of-thorns starfish (COTS, *Acanthaster planci*) have been reported since 1996 (Engelhardt, 2000). Populations of COTS are controlled through physical removal. Coral diseases are not widespread, but black-band and white-band diseases have been observed in several areas around Mahe (Engelhardt, 2004). The threat from the release of invasive species from ballast water is real, and a research project with CORDIO-IUCN support is currently being undertaken to determine the extent of this threat.

5. Climate Change and Global Warming

Coral reefs have narrow temperature tolerances, and many SST projections (Nurse *et al.*, 2001) suggest that the thermal tolerance of reef-building corals will be exceeded within the next few decades. Hoegh-Guldberg (1999) predicts that the incidence of bleaching will increase, and recent evidence indicates that the 'episodic' warming of the sea-surface (e.g. during El Niño years) can lead to significant coral bleaching.

Increase of CO_2 concentrations in the oceans is thought to have a direct impact on calcification processes in coral reefs. No such work has yet been done in the Seychelles but Kleypas *et al.* (1999) estimate that the calcification rate of corals would decline by approximately 14–30% by 2050.

METHODS

Coral Reef Monitoring

Coral reef monitoring was conducted at 78 sites in the Seychelles granitic islands from November 2000 to February 2004 as part of the coral reef component of the Global Environmental Facility (GEF) sponsored Seychelles Marine Ecosystem Management Programme (SEYMEMP). The number of sites monitored for each

Table 3. Number of coral reef sites surveyed in each of the monitoring sessions

	Nov –00	Jul –01	Feb –02	Jul –02	Feb –03	Aug –03	Feb –04
Technique used	VET	VET	LIT	LIT	LIT	LIT	LIT
Total No. Reefs surveyed	20	40	43	44	42	36	50
No. carbonate reefs surveyed	15	22	20	20	20	16	26
No. granitic reefs surveyed	5	18	23	24	22	20	24

period is given in table 3. Sites were monitored biannually, annually or as one-offs for greater geographical coverage. The design and subsequent implementation of this component was contracted to Reefcare International based in Townsville, Australia. Field data was collected with the support of the Marine Unit in the Ministry of Environment and various other organisations on a less formal basis. The visual estimation technique (VET) was used for data collection in 2000 and 2001 while line intercept transects (LIT) modified according to Engelhardt (2004) were used from 2002 to 2004.

Visual Estimation Technique (VET)

The VET estimated live hard coral cover (LHCC) in incremental classes of 10%. A small increment of 5% was used where LHCC was found to be extremely low (Engelhardt, 2004). For each site, the mean LHCC was calculated from the estimated LHCC from ten 10 m segments using the mid-point of the appropriate class as the estimate of LHCC for each segment.

Line Intercept Transect

For each 50 m LIT, each substrate type bisected by the transect was recorded in three 10 m segments that were separated by 10 m. All transects were laid obliquely so that the entire depth profile of the reef could be sampled and as such the 0–10m transect always corresponded to the shallowest depth and the 40–50 m transect always corresponded to the deepest depth. At each site, data were collected from a minimum of six 10 m segments. Data describing the live benthic cover were recorded according to 9 categories: coral of the genus *Acropora*, coral of the genus *Pocillopora*, branching non-*Acropora*, encrusting coral, massive coral, fungiid corals, soft coral, macro algae and zoanthids, and corallimorphs.

Calculating Pooled Yearly Recovery Rate

Two different rates of recovery were calculated. The first approach calculated the pooled yearly rate of recovery (PYRR) for all carbonate reefs and all granitic reefs between each survey using the equation:

$$PYRR = 2\,(\textit{Mean LHCC for period } X - \textit{Mean LHCC for period } (X-1))$$

where X is a monitoring session and X – 1 is the monitoring session 6 months earlier.

Since monitoring was done every 6 months, the calculated rate was multiplied by 2 to get a yearly rate.

Calculating Site Specific Recovery Rate

A sub-sample of the data was used for calculating site specific recovery rate. Only sites at which monitoring had been carried out in 2004 and where monitoring has been conducted at least three times since November 2000 were selected. This was to ensure that the status of the reefs in 2004 was taken into account and that there were sufficient yearly recovery rates from which longer-term (4 years) mean recovery rate could be calculated.

Site specific recovery rate (SSRR) was calculated using the equation:

$$SSR = 12\left(\frac{\textit{Mean LHCC for period } X - \textit{Mean LHCC for period } (X-1)}{\textit{Number of months between monitoring sessions}}\right)$$

where X is a monitoring session and X – 1 is one monitoring session before and 12 is the number of months per year.

For both PYRR and SSRR, value of less than 0% was taken to indicated a negative rate of recovery, whereas value between 0–2% , 2.1–5% and >5% were taken to represent low, medium and high rate of recovery respectively.

RESULTS

Monitoring the recovery of coral reefs from the devastating effect of the 1998 mass coral bleaching event in the Seychelles inner islands began in 2000 (Engelhardt, 2000). Overall, a positive trend in recovery is being observed despite the fact that the reefs were again affected by coral bleaching events of 2002 and 2003 brought about by sustained and elevated sea-surface temperatures (figure 2). Combined data for carbonate and granitic reef is showing an exponential increase in mean live hard coral cover. However, there are considerable differences in the rate of recovery between carbonate and granitic reefs. The granitic reefs are experiencing a strong exponential increase (R^2 = 0.917) in live hard coral cover whereas carbonate reefs are experiencing a weak linear increase (R^2 = 0.5454) (figure 3).

Calculated yearly rates of increase in LHCC was affected by the previously mentioned coral bleaching events in 2002 and 2003 on both carbonate and granitic reefs. The 2002 bleaching event, in particular, caused a negative rate of recovery in carbonate reefs, where it dropped from 1.47% yr^{-1} for the Jul 01 to Feb 02 period to –3.84% yr^{-1} for the Feb 02 to Jul 02 (table 4), the period in which the bleaching event occurred. On the other hand, results indicate that on the granitic reefs, the 2002 coral bleaching event did cause a reduction in the recovery rate but did not result in an overall negative rate of recovery for the period from 2000 to 2002 in which recovery was being measured. The 2003 coral bleaching event had a greater negative impact on granitic reefs as it reduced recovery rate from 6.02% yr^{-1} for the Jul 02–Feb 03 period to a negative recovery of –2.06% yr^{-1}, implying that the effect of this post-1988 bleaching event actually resulted in an effective decrease of 8.08% yr^{-1} in coral reef recovery. It is interesting to note that after the 2002 coral bleaching events both carbonate and granitic reefs entered into a phase of high recovery with 7.72% and 6.02% yr^{-1} LHCC recovery respectively. High rate of LHCC recovery was again observed for granitic reefs after the 2003 coral bleaching event with recovery reaching 11.90% yr^{-1}, the highest level recorded since the 1998 coral bleaching

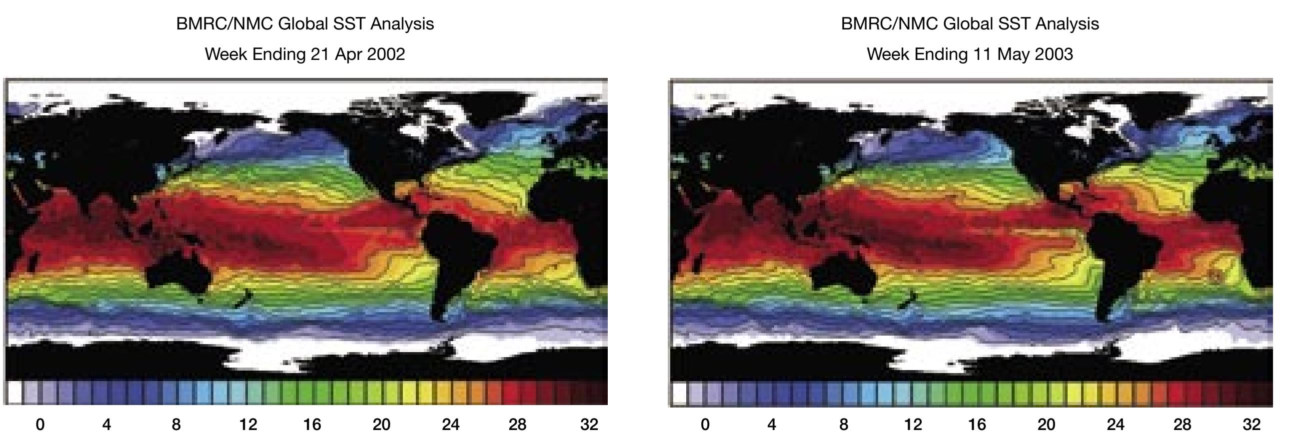


Figure 2. Remotely sensed sea surface temperature (SST) data identifying areas of warm sea water above 30°C during the coral bleaching event in a) 2002 and b) 2003. Source: Australian Bureau of Meteorology.

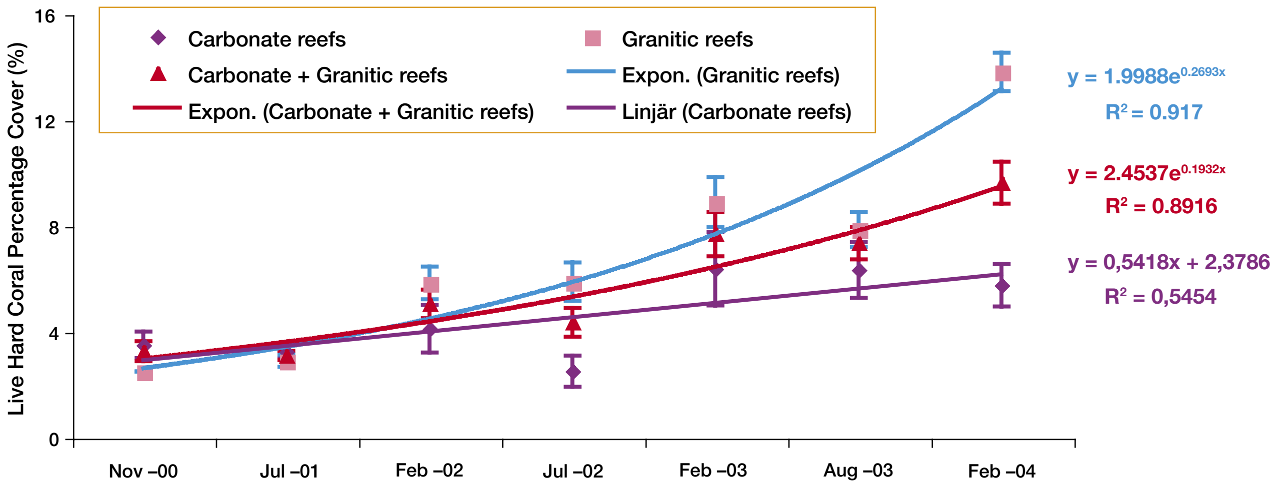


Figure 3. Trends in the recovery of carbonate and granitic reefs in the Seychelles inner islands between November 2000 and February 2004.

Table 4. Percentage yearly rate of increase in LHCC (% yr^{-1})

	Carbonate Reefs	Granitic Reefs
Nov 00–Jul 01	–0.38	0.60
Jul 01–Feb 02	1.47	5.04
Feb 02–Jul 02	–3.84	0.10
Jul 02–Feb 03	7.72	6.02
Feb 03–Aug 03	–0.08	–2.06
Aug 03–Feb 04	–1.16	11.90

Table 5. Percentage of carbonate and granitic reefs within the different calculated recovery potential categories

Mean rate of recovery	Carbonate Reefs (n = 16)	Granitic Reefs (n = 13)
Negative (<0% yr^{-1})	25	7.69
Low (0–2% yr^{-1})	37.5	7.69
Medium(2–5% yr^{-1})	31.25	46.15
High (<5% yr^{-1})	6.25	38.46

event. This was not the case for carbonate reefs on which a general trend of degradation was observed on subsequent surveys after the event.

Site specific mean rate of recovery calculated from a sub-sample of 29 reef sites (13 granitic, 16 carbonate) showed that 17% of all sites were undergoing further degradation (negative recovery) while 24% of the sites had low rates of recovery of between 0–2 % yr^{-1} and 38 and 21% of the sites had medium (2–5% yr^{-1}) and high rates (>5% yr^{-1}) of recovery respectively (table 5). Comparison between carbonate and granitic reefs showed that 84.5% of the granitic reefs had recovery rates which were higher than 2% yr^{-1} compared to 37.5% of carbonate reefs. Importantly 25% of carbonate reefs was degrading (negative recovery) as opposed to 7.69% of granitic reefs.

From our sub-sample, 8 sites stood out from the rest with high rates of recovery gaining close to or above 5% LHCC per year (figure 4 on next page). Out of these 8 reefs, 6 were of granite base and 2 of carbonate base, displaying once again the overall greater ability of granite based reefs to recover from coral bleaching events. Further more 5 of the sites are found in formally protected

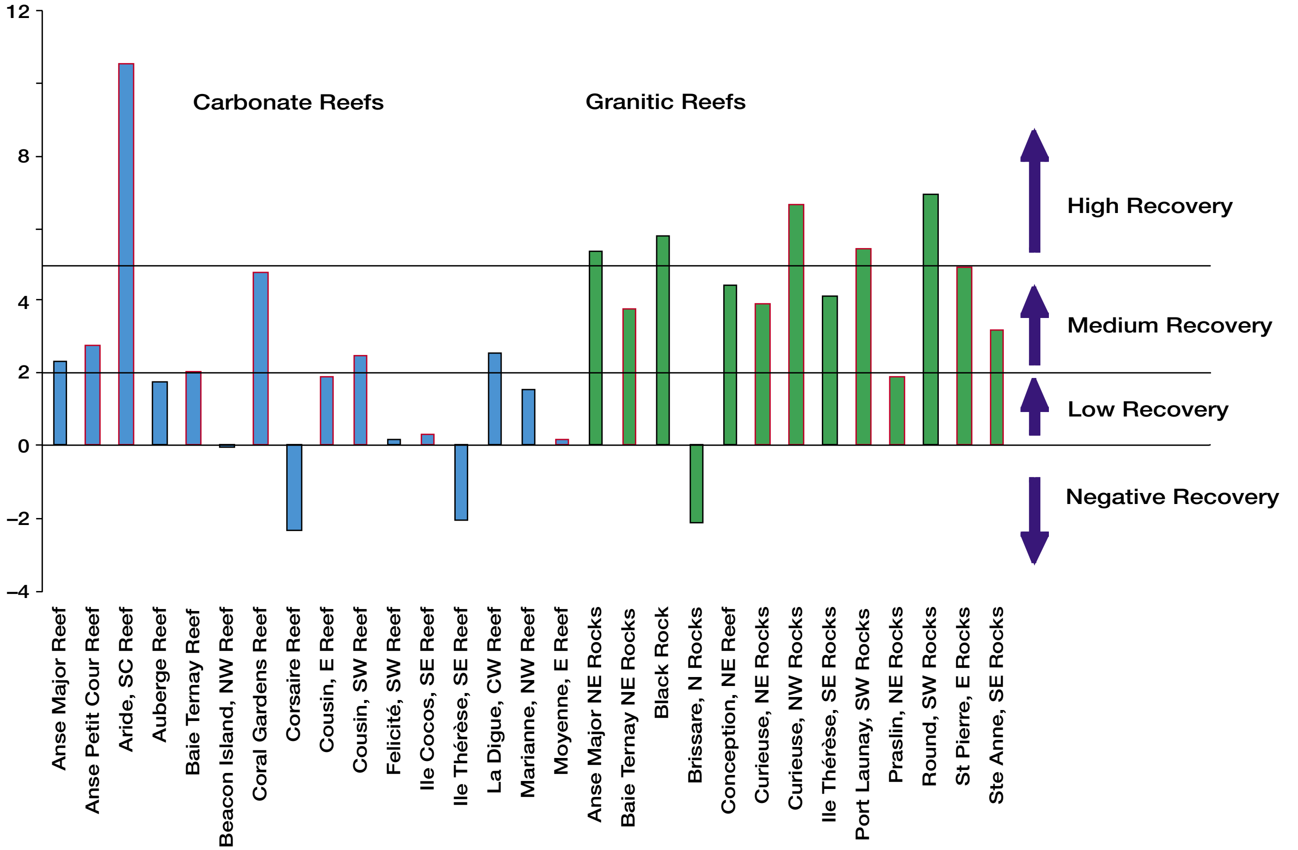


Figure 4. Site specific medium term (4 years) yearly recovery potential of sub-sample of monitored reef sites. Sites from Marine Protected Areas have red borders on the figure.

areas. It should be noted that high rates of recovery however does not always relate to high percentage LHCC.

DISCUSSION

Coral reef recovery rates have been determined using short-term monitoring data, without recourse to changes in other factors such as environmental and natural growth conditions of particular reef sites, as well as species diversity (e.g. Jennings *et al.*, 2000). However, the objective was to be able to determine whether such an approach could show the nature of this variability and how it may relate to management of bleached areas and also long-term prospects.

Analysis of monitoring data since 2000 (2 years post-bleaching) indicates very clearly that coral reefs in the Seychelles inner islands are recovering. The overall exponential increase in % LHCC from 2000 to 2004 is strongly influenced by granite base reef sites for which pooled data indicate an even higher rate of exponential increase. The strong exponential rate of increase in % LHCC for granite based reefs as opposed to the weak linear increase for carbonate reefs clearly outline the greater resilience of granite reef to carbonate reefs. There are several possible explanations for the observed difference in mean % LHCC between the granite based and carbonate based reefs.

The greater stability of granitic reefs over carbonate reefs is thought to be an important factor for the observed differences. More stable granitic reefs means that there are more suitable areas for the recruitment of coral spat and lower post recruitment mortality resulting from movement of rubble resulting from wave action. It is expected that granitic reefs are also suffering from lower level of indiscriminate grazing by invertebrates such as the black spined sea urchins (*Diadema* sp. and *Echinotrix* sp.) as compared to carbonate reefs. This is mainly due to the higher 3-dimensional nature of granite based reefs which limits access to grazing invertebrates. Better shedding of sediments, as a result of their high 3-dimensional morphology, by granitic reefs may also be significant in promoting reef recovery as it provide bare sediment free substrate for improved coral spat recruitment as few coral larvae settle on sediment-covered surfaces (Fabricius, 2005.).

However, all of these reefs will continue to be exposed to future coral bleaching events, such as those that were recorded in April 2002 and 2003. Whilst the 2002 bleaching reduced the rate of coral reef recovery on both granitic and carbonate reefs, recovery was actually negative on carbonate reefs and on granitic reefs in 2003. Overall, both granitic and carbonate reefs bounced back after the 2002 event with high rates of LHCC recovery. The period after the 2002 bleaching event exhibited the highest ever rate of recovery for carbonate reefs and it was the only period in which overall recovery on carbonate reefs (7.72 % yr^{-1}) exceeded that on granitic reefs (6.02% yr^{-1}). A somewhat different scenario was seen in the period after the 2003 event when recovery on granitic reefs reached its highest level so far recorded at 11.90% yr^{-1}. The carbonate reefs however experienced continued overall degradation at a rate of –1.16% yr^{-1}.

At present, there is no scientific explanation with regards to the increase rate of recovery observed on granitic and carbonate reefs after the 2002 bleaching event and on granitic reefs after the 2003 event, although it may indicate the acquisition of resilience by the reef system. Continuous decreases in mean LHCC on carbonate reefs could be the result of degradation of the carbonate reef structure which is being aggravated through time especially through bio-erosion which is not as important on granite reefs.

Site specific rates of recovery for the chosen subsample of carbonate and granitic reefs showed that 17% (25% carbonate and 6.69% granitic reef sites) of the reef sites were not showing any real signs of recovering. Reefs showing relatively high rate of negative recovery are clearly noticeable on figure 4 and includes the carbonate reefs of Corsaire and Ile Thérèse and the granite reef of Brissare.

Degradation of the carbonate Corsaire reef can be attributed to high cover of soft coral which is slowly taking over the reef, as a result of high levels of nutrients found in the bay of Beau Vallon (Jennings et al., 2000). In 2004, the Beau Vallon area was integrated in the wider Greater Victoria centralised sewage treatment system thus limiting the amount of sewage derived nutrients into the bay. It is expected that within a short time period the water quality of the area will improve and will create better conditions for reef building organisms to resettle.

The carbonate reef at Ile Thérèse is more or less 2-dimensional in nature with a gentle slope and lots of coral rubble. The coral rubble may be breaking adult corals and killing recruits when it is moved around by wave action. For these types of reefs, with low rugosity and lots of rubble, recovery is seriously hampered, and in many cases only artificial substrate stabilisation may be used to promote substrate recovery. Pilot studies by the Seychelles Centre for Marine Research and Technology are currently looking at a number of rubble slope stabilisation methods as ways of promoting reef recovery. The most successful method will be used on reefs encountering the same problem as Ile Thérèse.

Degradation of the granitic Brissare reef is probably due to its high composition of *Pocillopora* corals. *Pocillopora* corals are brooders and fast growing. As such, they are able to cause a rapid increase in LHCC on a reef. However, Pocilloporids are highly susceptible to elevated SSTs and bleach easily (McClanahan *et al.*, 2004). The

2002 and 2003 coral bleaching events almost wiped out the whole *Pocillopora* community at this site resulting in the observed degradation.

Five of the eight sites with rates of recovery close to or higher than 5 % yr^{-1} are found in Marine Protected Areas (MPAs), indicating that protection can have a positive effect on recovery potential of bleached coral reefs. Whilst, recovery rates are not the only important indicator of coral reef health, such a result provides an important rationale for continued protection of those reefs. The annual rate of recovery as used here can be an important tool for detecting reefs undergoing degradation or rapid recovery. However, prioritising sites for management on this basis only is not recommended as other factors such as species diversity (corals as well as other marine fauna), representativeness, ecological functioning and socio-economic value should also be considered.

Previous CORDIO status reports and a number of other scientific publications have been largely silent on quantifying the nature of the recovery process, primarily as a result of lack of long-term data. Reef recovery rate information is important for both coral reef managers and policy makers in providing a more complete health assessment of impacted coral reefs (Payet, 2004). Importantly now, is the need to identify other factors, apart from geological base and protection, that are promoting or limiting recovery of coral reefs. These will provide valuable insights into management actions needed to address any major problem and to encourage optimum reef recovery. This paper has stressed the importance of having a long-term and timely implemented coral reef monitoring programme. Future data collection, especially in the face of the predicted increase in the frequency of coral bleaching events, will shed more light on whether there is increased resilience to regain LHCC following successive but low-levels of bleaching episodes. One of the important arguments for conservation of resilient or unbleached corals is their potential roles in facilitating coral reef recovery. Hence, there is a need to identify the more resilient reefs and provide them with higher levels of protection so that they can effectively act as a source of coral larvae to bleached and degraded coral reefs. There is a need to take an integrated approach to coral reef management in the Seychelles as it is well known that there are various other factors that influence the health of coral reefs (see Souter & Lindén, 2000).

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Status of Cosmoledo Atoll,
Southern Seychelles,
Four Years after Bleaching-Related Mass Coral Mortality

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keywords: Cosmoledo Atoll, Aldabra, coral community structure, coral recruitment, coral bleaching, fish assemblages, Seychelles

ABSTRACT

Coral and fish community structure was examined at five permanent monitoring sites and several rapid assessment sites on the leeward reef slope and in the lagoon of Cosmoledo Atoll in the southern Seychelles in order to assess its current status and establish a long term monitoring and conservation programme. The atoll and reef structure of Cosmoledo are characteristic of atoll reefs, with a steep reef slope below 25–30 m, a central lagoon that is connected to the surrounding ocean by two major passes through the reef rim, and several islands distributed around the atoll rim. Almost 200 species of coral were recorded during the expedition. Coral communities were severely affected by the El Niño of 1998 showing near 100% mortality in the lagoon and on reef slopes to a depth of 8 m. Deeper reef slopes (>15 m) supported 20–25% live coral cover, which decreased to 1–5% at depths <10 m. The average number of coral recruits ranged between 5 and 6.7 m^{-2} on the slope and 6.8 m^{-2} in the lagoon. On reef slopes, recruitment was greater at 20 m than 10 m. The species composition of recruits differed from the pre-bleaching adult community indicating that a shift in the species composition of the coral community is underway. In shallow waters on the reef slope, pocilloporids dominated recruit assemblages while faviids were most abundant at depth. In the lagoon, *Porites* and *Fungia* recruits were most abundant while the previously dominant acroporids were rare. More than 200 species of fish were recorded. Acanthurids were common, large and medium sized serranids were recorded at all sites and lutjanids and lethrinids were frequently sighted. The obligate corallivores *Chaetodon trifascialis* and *C. trifasciatus* were rare even where coral cover was greater. Not a single shark was sighted. While recovery from coral bleaching impacts is evident, especially below 10 m, recovery has been slow, particularly in shallow water (<5 m).

INTRODUCTION

During 1998, coral reefs throughout the central and western Indian Ocean suffered severe coral mortality as a result of bleaching caused by anomalously high sea temperatures (see Lindén & Sporrong, 1999, and papers therein). Some of the reefs of the Seychelles were among the worst affected with coral mortality exceeding 90% in some places (Quod, 1999; Turner *et al.*, 2000). Recovery from this bleaching event on other reefs within the inner granitic islands of Seychelles (Payet *et al.*, this volume) and on other reefs in the Indian Ocean (Obura; Rajasuriya, Suleiman *et al.*, Zahir *et al.*, all this volume) has been slow and highly variable between sites. Often, this variation is attributable to differences in the magnitude of the impacts of human activities. Recovery on reefs that are easily accessible and heavily overexploited or subjected to destructive fishing, coral mining, pollution or sedimentation is often negligible, while on those reefs that are managed properly or have escaped serious degradation, recovery is progressing well. Investigation of the status of coral and associated fish communities on inaccessible reefs that are isolated from land-based disturbances provides an opportunity to examine the patterns and rate of recovery in an unperturbed environment enabling an assessment of the influence of human activities on the recovery of reefs elsewhere. In addition, the acquisition of baseline data describing the current status of coral and fish populations on remote reefs enables the assessment of the impacts of climate change and the subsequent changes in community structure and composition in an environment that is not confounded by the influence of human activities.

Cosmoledo Atoll, along with Astove, Assumption and Aldabra itself belongs to the Aldabra Group of islands located in the southern Seychelles. The Aldabra Group lies east of the Mascarene plateau at approximately S12° E45°, about midway between the northern tip of Madagascar and northern Mozambique in the western Indian Ocean. Their isolation from significant land masses and dependent human populations makes them ideal locations to study the impacts of climate change on coral reef ecosystems and the mechanisms by which they are recovering and adapting. Although a number of surveys of the impacts of bleaching-related mortality of coral and fish communities have been conducted on Aldabra Atoll (Spencer *et al.*, 2000; Teleki *et al.*, 2000; Stobart *et al.*, 2001, 2002), the condition of coral and fish communities on Cosmoledo Atoll following the 1998 El Niño is unknown.

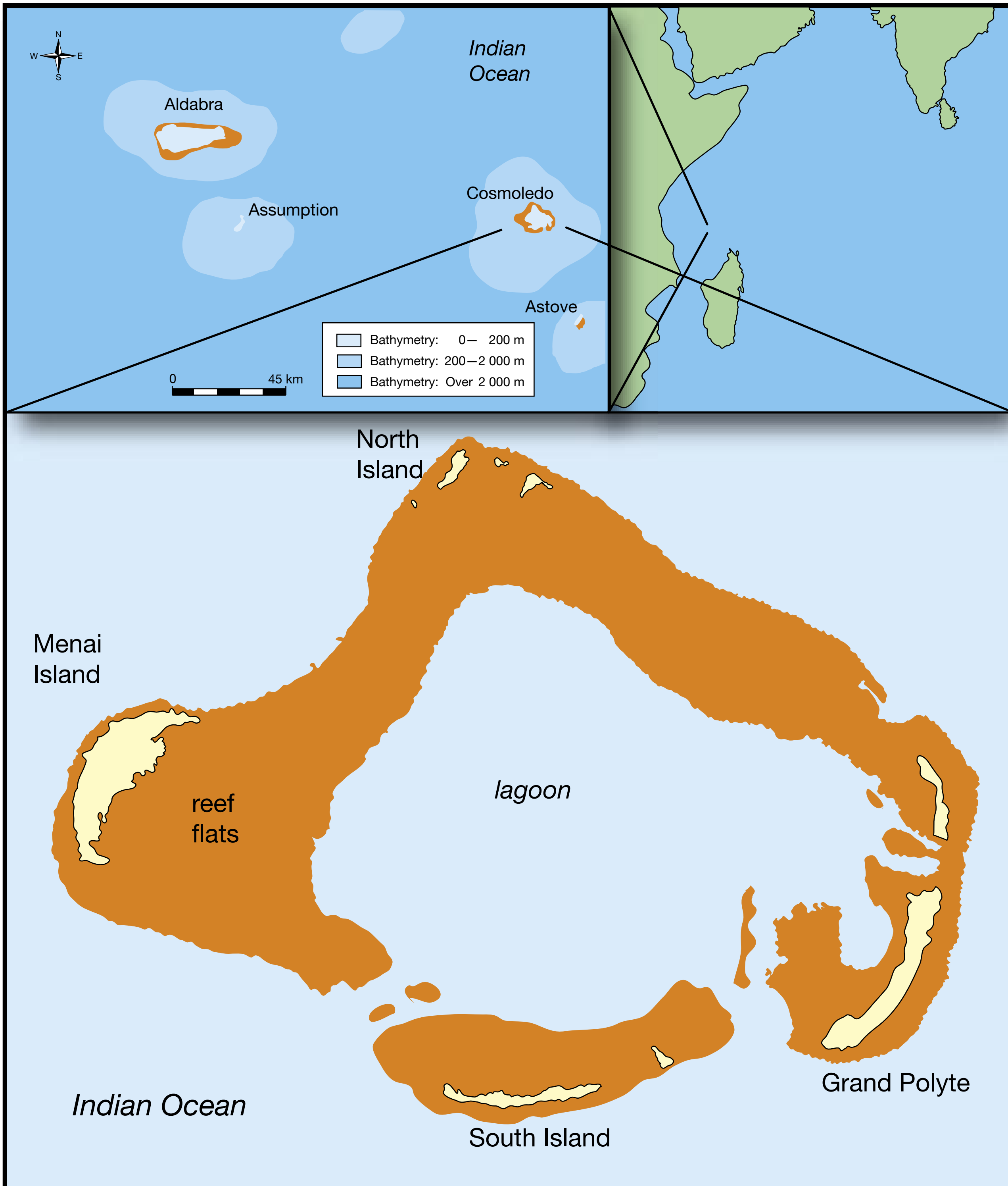
The data presented in this report were obtained during the first scientific expedition to Cosmoledo Atoll. The purpose of this expedition was to determine the status of both the marine and terrestrial environment of Cosmoledo Atoll, including the coral reefs and their associated fish and invertebrate fauna, turtle and bird populations, plants and terrestrial invertebrates. The data gathered during the expedition established a baseline against which changes in community structure can be compared during future monitoring. Another purpose of the expedition was to assess the species diversity of the atoll (see Obura & Sheppard, 2005) and make conservation management recommendations (see Obura *et al.*, in press). This paper describes patterns of reef zonation and reports the current condition of coral and fish communities and patterns of coral recruitment and reef recovery.

ATOLL STRUCTURE AND DESCRIPTION

Comprehensive descriptions of the granitic and outer islands of the Seychelles were obtained during the Indian Ocean expedition (Barnes *et al.*, 1971; Braithwaite, 1971; Rosen, 1971a, b) and a variety of other investigations conducted over the last 100 years (Jennings *et al.*, 2000). A large literature of marine studies conducted on Aldabra Atoll has been summarized by Teleki *et al.* (1999), however, Cosmoledo, Assumption and Astove, the other three islands comprising the Aldabra Group, have received little attention.

The four islands of the Aldabra Group are located on a submarine mountain that rises from the ocean floor 4 000 m below and are separated by distances ranging from 20 to 60 nautical miles. The islands differ considerably from each other (Stoddard, 1984), with Aldabra being the largest (365 km^2) and having an almost totally enclosed lagoon, a deep channel and significant land area (155 km^2), and Cosmoledo (152 km^2) having a submerged atoll rim with scattered small islands (land area 5 km^2). Assumption and Astove are single islands with similar total size (14.2 and 16 km^2, respectively), but with a smaller total land area on Astove (11.5 and 5.6 km^2, respectively). Astove has a central small lagoon with a single outlet to the sea.

Geologically, Cosmoledo is an uplifted coral reef similar to Aldabra, and displays many similarities in terms of marine and terrestrial habitats (Bayne *et al.*, 1970). It consists of thirteen small scattered islands and islets on the atoll rim. The largest island is Menai (figure 1 on next page), which has an area of about 240 ha and an elevation of 3.6 to 4.6 m above mean sea level. The second largest island is Grand Ile (192 ha). The total land area of the atoll is 5 km^2. The lagoon covers an area of about 80 km^2. Inside the atoll rim and the inner shores of the islands extensive shallows several kilometres wide are exposed at low tide. The central part of the lagoon supports


N
W
E
S
Indian Ocean
Aldabra
Assumption
Cosmoledo
Astove
Bathymetry: 0– 200 m
Bathymetry: 200–2 000 m
Bathymetry: Over 2 000 m
0
45 km
North Island
Menai Island
reef flats
lagoon
Grand Polyte
South Island
Indian Ocean

extensive seagrass beds, sand flats and patch reefs that reach the surface. Two primary passes between 10–15 m deep are situated in the southeast and southwest and permit water exchange between the lagoon and surrounding ocean. Complex channels bisect the central lagoon connecting the two passes, with minimum depths of 2–3 m in the centre of the lagoon.

All islands on Cosmoledo Atoll are vegetated and have nesting sea birds and migratory birds in significant numbers (Rocamora, 2002). Although the atoll has been uninhabited since 1990, periodically there have been human settlements on some of the islands during the last 100 years. The dilapidated remains of buildings on Menai and Grande Ile, and the presence of introduced plant species on the other islands are evidence of the last period of human occupation during the 1950s. The inhabitants made a living from guano, sisal and copra production and, of course, fishing. Today, the absence of a permanent settlement or regular policing of activities conducted on the atoll leaves it open for poaching of sharks, turtles and birds.

METHODS

All surveys were carried out on the leeward western fore reef slope, the lagoon and the passes (figure 1). Poor weather and sea conditions prevented investigation of the northern and eastern slopes. Permanent transects for long term monitoring were established at 10 m and 20 m on the leeward reef slope off Menai and North Islands, and in the lagoon. All quantitative surveys of benthic and fish communities were conduced along these permanent transects.

Benthic Community

Digital videography was used to record the benthic habitat bisected by each permanent 50 m transect. All video footage was obtained while swimming at slow speeds in order to maintain high image quality and to keep the area of reef recorded by the camera constant. In order to describe the benthic community, between 48 and 50 still images were extracted at timed intervals from the video footage of each transect. The benthic composition of each image was analysed by laying a transparent film over the image on which 20 evenly spaced points were marked. The substrate type under each point was recorded according to the life form categories described by English *et al.* (1997). Data were recorded from approximately 1 000 points from each transect. Additional qualitative observations of reef profile and structure were obtained at other locations in the lagoon, on the northwest reef slope, and in the southeast and southwest reef passes.

Differences in the composition of the benthic community were analysed using a non-parametric permutation Analysis of Similarities (ANOSIM) procedure (Clarke, 1993) based on a rank similarity matrix using the Bray-Curtis similarity measure calculated from square-root transformed data. Data obtained from each image was treated as a single sample giving approximately 50 samples from each permanent transect. For these analyses, all forms of living hard coral were aggregated into a single category 'Live Hard Coral' and because of their low abundance and lack of power to discriminate between sites, data describing the cover of macro-algae, sponges, seagrasses, and other benthic invertebrates such as corallimorpharians and zoanthids were combined into the single category 'Other'. The resulting benthic cover categories used to examine differences between sites were: Live Hard Coral (LHC); Dead Coral with Algae (DCA); Coralline Algae (CA); Soft Coral (SC); Other (O); Rubble (R); and Sand (S). A post-hoc SIMPER analysis (Clarke, 1993) was conducted to identify the substrate types responsible for differences in the composition of the benthic community between sites.

In order to estimate the rate of recovery of coral populations since the coral bleaching event of 1998, the number of coral recruits within 6–12 1 m^2 quadrats placed haphazardly in the vicinity of each permanent transect

Figure 1. Map of Cosmoledo Atoll showing its location in the Aldabra Group of islands, top left (source: WCMC/Reefbase) and the western Indian Ocean, top right. The atoll measures approx. 10 km across from east to west.

was recorded. All colonies of coral smaller than 5 cm in diameter were identified to family level and counted. A 2-way nested ANOSIM procedure based on a similarity matrix using the Bray-Curtis similarity measure calculated using square-root transformed data was used to determine first, if there were significant differences in the composition of the recruit community at different depths at Menai and North Islands, and second, if there were differences between these two reef slope sites. Differences in the composition of coral recruits between the reef slope sites and the lagoon site were investigated using a 1-way ANOSIM procedure.

Fish Community

The fish community was recorded at four locations along each permanent transect. Using a modification of a point based visual census technique (Jennings *et al.*, 1996; Samoilys & Carlos, 2000), the abundances of 11 target families (Acanthuridae. Balistidae, Carangidae, Chaetodontidae, Serranidae (in this survey limited to the tribe Epinephelini), Haemulidae, Labridae, Lethrinidae, Lutjanidae, Pomacanthidae, Scaridae) within a circle with a radius of 7 m (153 m^2), including the overlying water column, were recorded by two divers conducting two censuses each. Fish smaller than 10 cm were not recorded.

Fish abundances were analysed using simple descriptive statistics. Since the data did not approximate normality, non-parametric Kruskal-Wallis ANOVA and Mann-Whitney U-tests were used to examine differences in abundances of fish among sites. Four families were excluded from these analyses either because of the low frequency with which representatives occurred in census areas (Haemulidae and Carangidae) or the enormous variation in abundances between locations resulting from their schooling behaviour (Lutjanidae and Lethrinidae). Similarities in fish community structure among samples were investigated using non-metric multidimensional scaling (MDS), based on rank similarity matrices using Bray-Curtis similarity measure (Clarke, 1993) calculated using square-root transformed data.

In addition, a cumulative list of fish species was developed for Cosmoledo Atoll from the results of fish censuses and also from species identified from video recordings made elsewhere around the atoll, predominantly in relatively shallow waters (5–10 m).

RESULTS

Bathymetry

The bathymetry of Cosmoledo atoll is typical for oceanic atolls, with a steep wall and reef slope with an inclination of between 80–90° at 40 m and deeper (figure 2). The depth at which the transition from the wall to the shallow platform occurred varied between 10 m and 25 m, and from a sharp edge at the top of the wall to a gradual decrease in slope to 10–20°. The main reef platform at 10–20 m depth sloped up gradually to a reef crest that was subtidal (about 1 m midway between Menai and North Islands) to inter-tidal at the islands and scattered islets. In-

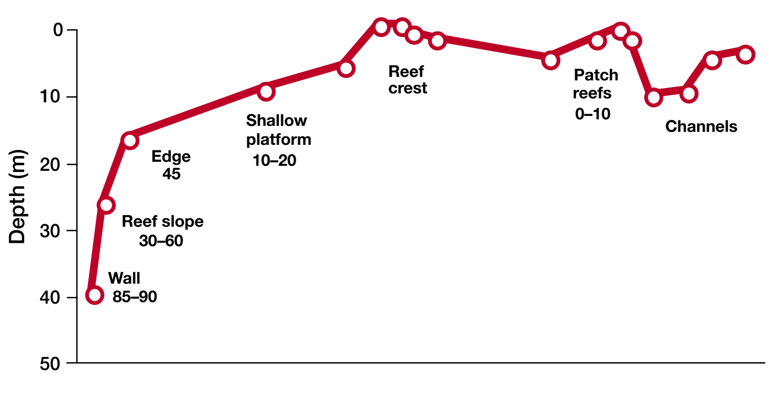


Figure 2. Typical reef profile across Cosmoledo Atoll from the outer reef wall to the inner lagoon. Note: horizontal axis is not to scale.

shore of the reef crest, the atoll has an extensive back reef area with depths <1 m which, in some places, was several kilometres wide according to navigational charts. The central part of the lagoon is about 8–10 km across and was predominantly 5–6 m deep with complex channels and patch reefs that extend to the surface. The majority of the lagoon floor was sandy and supported extensive seagrass beds, predominantly *Thalassondendron ciliatum*.

Benthic Community

Almost 200 species of hard coral were recorded during surveys conducted during this expedition (Obura & Sheppard, 2005). On the leeward reef slopes at depths shallower than 10 m, the cover of live hard coral (LHC) was generally only 5% or less, with occasional patches up to 20%. Evidence of widespread bleaching associated mortality of corals was common at these depths, with small and large coral heads covered by mature coralline and turf algal communities. In particular, algal-covered skeletons with the thick-columnar form of *Acropora palifera* were abundant in the shallow water north of the anchorage at Menai and along the leeward reef slope. Significant partial mortality of many colonies several years previously was also suggested by the existence of remnant patches of living tissue on some of these predominantly dead skeletons.

The cover of LHC was considerably more extensive on the reef slope deeper than ~8 m and was greater at 10 m than it was at 20 m. At 10 m, North Island and Menai Island exhibited 33.2% and 29.2% cover of LHC respectively, while at Menai at 20 m, LHC occupied 23.4% of the substrate (figure 3). The coral community was dominated by massive corals (figure 4), particularly poritids

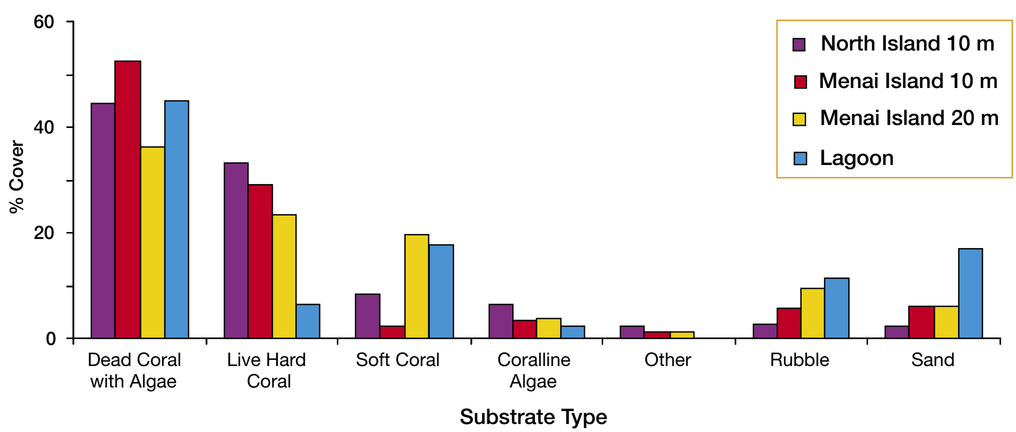


Figure 3. Percent cover of each substrate type along each permanent transect.

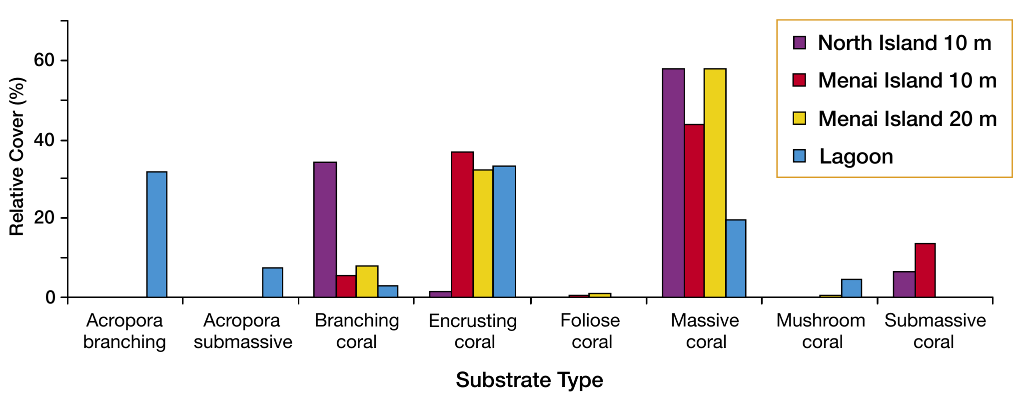


Figure 4. Relative contribution of each type of live hard coral to the total cover of live hard coral along each permanent transect.

Table 1. Summary of the results of SIMPER analyses investigating the contribution of variation in the cover of each substrate type to the overall differences in benthic communities observed between sites

Substrate Type	Average Dissimilarity	S.D.	Contribution %
Lagoon – Menai Island 20 m Average Dissimilarity = 48.64			
SC	10.22	1.13	21.02
LHC	9.43	1.4	19.38
S	8.30	1.16	17.07
DCA	8.19	1.23	16.84
R	7.46	1.14	15.34
CA	3.83	0.77	7.88
Lagoon – Menai Island 10 m Average Dissimilarity = 47.77			
LHC	10.82	1.49	22.64
SC	8.57	1.01	17.94
S	8.4	1.17	17.57
DCA	7.7	1.11	16.11
R	7.47	1.02	15.64
CA	3.68	0.73	7.7
Lagoon – North Island 10 m Average Dissimilarity = 55.71			
LHC	12.09	1.35	21.71
SC	10.02	0.98	17.98
S	9.41	1.12	16.89
DCA	9.4	1.17	16.88
R	7.17	1.02	12.87
CA	5.83	1.13	10.47

and a variety of faviids. Branching poritids were common along the transect at North Island, while encrusting forms constituted a considerable proportion of the cover of LHC along both transects (10 m & 20 m) at Menai Island. Acroporids were universally rare and were observed on the reef slope only in rapid visual surveys conducted away from the permanent transects. No acroporid corals were recorded along any permanent transects surveyed on the reef slope. Species diversity was noticeably low in the genera *Favia*, *Fungia*, *Pavona*, *Millepora*, *Alveopora*, and *Goniopora* and some species typically common on western Indian Ocean reefs were absent or rare, such as *Galaxea fascicularis* (rare), *G. astreata* (absent) and *Goniastrea pectinata* (absent) and *Lobophyllia* spp.

Between depths of 20 m and 30 m the reef slope varied: a broader shelf at the anchorage at Menai Island was dominated by *Halimeda*, while steeper slopes exhibited a more diverse coral community, with greater cover of hard and soft corals and coralline algae. At depths greater than 30 m, the substrate of the reef slope was dominated by coralline algae and bare rock surfaces, with only a small proportion of LHC (<5%). Black coral and gorgonian soft corals were abundant with some colonies exceeding 2 m in diameter.

In the lagoon, the cover of LHC along the permanent transect was only 6.6% (figure 3) and was ubiquitously low throughout the remainder of the lagoon. As on the shallow outer reefs, evidence of severe coral mortality approaching 100% was ubiquitous. At the boat anchorage, large dead *Millepora* colonies up to 1–2 m high were common. Living colonies of *Acropora* were recorded along the transect (figure 4), although most either were

Substrate Type	Average Dissimilarity	S.D.	Contribution %
Menai Island 10 m – Menai Island 20 m Average Dissimilarity = 43.05			
SC	8.87	0.91	20.60
LHC	8.26	1.25	19.19
DCA	7.30	1.15	16.95
R	6.69	0.92	15.55
S	5.71	1.07	13.27
CA	4.28	0.90	9.95
Menai Island 10 m – North Island 10 m Average Dissimilarity = 40.81			
LHC	9.75	1.34	23.89
DCA	8.29	1.10	20.3
CA	5.74	1.17	14.06
S	5.33	0.93	13.06
SC	4.93	0.55	12.07
R	4.3	0.60	10.54
Menai Island 20 m – North Island 10 m Average Dissimilarity = 48.42			
LHC	10.32	1.29	21.31
SC	10.16	0.90	20.98
DCA	8.54	1.19	17.64
R	6.28	0.92	12.96
CA	5.65	1.18	11.68
S	4.98	0.85	10.29

small and likely to have settled after the 1998 bleaching event or were surviving sub-massive colonies of *A. palifera*. The dead skeletons of branching *Acropora formosa*, *A. grandis* and *A nobilis* killed during the 1998 bleaching event were still recognisable. Dead coral covered with algal turf (DCA), sand, rubble and soft corals were the dominant substrate types within the lagoon (figure 3). The high proportion of sandy substrate in the lagoon would also limit the availability of suitable substrate for hard coral growth. Extensive seagrass and (several 100 m across) *Halimeda* beds growing on sandy substrate were also encountered in the lagoon.

The major reef passes, to the southeast and southwest, were surveyed on drift dives. Channel mouths were not steep-sided but instead were smoothly sloping from the reef crests on each side. The bottom substrate was predominantly rocky, with algal turf, coralline algae, *Halimeda* and seagrass. In places, extensive carpeting soft corals was common, and patches with small low-growing hard corals.

Limited coral bleaching was observed during surveys. Coral disease and signs of other damage to corals were absent.

The composition of the benthic community along each of the permanent transects surveyed was significantly different (Global R = 0.151; p = 0.001). Pairwise comparison between the transects showed that the greatest differences occurred between the lagoon and the two shallower reef slope sites (Lagoon – North Is. 10 m: R = 0.296; p = 0.001. Lagoon – Menai 10 m: R = 0.24; p = 0.001) and were attributable to the greater abundance of LHC on the reef slope and more soft coral and sand in the lagoon (table 1). Although the greater abundance of

LHC at Menai at 20 m contributed to differences in the benthic community between this site and the lagoon (Lagoon – Menai 20 m: R = 0.107; p = 0.001), the primary discriminating factor was the greater abundance of soft coral at depth on the reef slope. The greater abundance of soft coral at this deeper site also distinguished it from the two shallow reef slope sites, although the greater abundance of LHC and DCA at 10 m were additional contributing factors. (Menai 20 m - Menai 10 m: R = 0.082; p = 0.001. Menai 20 m – North Is. 10 m: R = 0.105; p = 0.001). Significant differences in the benthic composition of the two shallow reef slope sites (Menai 10 m – North Is. 10 m: R = 0.079; p = 0.001) were attributable to the greater abundance of LHC and coralline algae at North Island and the greater abundance of DCA at Menai.

Coral Recruitment

The average density of coral recruits varied little among sites, ranging between 5.1 m^{-2} (± 2.93 s.d.) at 10 m at Menai Island to 6.8 m^{-2} in the lagoon (figure 5). On the reef slope, recruitment was slightly greater at 20 m than 10 m, although the differences were not statistically significant (ANOVA, p >0.10). The taxonomic composition of the recruit community on the reef slope did not differ significantly between depths within sites (Global R = 0.082; p = 0.095) or between sites (Global R = 0.25; p = 0.667). One-way ANOSIM comparing the composition of coral recruits between sites confirmed that there were no differences between the two reef slope sites (R = -0.04; p = 0.025) but that the recruit community of both reef slope sites was significantly different from that of the lagoon (Menai – Lagoon: R = 0.884; p = 0.001; North Is. – Lagoon: R = 0.531; p = 0.001). Pocilloporids were the dominant family amongst recruits with the greatest average abundances (3 recruits·m^{-2} ± 2.70) recorded on the reef slopes at 10 m, averaging (figure 6). At 20 m, faviids were dominant ranging between 2.3 recruits·m^{-2} (± 1.89) and 2.5 recruits·m^{-2} (± 1.87) followed by pocilloporids and agariciids. Within the lagoon, recruitment was dominated by poritids and fungiids, at 4.1 recruits·m^{-2} (± 3.58) and 2.2 recruits·m^{-2} (± 3.51) respectively. The average number of acroporid recruits per m^2 did not exceed 0.5 at any of the locations sampled. The result of a subsequent multi-dimensional scaling analysis illustrates the relative similarity of the samples within and between sites on a 2-dimensional plot (figure 7). The intermixing of the

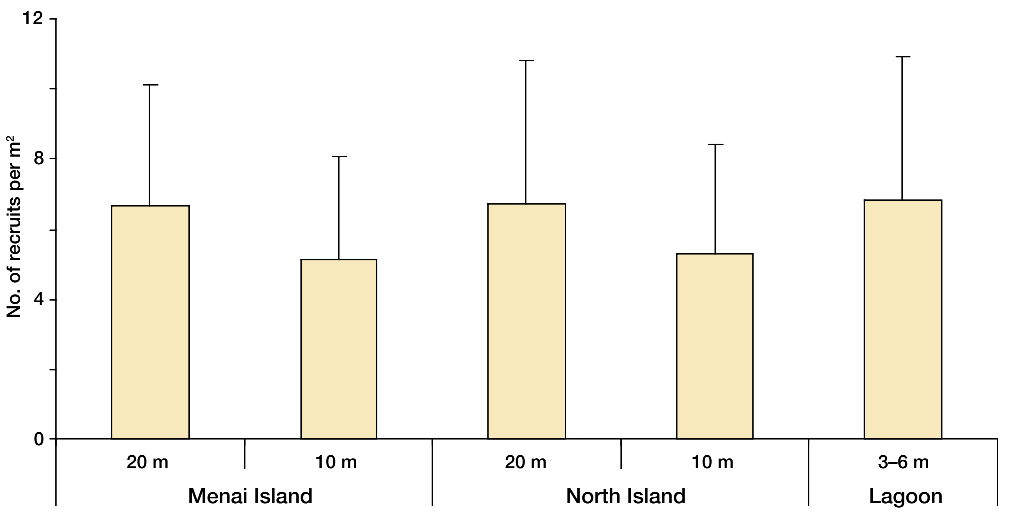


Figure 5. Mean number of coral recruits per m^2 (± SD) recorded in the vicinity of each permanent transect.

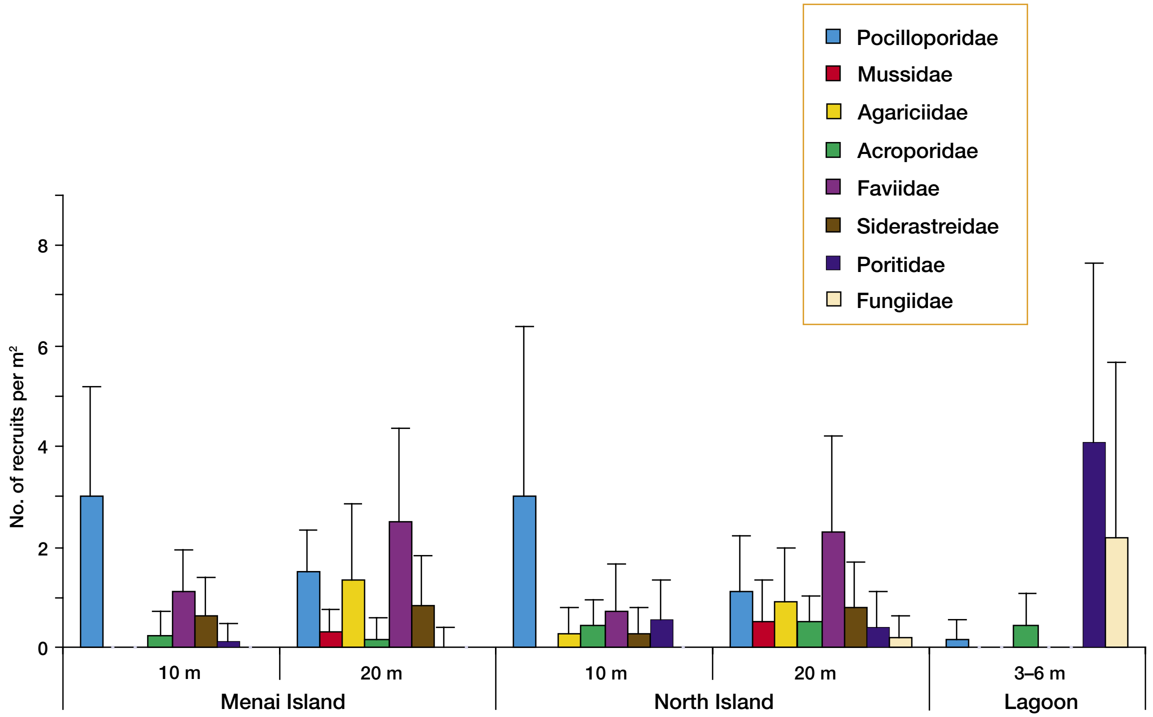


Figure 6. Mean number of coral recruits from each family per m² (± SD) recorded in the vicinity of each permanent transect.

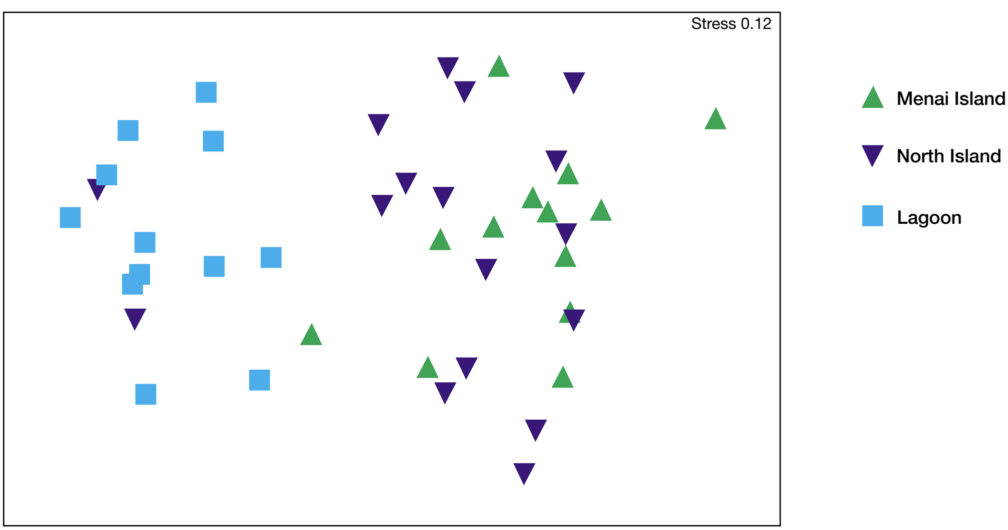


Figure 7. Multi-dimensional Scaling (MDS) plot illustrating the relative similarity of the assemblage of coral recruits recorded in each quadrat sampled along each permanent transect. The MDS plot is based on a Bray-Curtis similarity matrix calculated from square-root transformed data.

Table 2. Summary of the results of SIMPER analyses investigating the contribution of variation in the abundance of each family of recruits to the overall differences in recruit assemblages observed between sites

Family	Average Dissimilarity	S.D.	Contribution %
Menai Island – North Island Average Dissimilarity = 62.69			
Pocilloporidae	20.50	1.17	32.70
Faviidae	15.19	1.21	24.23
Siderastreidae	7.06	1.01	11.26
Agariciidae	6.83	0.88	10.89
Poritidae	5.30	0.61	8.45
Acroporidae	4.40	0.81	7.01
Lagoon – Menai Island Average Dissimilarity = 93.97			
Poritidae	31.46	1.46	33.48
Pocilloporidae	19.10	1.24	20.33
Fungiidae	15.72	0.74	16.73
Faviidae	14.18	1.19	15.09
Siderastreidae	5.47	0.83	5.82
Lagoon – North Island Average Dissimilarity = 87.18			
Poritidae	29.24	1.34	33.54
Fungiidae	15.54	0.74	17.82
Pocilloporidae	14.78	0.81	16.97
Faviidae	12.30	1.03	14.11
Acroporidae	4.64	0.89	5.32
Siderastreidae	4.50	0.77	5.16

samples obtained from the two reef slope sites and the distinct separation of the samples obtained from the reef slope from those obtained from the lagoon illustrates the results of the ANOSIM. Subsequent comparison of the species composition of recruit assemblages at each sites using SIMPER indicated that the difference in the abundance of recruits belonging to the families Poritidae, Pocilloporidae and Fungiidae accounted for approximately 70% of the variation in recruit composition between the reef slope sites and the lagoon (table 2).

The community composition of recruits differed considerably from that of the adult coral community that existed prior to the bleaching event of 1998. Previously, the shallow sites on the reef slope and the lagoon site were dominated by large colonies of branching and tabulate *Acropora*, as seen by the dead standing corals and rubble visible at the time of sampling. Among recruits, however, acroporids, while present at each site, were rare.

Fish abundances and community structure

A total of 172 fish species, belonging to 97 genera and 37 different families were recorded (table 3). Generally, acanthurids were the most abundant at each site, particularly in the lagoon (figure 8). Only at North Island at 20 m, where several schools of lethrinids and lutjanids were encountered within census areas, were acanthurids displaced as the most abundant family. Large and medium sized serranids were commonly recorded at all sites, particularly specimens of *Aethaloperca rogaa* and *Cephalopholis argus* on the reef slope sites and *Plectropomus punctatus* in the lagoon. Chaetodonts were commonly represented in each census, although species identified tended to be omnivorous. Obligate corallivores such as

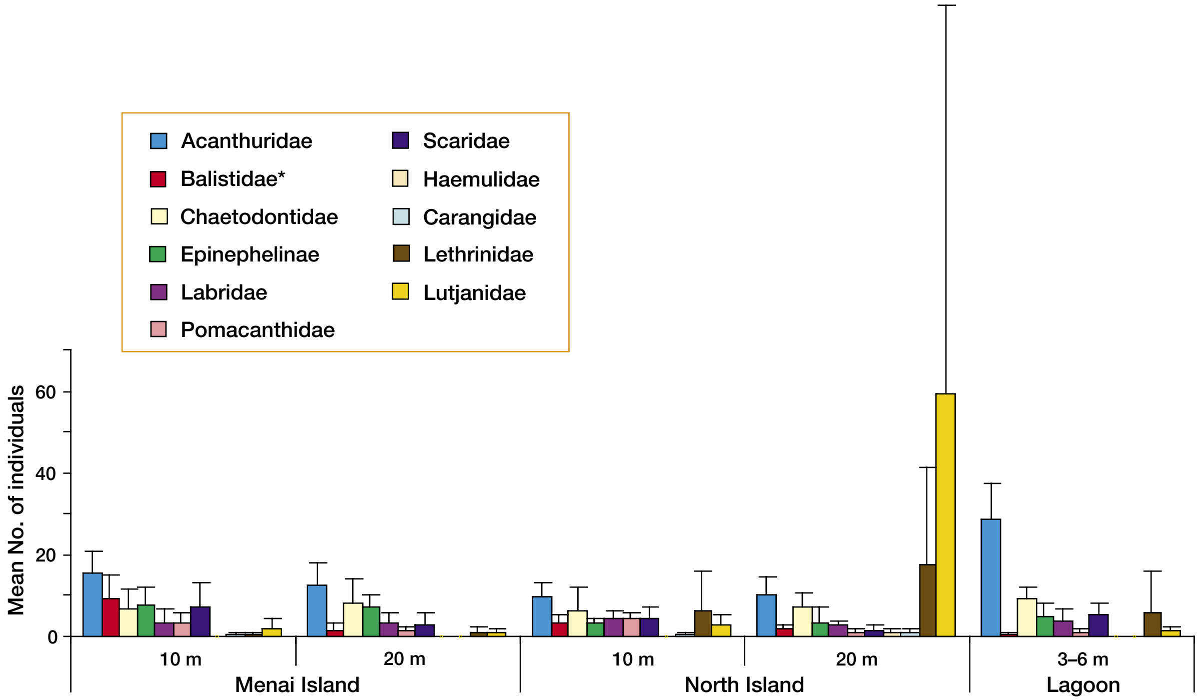


Figure 8. Mean number of individuals (±SD) from each family of fish recorded per fish census (153 m^2) conducted at each site. *The only family of fish to show significant differences in abundance between sites was the Balistidae.

Table 3. Summary of the number of genera and species recorded within each family of fish.

Family	No. of genera	No. of species	Family	No. of genera	No. of species
Acanthuridae	5	12	Muraenidae	2	4
Apogonidae	2	5	Nemipteridae	1	1
Balistidae	5	8	Ostraciidae	1	1
Belonidae	1	1	Pempheridae	1	1
Blenniidae	2	3	Pomacanthidae	4	5
Caesionidae	2	2	Pomacentridae	7	13
Carangidae	2	3	Priacanthidae	1	1
Chaetodontidae	4	18	Scaridae	3	7
Chanidae	1	1	Scombridae	2	2
Cirrhitidae	2	2	Scorpaenidae	3	4
Congridae	1	1	Serranidae	8	17
Haemulidae	1	2	Siganidae	1	2
Holocentridae	2	4	Sphyraenidae	1	1
Labridae	13	21	Syngnatide	1	1
Lethrinidae	3	7	Synodontidae	1	2
Lutjanidae	4	8	Tetraodontidae	2	2
Microdesmidae	1	1	Torpenidae	1	1
Monocanthidae	1	1	Zanclidae	1	1
Mullidae	2	6			

Chaetodon trifascialis and *Chaetodon trifasciatus* were scarce. Labrids, pomacanthids and scarids were recorded at each site with little variation in their abundances between sites. Lutjanids and lethrinids were frequently sighted, although their abundances within census areas varied enormously with the occurrence of large schools. Haemulids and carangids were rarely recorded in censuses, although they were commonly sighted elsewhere around the atoll. Not a single shark was sighted during approximately 90 person-dives conducted at Cosmoledo. The methods used leave some uncertainty in the species identification, especially within the families Scaridae and Labridae, and thus some records were excluded.

No significant differences in total fish abundance were found between sites (figure 9) although the small sample size and area surveyed (4 counts of 153 m^2) limited the statistical power of the data allowing the outcome of the analysis to be heavily influenced by the enormous variation between samples within sites caused by the irregular occurrence of large schools of fish in some censuses. The highest average density of fish was recorded at North Island at 20 m (106.8 fish per 153 $m^2 \pm 116.7$), although this is attributable to the occurrence of schooling lutjanids and lethrinids in one sample, resulting in a very high standard deviation. The remaining 4 sites had densities of about 50 fish per 153 m^2. The Ballistidae was the only family to show statistically significant variation in abundance between sites (figure 8), with fewer representatives in the lagoon compared with the sites surveyed on the reef slope. The composition of the fish community in the lagoon was significantly different from all other sites except Menai Island at 10 m ($p<0.05$) primarily due to the greater abundance of acanthurids within the lagoon. In addition, the tighter grouping of the samples obtained from the lagoon in the MDS plot (figure 10) illustrates that the composition of the fish assemblage surveyed in the lagoon was more homogenous than those surveyed at the reef slope sites. In contrast, the disaggregated appearance of samples obtained from Menai Island at 10 m illustrates the considerable variation in the composition of the fish community observed at this site, and also explains why no significant differences in the fish assemblages were found between these samples and those obtained from the lagoon.

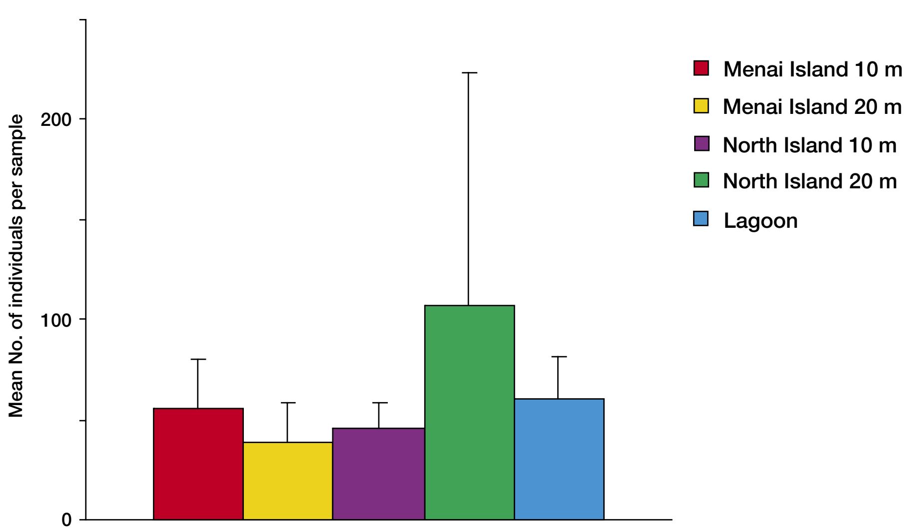


Figure 9. Mean total abundance of fish per 153 m^2 (±SD) sample recorded at each site.

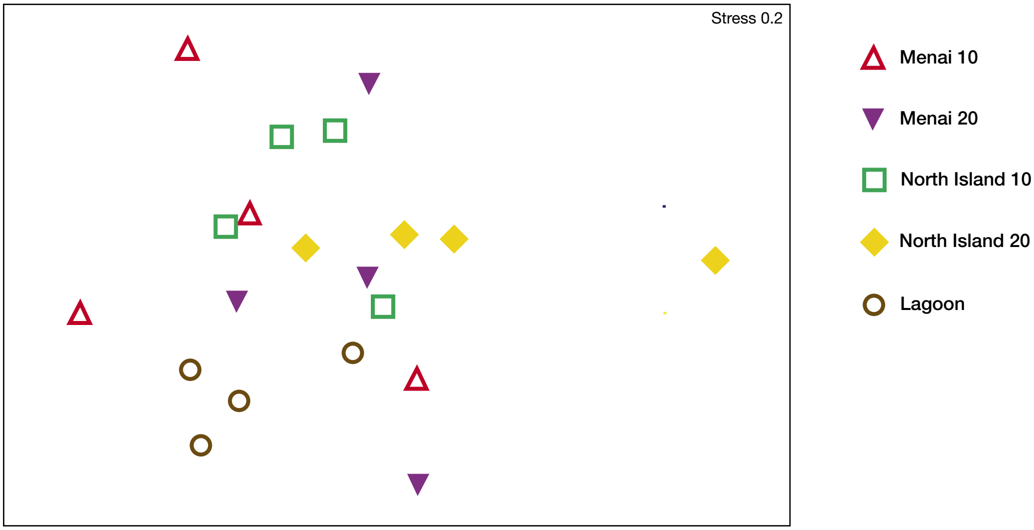


Figure 10. Multi-Dimensional Scaling (MDS) plot illustrating the relative similarities in the fish community composition recorded in each census (4 replicates at each of 5 sites). The MDS plot is based on a Bray-Curtis similarity matrix calculated using square root transformed data. Each point represents one census.

DISCUSSION

The coral reefs of Cosmoledo Atoll show characteristics consistent with those reported for the central Indian Ocean and consistent with early studies of the Seychelles islands (Barnes *et al.*, 1971) and recent studies of Aldabra (Teleki *et al.*, 2000; Downing *et al.*, in review). Highest coral cover (25–40%) and diversity was observed at intermediate depths on the reef slope, where the shallow reef platform curves downwards towards the deep reef wall, although evidence of up to 50% mortality of corals at these depths and even greater mortality in the lagoon and in shallower waters (<10 m) on the reef slope was abundant (Sheppard & Obura, 2005). The appearance of dead coral heads with mature algal communities and many young corals estimated at 2–4 years old provided additional compelling evidence that the mortality of corals on Cosmoledo occurred during the El Niño of 1998, coincident with widespread coral mortality throughout the Indian Ocean (Lindén & Sporrong, 1999; Wilkinson *et al.*, 1999). The level of mortality was similar to that reported for Aldabra Atoll during the El Niño (Spencer *et al.*, 2000; Teleki *et al.*, 1999, 2000), but less severe than that which occurred in the inner granitic islands of the Seychelles (Quod, 1999; Turner *et al.*, 2000).

Almost 200 species of scleractinian corals were found during this expedition (see also Sheppard & Obura, 2005). Many *Acropora* species were notably absent (e.g. the staghorn *A. formosa*, *A. grandis* and *A. nobilis*) though their dead skeletons were still recognizable in the lagoon. The coral communities on the reef slope at 10–20 m were dominated by massive, encrusting, sub-massive and branching coral forms, including *Porites* species and a variety of faviids. Species diversity was noticeably low in the genera *Favia, Fungia, Pavona, Millepora, Alveopora*, and *Goniopora*, which may be due to the isolation of the atoll, or mortality during the El Niño (Sheppard & Obura, 2005). Some species typically common in western Indian Ocean reefs (Rosen, 1971b) were absent or rare, most noticeably *Galaxea fascicularis* (rare), *G. astreata* (absent) and *Goniastrea pectinata* (absent) and *Lobophyllia*.

Acropora, which older literature suggests was once the dominant genus in shallow waters of reefs of this region (Rosen, 1971b), was the genus most severely affected. *Acropora* colonies were virtually eliminated in 1998. In contrast, the genus *Porites* was one of the best survivors and dominates recruitment in the lagoon, and many faviid corals also survived well. The sizes of most corals in waters less than 8 m deep indicated that they were mainly less than 4 years old. On reef slopes at depths of 10 m and greater, survival had been considerably greater preserving significantly higher coral cover and coral species diversity (Sheppard & Obura, 2005). Consistent with many oceanic atolls, Sheppard and Obura (2005) hypothesize that 10 m represents a 'transition depth' between upper waters that suffered near 100% mortality of corals in 1998 and deeper waters where mortality was high but not catastrophic, perhaps at levels of 50% and decreasing to zero below 30 m. This suggests that at Cosmoledo, the thermocline between upper warmer waters and deeper cooler waters varies around 10 m and deeper, with the top 10 m becoming superheated during El Niño doldrums conditions. As a consequence, the entire lagoon and the shallower portions of the reef slope suffered near total mortality of corals. The presence of remnant and diverse coral communities below 10 m on Cosmoledo likely supplies the reservoir of larvae which are recolonising the lagoon and the shallow reef slope. This pattern appears consistent at many atolls, and presents some hope that the El Niño and climate change-related threat may be less severe for oceanic atolls than continental reefs, especially if acclimatization of corals and zooxanthellae to warming conditions occurs (Coles & Brown, 2003; Hughes *et al.*, 2003). However, Cosmoledo is situated at 12°S, which is predicted to be the most vulnerable latitude in the western Indian Ocean to warming sea surface temperatures (Sheppard, 2003). Conditions similar to those in 1998 are predicted to recur approximately every 5 years by 2012–2015, thus preventing successful reproduction and recovery of coral communities.

At present though, coral recruitment is not limiting with recruit densities ranging between 5 and 6.8 recruits per m^2, which were similar to recent surveys conducted at neighbouring Aldabra Atoll (Teleki *et al.*, 2000; Stobart *et al.*, 2001, 2002) and the granitic islands focusing on Mahé (Wendling *et al.*, 2002; Engelhardt, 2003). On the reef slope, the greater recruitment at 20 m compared with 10 m suggests either that the greater abundance of adult colonies at depth act as a reservoir for coral recruitment or that the deeper environment is more conducive to settlement and survival. These preliminary surveys of coral recruitment determined that there were positive signs of recovery from the extensive mortality caused by the 1998 bleaching event.

Prior to the 1998 bleaching event, the shallow reef areas of Cosmoledo were dominated by branching and tabulate forms of *Acropora*. However, all genera belonging to the family Acroporidae were rare at all sites sampled. In shallow water, where mortality of corals was most severe, pocilloporids were the most abundant recruits on the reef slope while poritids and fungiids dominated the lagoon. At deeper sites on the reef slope, differences between the community composition of adults and recruits were less obvious. Faviids were the most abundant recruits and were also well represented among adult colonies. The commonness of the agariciid genus *Pavona* and the siderastreid genus *Coscinaraea* among recruits on the reef slope is consistent with other surveys of coral recruitment conducted at Aldabra (Stobart *et al.*, 2001), the Maldives (Clark, 2000; Zahir *et al.*, 2002) and in northern Kenya (Obura, 2002; and this volume). The variation between the communities of adult corals, which were remnants of the community that existed prior to 1998, and post-bleaching recruits, particularly in shallow waters, suggests that Cosmoledo's reefs are experiencing a shift in species composition and that the reefs that are now developing may become quite different to those that existed prior to 1998.

More than 170 species of fish were recorded at Cosmoledo Atoll and although the time available for rigorous surveys was small, this is comparable with the 212 species counted for Aldabra Atoll in 12 days of surveys in November 1999 (Teleki *et al.*, 2000), 205 species in 2001 (Stobart *et al.*, 2001) and 221 species in 2002 (Stobart *et* *al.*, 2002). With increased surveys, these numbers may approach estimates of fish diversity of >350 species for similar-sized areas on the nearby Tanzanian mainland (Garpe & Ohman, 2003; Obura *et al.*, in review) and an estimated figure of about 400 species for the Mascarene plateau (Jennings *et al.*, 2000).

The fish families Serranidae, Lutjanidae, and Lethrinidae include many economically valuable species targeted by artisanal fishermen (Jennings *et al.*, 1996). High abundances of species within these families at Cosmoledo suggest that the atoll is currently subject only to low or moderate fishing pressure. Although it was not possible to examine long-term trends in fish densities, fishermen active in the area claim that the average body size of fishes in these families has declined considerably during the past two decades. In addition, the absence of sharks during 90 person-dives is cause for concern, particularly considering that sharks were abundant at Cosmoledos during the 1980s and remained so through to at least the early 1990s (Mortimer J., pers comm.). Legal fishing has been a regular activity on Cosmoledo Atoll for decades, and while its isolation and lack of enforcement lends itself to the activities of poachers and illegal fisherman from other countries (Government of Seychelles, 2002), it also confers a degree of protection through its inaccessibility to anything other than larger ocean-going fishing vessels. The reef fish communities at Cosmoledo Atoll are relatively healthy although the absence of sharks indicates that fishing pressure is having some influence.

It is also evident that the extreme coral mortality in shallow waters suffered during 1998 has also affected the coral associated fish community. The abundance of *Chaetodon trifascialis* and *C. trifasciatus,* often numerically dominant among chaetodonts on relatively undisturbed coral reefs (Bouchon-Navaro & Bouchon, 1985; Chabanet *et al.*, 1997; Öhman *et al.*, 1998), has been shown to be positively correlated with the amount of live coral (Jennings *et al.,* 1996). The low abundance of *C. trifascialis,* an obligate predator of *Acropora* polyps (Findley & Findley, 1989), is likely to be a consequence of the almost total absence of this coral genus at Cosmoledo. In addition, increases in abundance of herbivorous acanthurids and, in some cases, scarids, can be attributed to the increased abundance of filamentous algae growing on coral substrata killed during the El Niño of 1998 (Lindahl *et al.*, 2000; Chabanet, 2002; McClanahan *et al.*, 2002; Sheppard *et al.*, 2002). It would be interesting to study the changes in the abundance of herbivorous fish communities in response to potential changes in coral and algae cover at the sites to understand the higher order impacts of bleaching-related coral mortality and reef recovery.

It is evident that the coral communities at Cosmoledo, particularly in the lagoon and on the shallow reef slope (<10 m) were severely affected by the increase sea temperatures caused by the El Niño of 1998 and that this, in turn, has influenced the abundance of both corallivorous and herbivorous fish. However, despite these changes, it is also evident that the coral community is recovering, albeit slowly and with a different species assemblage. The data obtained during this first scientific expedition describes the current condition of the coral and fish communities at Cosmoledo Atoll and has established a baseline against which future changes and recovery can be compared. In addition, these data enable a comparison of the patterns and rate of recovery between reefs that are relatively undisturbed by human activities with those that are heavily influenced, such as those along the coast of east Africa. Moreover, regular monitoring of the condition of Cosmoledo Atoll conducted over a long period will be invaluable for the future management of this biodiverse atoll and for the investigation of the influences of global climate change on coral reef habitats.

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Section 2

Thematic Reports

Coral Settlement Patterns in the Mombasa Marine National Park

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key words: coral recruitment, settlement, seasonal variation

ABSTRACT

Coral settlement patterns were measured at two sites in the Mombasa Marine National Park for a 2-year period from May 2001 to February 2003. Artificial settlement tiles were deployed for approximately 3-month periods and were collected in February, May, August and November of each year. The mean number of coral spat settled on collected tiles varied from 0.75 (± 0.79 s.d.) per tile in August 2001 to a maximum of 16.70 (± 7.53 s.d.) in November 2002, corresponding to mean densities of 8–740 m^{-2}. The maximum number of spat recorded on a single tile was 38 (November 2002). Although peak settlement rates were recorded in November of each year, settlement was sufficiently variable between months and years to obscure a clear seasonal cycle. Settlement was highest at the study site with the best water flow and exchange with the open ocean. Pocilloporids (*Pocillopora* spp.) dominated settlement (76%), followed by poritids (19%), then 'others'. Patterns suggest peak coral recruitment in September–November each year when water temperatures are increasing the fastest prior to reaching their seasonal maxima in March–April, but with substantial recruitment of pocilloporids and poritids throughout the year.

INTRODUCTION

Coral recruitment refers to the addition of new individuals to the coral population and can be defined as the initial sighting of recently settled juveniles in the adult habitat (Caley *et al.*, 1996). Recruitment has a major influence on the adult coral community structure (Birkeland *et al.*, 1981), with temporal and spatial variations in recruitment pattern playing an important role in the population dynamics of coral communities. Local populations may be regulated by recruitment such that when recruitment limitations occur, there are likely to be fluctuations in population size (Hughes *et al.*, 1999).

Artificial settlement plates for coral recruits can be used to provide a measure of the relative abundance of coral recruits in time and space (Harrison & Wallace, 1990), as an indicator of potential recruitment to natural surfaces. Genetic studies suggest that most recruitment to reefs is from larvae produced locally (Ayre *et al.*, 1997), thus the settlement of coral planulae on or near colonies of their own species is a common occurrence (Birkeland *et al.*, 1981). However, the extent to which variation in recruitment reflects variation in adult populations is unclear.

This report explores the spatial and temporal patterns of recruitment in the Mombasa Marine National Park (MMNP) through the use of artificial settlement tiles. Two sites are studied, with data presented here for two years (May 2001 to February 2003) of quarterly deployments of the tiles. The general objective of this project was to identify patterns of coral recruitment at the two sites by investigating:

- Variation in the number of coral recruits between the two sites;
- Variation in the number of coral recruits among the eight samples obtained over two years;
- The composition of coral recruits at the family level;
- Size relationships of recruited corals.

Recent studies at the MMNP have examined the recovery of the coral reef following mass bleaching and mortality during the El Niño of 1998, focusing on overall benthic cover (McClanahan *et al.*, 2001), and dynamics of coral recruits on natural surfaces (Tamelander, 2002). This study focuses on an earlier phase of coral life history and investigates settlement patterns at early stages of recruitment.

METHOD

The Mombasa Marine National Park (4° 0.0' S, 39° 45' E; figure 1) was established and formally gazetted as a protected area in 1986, and encloses part of the lagoon, back reef and reef crest habitats of the Bamburi-Nyali fringing reef. The marine environment is characterized by warm tropical conditions varying at the surface between 25° C and 31° C during the year, stable salinity regimes and moderately high nutrient levels from terrestrial runoff and groundwater. The area has semi-diurnal tidal regimes varying from 1.5 to 4 m amplitude from neap to spring tides, creating extensive intertidal platform and rocky-shore communities exposed twice-daily during low tides.

Monsoon winds are the dominant climatic influence in this area, blowing from the northeast (December–March) and southeast (May–October) with 1–2 months in between characterized by variable and gentler winds. Two study sites located within the back reef/lagoon areas were used. The first, Coral Gardens, is situated adjacent to a small depression forming a small channel through the reef crest that enables water exchange on rising and falling tides. The second, Starfish, is farther inside the lagoon and has less vigorous water exchange.

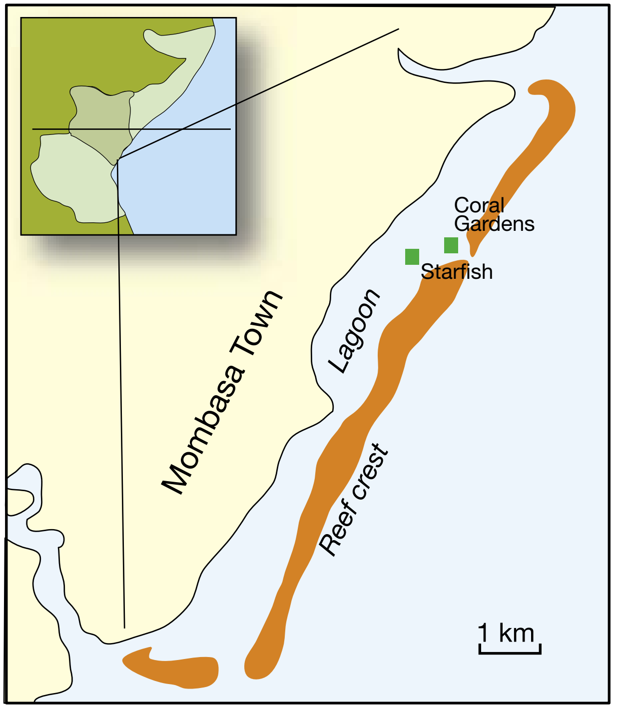

Figure 1. Map of the Mombasa Marine National Park, showing the reef crest, the enclosed lagoon, and the location of the two study sites. Coral Gardens is located near a shallow channel through the reef crest allowing high water exchange, while Starfish is located in the lagoon.

This report presents data obtained between May 2001 and February 2003 when settlement tiles were deployed concurrently at both sites. The study used settlement tile methods modified from English *et al.* (1997). Wire mesh racks were firmly attached to the bottom using metal pegs at a depth of approximately 0.5 m at maximum low tide. Terracotta bathroom tiles (15 cm x 15 cm) were attached to these racks inclined at 45 degrees with the unglazed side facing downwards. Tiles were attached to the racks using wire ties and deployed for a 3 month period. Once collected from the field, the tiles were placed in household bleach for 2–3 days and then dried. Dried tiles were examined using a dissecting microscope. The number of coral spat on each tile was recorded along with the surface (rough/smooth) of settlement. Each coral was identified to family level and its maximum diameter measured. Other organisms settled on tiles such as tubeworms, bivalves and oysters were counted and general observations were made on the amount of debris present.

RESULTS

Deployment and recovery dates and durations of tiles are shown in table 1, which have been compiled into approximate quarterly periods or 'seasons' for further analysis. The seasons are numbered 1–4 starting with the first tile recovery each year, which corresponds to the early onset of the northeast monsoon and settlement of spat from approximately November to February each year. The appearance of the racks and tiles after three months, a 2 mm coral recruit on the tiles and natural recruits of *Pocillopora* and *Porites* are shown in figure 2 on next page.

The mean settlement rates of coral spat per tile varied from 0.75 (± 0.79 s.d., August 2001) to a maximum of 16.70 (± 7.53 s.d.; figure 3 on next page). The greatest number of spat recorded on a single tile was 38 (November 2002). Recruitment was consistently higher at Coral Gardens compared with Starfish, ranging from 2.1 to 27 times higher. Each factor, site, year, season and coral family had a significant effect on recruitment rates, though a fully factorial ANOVA was not possible due to missing samples (table 2 on page 171). By inspection of figure 3, a strong interaction effect of site*year*season*taxon is evident, being highest for pocilloporids in the northeast monsoon (Dec–Feb) of 2002 at the Coral Gardens. Abundance of coral spat on tiles corresponded to recruit densities of 30–740 m^{-2} at Coral Gardens and 8–60 m^{-2} at Starfish.

Recruitment was overwhelmingly dominated by corals of the family Pocilloporidae (76%, figure 4 on page 171) and Poritidae (19%) and only 5% from other families. Non-pocilloporids were only prominent among recruits during the September–November season in both years and in June–August in 2002, and all 'others' were noted only during this latter period. Starfish had a lower diversity of corals than Coral Gardens, with 93% pocilloporids, 5% poritids and 1.8% 'other'.

The average size of coral spat on the tiles varied from 1 to 3 mm in diameter, with a maximum recorded size of 17.5 mm for a pocilloporid in February 2002. Spat sizes were smallest in November–February when density was highest (table 3 on page 171), and highest a few months later in June–August. Pocilloporids were significantly larger, and poritids significantly smaller than other coral spat. No annual effect was seen, and spat sizes were larger at Coral Gardens than at Starfish, most likely due to the predominance of larger pocilloporids. There was high

Table 1. Sampling details of settlement tiles in the Mombasa Marine National Park. 'Month' indicates the standardized periods used in the paper

Year	Season	Date		Coral Gardens		Starfish	
		immersed	retrieved	# tiles	# corals	# tiles	# corals
2001	May	13-Mar-01	22-Jun-01	21	101	20	32
	Aug	22-Jun-01	20-Oct-01	20	14		
	Nov	1-Oct-01	18-Jan-02	18	96	20	4
2002	Feb	18-Jan-02	25-Apr-02	21	94	20	27
	May	25-Apr-02	13-Aug-02	20	112	20	15
	Aug	13-Aug-02	12-Nov-02	20	200	19	24
	Nov	12-Nov-02	24-Feb-03	20	329	20	28
2003	Feb	17-Feb-03	19-May-03	24	174	20	22
Grand Total				1 120		152	

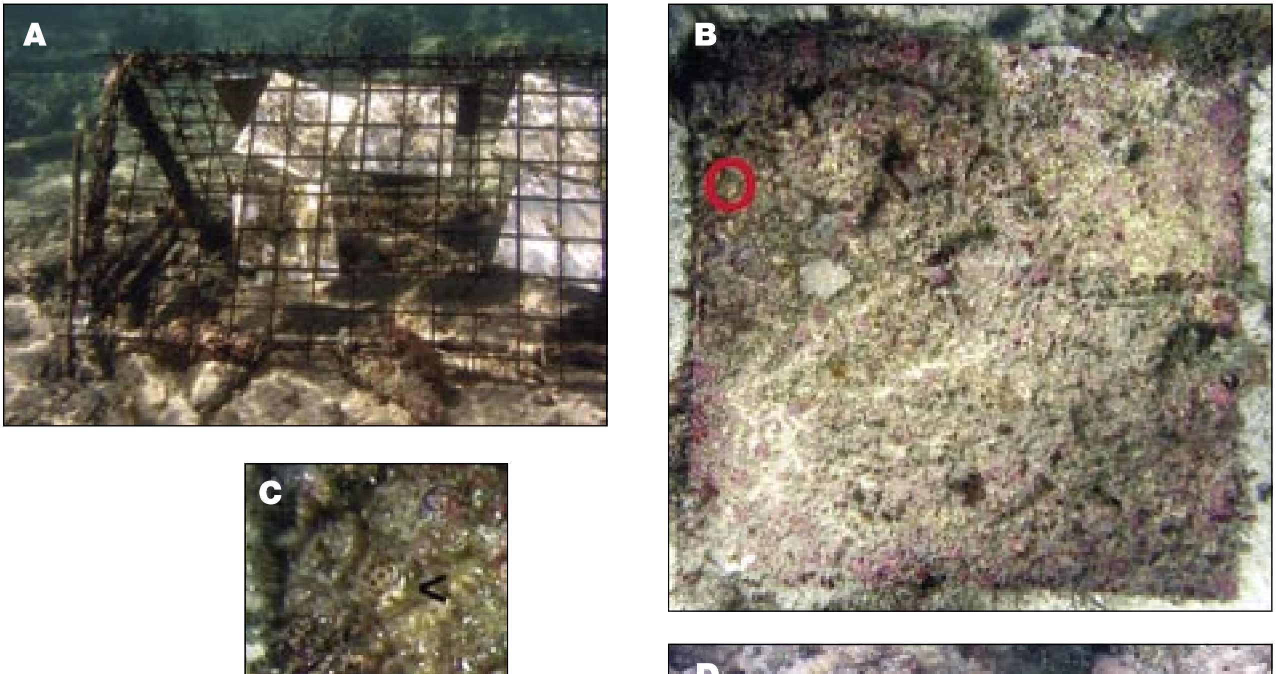

Figure 2. A) Settlement tile rack: tiles are angled at 45° with the rough surfaces facing downwards. B) Tile after approx. 3 months in submergence and growth of algal turf, coralline algae and various invertebrates. A coral spat is circled in red at top left, and shown in detail in (C) at approx. 2 mm diameter and 7 polyp stage. D) coral recruits on natural substrates at about 2 cm size, with Pocilloporidae (left, *Pocillopora damicornis*) and Poritidae (right, *Porites lichen*).

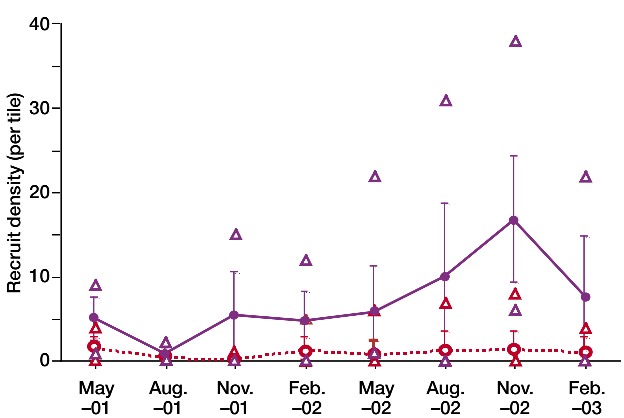

Figure 3. Abundance of recruits per tile (225 cm^2) for the 2 year period from May 2001 to February 2003 (mean, standard deviation, minimum and maximum).

Table 2. One-way ANOVA results of settlement rates by year, season, site and family (data from figure 3). Fully factorial ANOVA could not be conducted due to missing data

Factor	F	p	Post-Hoc test (LSD)
Year	14.367	<0.001	2002 >> 2001, 2003
Season	8.498	<0.001	Dec-Feb >> Mar-May,Jun-Aug,Sep-Nov
Site	98.164	<0.001	Coral Gardens >> Starfish
Coral	69.3	<0.001	Pocilloporidae >> Poritidae>> Other

Table 3. One-way ANOVA results of coral spat diameter by year, season, site and family. Fully factorial ANOVA could not be conducted due to missing data

Factor	F	p	Post-Hoc test (LSD)
Year		ns	
Season	5.655	0.001	Jun-Aug > Mar-May, Sep-Nov > Dec-Feb
Site	11.044	<0.001	Coral Gardens >> Starfish
Coral	54.063	<0.001	Pocilloporidae >> Other > Poritidae

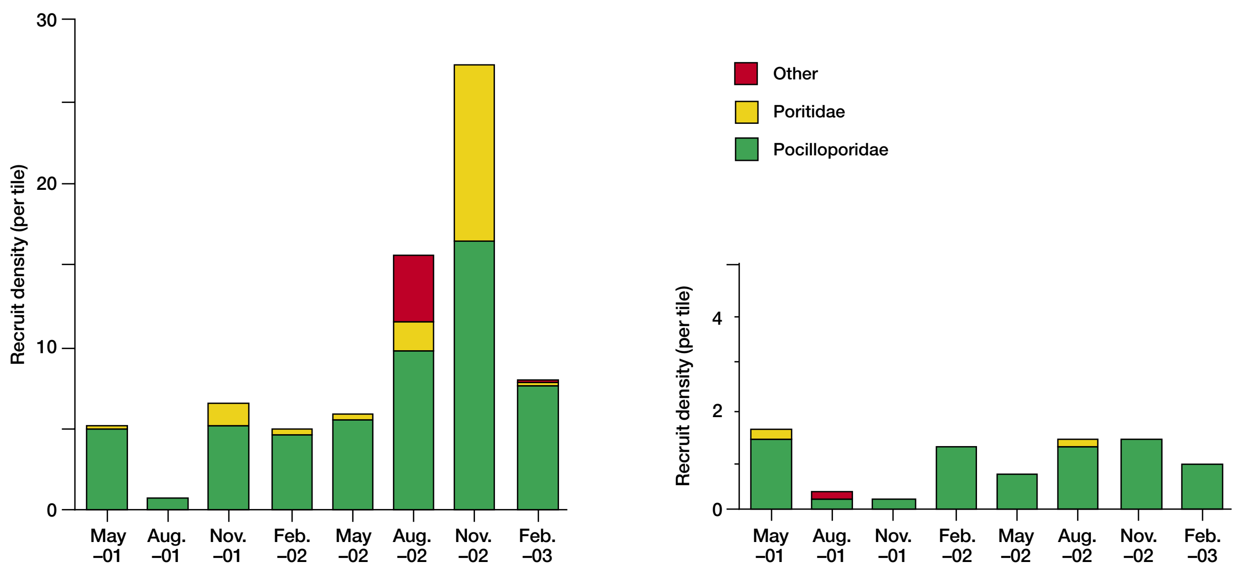

Figure 4. Composition of recruit populations at Coral Gardens and Starfish.

variation in the sizes of Pocilloporidae and a large degree of overlap with those of Poritidae (figure 5 on next page), however the Pocilloporidae showed larger maximum size colonies.

DISCUSSION

The dominant pattern in this dataset was of significant variability across sites, seasons and years (table 3). Within that, patterns were not statistically significant, but clearly

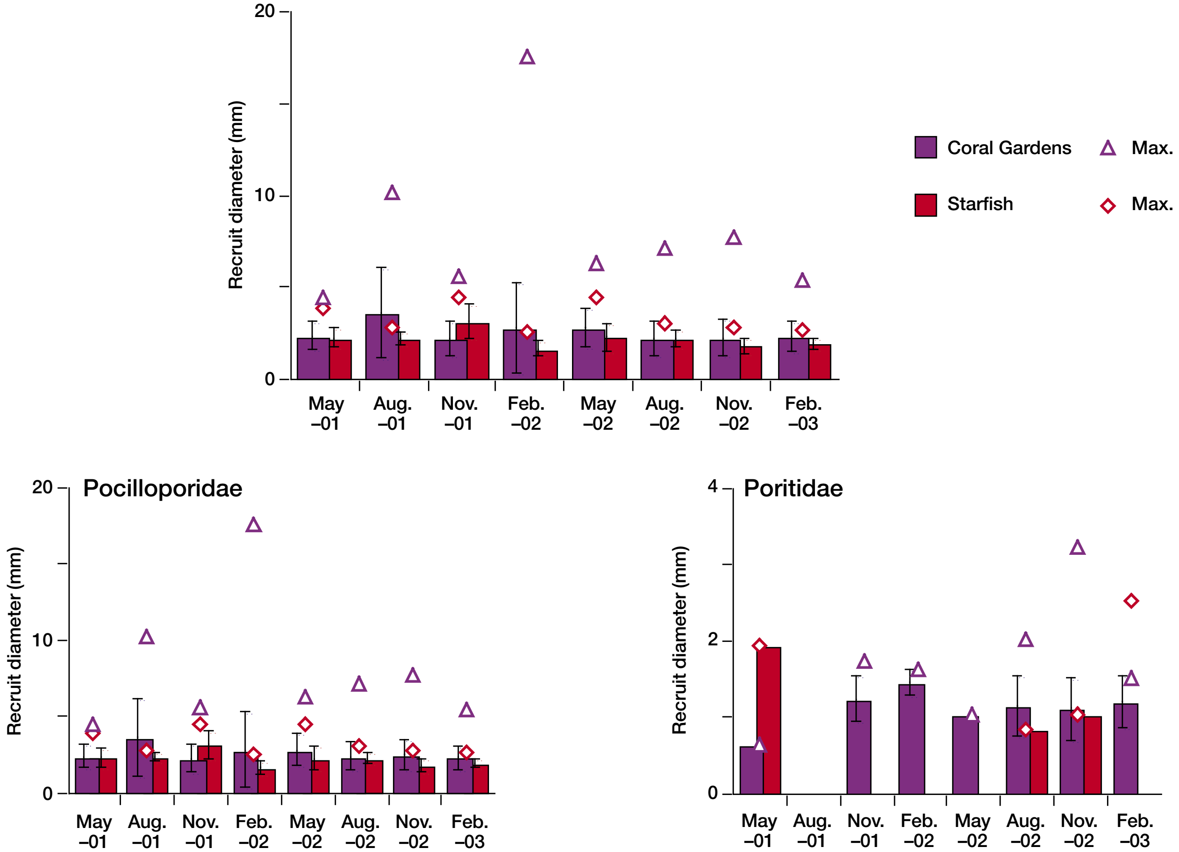

Figure 5. Mean, standard deviation and maximum sizes (mm) for all corals (above), Pocilloporidae (bottom left) and Poritidae (bottom right).

showed higher settlement at Coral Gardens compared with Starfish and during September–November relative to other times of the year (though additional years of sampling will be needed to confirm this). Additionally, pocilloporids (mostly *Pocillopora* spp.) were the dominant settlers throughout the year. Coral Gardens is located adjacent to the only cross-reef channel for over 3 km north and south, giving it the strongest current flow conditions and therefore most likely the greatest exposure to coral larvae carried in from the reef front. Both the level of settlement and diversity are indicative of greater exposure to potential recruits. Additionally, water and substrate conditions may be more conducive to successful settlement and post-settlement survival of corals, as the water may be more aerated and substrate surfaces cleaner than at Starfish, which experiences calmer conditions within the lagoon. Coral Gardens is also more topographically complex, and has more fish than Starfish, which may confer better conditions for settlement and post-settlement survival.

Corals of the family Pocilloporidae dominate the settlement plates, and are the most abundant recruits to natural surfaces in the area (Tamelander, 2002) and are among the most abundant recruits at other sites in Kenya (Obura, in review). Most of these are in the genus *Pocillopora*, and abundant *P. damicornis*, *P. verrucosa* and

P. eydouxi of multiple year classes were found adjacent to and on the settlement racks (Obura, pers. obs.). Corals in the genus *Pocillopora* are well known from other parts of the world for their prolific reproductive output, primarily of brooded planula larvae that often settle very close to the parent colony (Richmond & Jokiel, 1984; Richmond, 1985; Glynn *et al.*, 1991). The year-round presence of *Pocillopora* recruits recorded here (and pers. obs) suggest a similar year-round reproductive output in Kenya, with a strong peak, in September–November, particularly noted in 2002. This occurs when water temperatures are rising at their maximum rate (McClanahan, 1988; Obura, 2001), and prior to maximum temperatures experienced in March–April at the end of the northeast monsoon season. The presence of poritids was most strongly noted in September–November of both years, though low levels were present throughout the year. Other corals were not abundant enough to draw any strong conclusions concerning seasonality in their reproduction.

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Local Level Coral-Reef Fisheries Management in Diani-Chale, Southern Kenya:

Current Status and Future Directions

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key words: Diani-Chale, fisheries, local level management, co-management, local institutions

ABSTRACT

The current regime of fisheries management and issues concerning the achievement of a more locally oriented system of fisheries management in Diani-Chale, southern Kenya are examined. Fisheries management in the area is characterized by a lack of strong government capacity for regulation, weakened local institutions, and an absence in the ability to exert control over the use of the fishery. Local level management requires the development and use of local institutions that can govern the use of fishery resources. The landing sites and associated fishing grounds constitute a socio-ecological unit and were identified to be the appropriate level at which many fishery management issues could be resolved. A more formal role for these entities, together with clarification of tenure of fishing grounds and support for the development and enforcement of local rules for the use of the fishery are essential actions that should be taken by government to enable more local level fisheries management. The socio-economic condition of fishers, the fear fishers have over the loss of landing sites, and the continued perception of the imposition of a marine reserve in the area pose barriers to initiatives seeking to further local level management. The need for a coordinated approach among agencies working on fisheries issues in the area is essential so as to avoid the erosion of social trust with local fishing communities.

INTRODUCTION

The Diani-Chale area on the south coast of Kenya has been the focus of much of the participatory monitoring work undertaken by CORDIO East Africa (figure 1). The area represents one of the most degraded coral reef systems in East Africa (McClanahan & Obura, 1995) and is characterized by high fishing effort, high levels of conflict among fishers and other coastal resources users, with relatively poor enforcement of regulations. The efforts of CORDIO East Africa have focused on the use of participatory monitoring and research approaches as a strategy to create awareness among fishers and engage them to be more involved in resource management (Obura, 2001; Obura *et al.*, 2002). The development of a local system of resource management in Diani-Chale is an evolving process and is of interest to a number of organizations active in the area, including CORDIO East Africa. The aim of this paper is to provide a context to the current regime of fisheries management in Diani-Chale and to relate this to attaining a more locally oriented system of fisheries management. The paper examines local level institutions and initiatives relevant to fisheries management and highlights some of the issues relevant to the development of a local and collaborative system of fisheries management. It concludes with a number of recommendations that are pertinent to

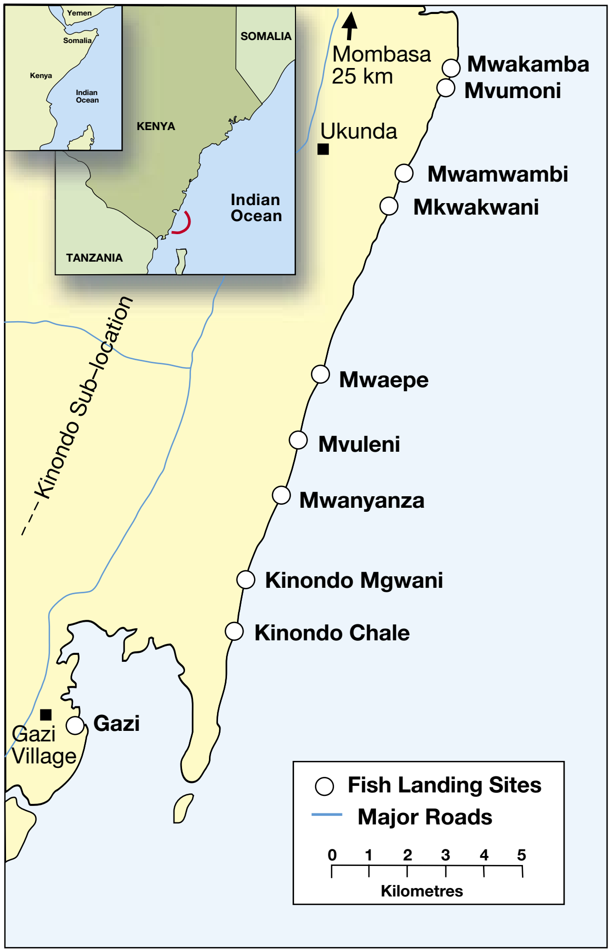

Figure 1. The general location of the Diani-Chale area on the south coast of Kenya (inset) and some the fish landing sites used by fishermen within the study area (outset).

improve local level resource management in Diani-Chale.

FISHERIES IN DIANI-CHALE: AN OVERVIEW

Fishing Activities

The near shore fisheries in Diani-Chale, as in most parts of East Africa, are largely artisanal in nature, serving both subsistence needs as well as local markets. Fishing activities occur within the coral reef lagoons and sea grass beds sheltered by the fringing reefs and extend beyond the reef in calmer conditions. An estimated 600 fishers fish in Diani-Chale (Malleret-King *et al.*, 2003), within an area that encompasses between 30–40 km^2, equivalent to a fisher density of 15–20 $fishers \cdot km^{-2}$ which is much higher than that reported elsewhere (Obura *et al.*, 2002). Fishing and fish trading related activities constitute between a fifth and a quarter of all activities of households in Diani-Chale (CORDIO, unpublished data). The catch primarily consists of demersal reef species and some pelagic species (King, 2000; McClanahan & Mangi, 2004). Fishing is undertaken using traditional vessels and traditional gears that include basket traps, hand lines and hand spears, as well as more modern gear types such as spear guns, gill nets and beach seines (Obura *et al.*, 2002). Fishers are each associated with a landing site at which catches are landed (figure 1). Each landing site in turn, is loosely associated with an adjacent fishing ground where fishers from a landing site fish. The fishing ground is generally considered as the area of sea in front of the landing site. It has been noted that boundaries between fishing grounds are maintained by the daily interaction of fishers (McClanahan & Mangi, 2001). However, fishers fish various recognizable fishing sites within the fishing grounds and many of these fishing sites are shared among fishers from adjacent landing sites (Obura, pers. comm.). Fishers from a landing site generally accommodate fishers from adjacent landing sites fishing in their fishing ground. Thus, there aren't strong tenure arrangements for fishing grounds at least between closely associated and adjacent landing sites.

State of Fish Stocks

The reef fisheries in Diani-Chale are considered to be heavily exploited and are fished at or above sustainable levels (McClanahan *et al.*, 1997; Obura *et al.*, 2002). Catch per unit effort (CPUE) for most species fished between the years 1995-1999 was reported to be declining (McClanahan & Mangi, 2001). The average catch per fisher per day is considered very low and varies between 2 and 6 kg·fisher^{-1}·day^{-1} depending on the season (Obura *et al.*, 2002). The coral reefs of Diani-Chale are also considered to be one of the most degraded, having low coral cover, low fish abundance and a high abundance of sea urchins resulting from overfishing (McClanahan & Muthiga, 1988; McClanahan & Obura, 1995). On Kenyan fringing reefs, fisher densities of between 8–9 fishers·km^{-2} have been estimated to induce an ecological shift from herbivorous fish dominated reef communities to sea urchin dominated communities (McClanahan, 1990).

Fishery Management Measures

The Fisheries Department is the primary agency responsible for fishery management and development in Kenya. The *Fisheries Act* (GOK, 1991; GOK, 2001) contains regulations that include measures for licensing fishers, restricting destructive gear types and protection of breeding areas. In Diani-Chale, interventions by the Fisheries Department have focused on restricting gear types by prohibiting the use of beach seining and spear guns. The lack of enforcement capacity within the Fisheries Department however, has limited the effectiveness of these interventions. While there has been widespread local resistance to beach seining by local fishers using traditional gear types, beach seiners have managed to carry on fishing in some areas and it is claimed that officials have been convinced to ignore their activities (Glaesel, 2000a). Beach seining utilizes fine mesh nets and has been associated with damaging bottom habitats, capturing juvenile fish and competing with other traditional gear types (Rubens, 1996; Glaesel, 2000a; McClanahan & Mangi, 2001). Spear guns, on the other hand, are cheap to construct and have become one of the most widely used gear types (Glaesel, 2000a; King, 2000; Obura *et al.*, 2002).

Local and Traditional Fishing Arrangements

Fishers in Diani-Chale have historically had various forms of traditional and customary practices that served in some ways as fishery management measures (McClanahan *et al.*, 1997; Glaesel, 2000b; and see Tunje, 2002). These practices were not explicitly associated with conservation concerns but rather with relieving anxieties of dangers at sea and of spirits directing fish away from the community (Glaesel, 2000b). A number of taboos such as using poison to capture fish, capturing juvenile fish, and catching more fish than could be used, are thought to have influenced the conservation of fish stocks (Glaesel, 2000b). Elders were respected for their authority and exerted a significant influence over where and how fishing was conducted on a daily basis. These elders were a central part of the social organization of a landing site and regulated access to fishing grounds by non-resident fishers who had to pay compensation in exchange for permission to fish in an area (McClanahan *et al.*, 1997).

Unfortunately, most of these measures have broken down for a variety of reasons (see Glaesel, 2000b; Tunje, 2002) and, at present, they do not appear to have a measurable impact on the conservation of fishery resources (McClanahan *et al.*, 1997). Relatively modern fishing methods of beach seining and spear guns are considered by elders to be unacceptable to ancestral sprits (Glaesel, 2000a). While elders have discouraged their use, younger fishers still make use of them causing an inter-generational conflict (Glaesel, 1997). Conflict among gear types has been most notable between beach seine users and other gear type users, and between younger fishers using spear guns and older fishers using traps (Obura *et al.*, 2002). A number of landing sites have sought to ban the use of beach seines in their waters through passive means and by disallowing the landing of fish caught by this gear at their landing sites but have only had moderate success (McClanahan *et al.*, 1997). In essence, traditional authority at a landing site can only control whether fish are landed at the site, but cannot control who fishes on the reefs in front of the landing site.

PROSPECTS FOR LOCAL LEVEL FISHERIES MANAGEMENT IN DIANI-CHALE

The continuing decline of fishery resources in Diani-Chale does beg the question as to who really exercises the right to manage the fishery resources. In the absence of a strong government capacity for regulation, weakened local institutions and traditional measures, there is a general absence in the ability to exert control and formally or informally define rules among fishers for the use of fishery resources. When those participating in resource extraction undermine rules without incurring a penalty, then the use of resources can be considered unregulated and open access. This is arguably the case in Diani-Chale, and those concerned with promoting local level management need to be concerned with strengthening or creating local institutions that can govern the use of fishery resources.

There are two sets of questions that are central to the development of local level fisheries management in Diani-Chale that are of importance to ask. First, does the government, primarily the Fisheries Department, recognise the need for involving fishers in the management of resources and hence the need for a more collaborative approach to fishery management (co-management)? Is there a genuine willingness to create and use local institutions and to share responsibility with the very people whom the Department has sought to regulate? Does current policy enable the development of a more locally-focused system of fisheries management? Second, are fishers and/or others at the local level capable of playing a role in shared management? Are fishers motivated and sufficiently organised to begin to undertake management functions and does their socio-economic condition allow them to participate in management actions?

These sets of questions are central to those concerned with local level management and the paradigm of fisheries co-management. While it is not in the scope of this paper to provide a detailed review of fisheries co-management, the issues discussed in the following sections describing the local conditions in Diani-Chale are examined with regard to fisheries co-management and interactions between different institutions in a co-management framework.

Government/Policy Environment

The guiding legislation for fisheries management in Kenya is the Fisheries Act (GOK, 1991) and its various subsidiary regulations (GOK, 2001). Current legislation vests significant authority in the Director of Fisheries for fisheries management and is heavy on various regulatory measures. Current legislation does not accord any role to local communities or groups to undertake tasks relating to fisheries management. The references made to fishers all relate to regulations associated with harvesting and trading fish. A policy that would enable co-management should seek to empower local institutions through a delegation of some resource management functions to local authorities, community groups or other capable organizations over time. As has been noted elsewhere, the government has the *de facto* control over fishery policy and therefore holds the power to determine the type of co-management arrangement that is developed (Pomeroy & Berkes, 1997; Charles, 2001).

Local Institutions for Fishery Management

A number of informal arrangements carried over from historical times, although weakened, still persist and play a role in day-to-day management of the fishery. For instance, many landing site leaders still hold authority to allow or disallow fishers to use a landing site. It is traditional practice for fishers to seek permission before fishing in an area that is considered the fishing ground of another landing site. However, there is no recourse fishers can take with those who have been disallowed from landing fish at a landing site from fishing in their fishing ground. In essence, there is no secure claim over the tenure of the fishing ground by the landing site. There are 12 landing sites and adjacent fishing grounds in Diani-Chale, with various degrees of overlap in the use of fishing sites between them. Most have some form of traditional authority or beach/landing site chairman present,

Figure 2. The landing site where fishers interact, and the fishing ground in front of it where fishers fish, collectively form a socio-ecological unit at which many local fishing arrangements can be negotiated.

but the authority of these chairmen and respect among fishers varies.

These collections of landing sites and the associated fishing grounds form an identifiable socio-ecological unit, both in terms of their membership and the spatial area over which they occur (figure 2). Strengthening these units can serve to address many fishery management related issues. This is the lowest level at which one can conceive the negotiation of fishery management measures since it collects together all those who utilize a fishing ground. Within the current regime of fisheries management, there is no apparent recognition of the role that such local entities can play in day-to-day management of fisheries.

Strengthening Local Institutions

The use of existing social organizations and the revitalizing of traditional forms of organization have been noted to be appropriate ways in which to initiate and engage into fisheries co-management (Pomeroy, 1995; Pomeroy & Carlos, 1997). Nonetheless, existing social organizations may in some cases not be appropriately structured or sufficiently represent local interests. Under a traditional landing site organization, the authority is vested in an elder or elected leader who reaches decisions that fishers were expected to abide by. With traditional authority and leadership being eroded and undermined by migrant and younger fishers, it is doubtful whether traditional landing site organizations can effectively function under an authority-based system. The fishers are clearly not a homogeneous group and some, despite sharing kinship, are divided across age and gear barriers, whereas others are divided by origin (Glaesel, 2000a). Any landing site organization is going to have to contend with these differences and seek to resolve the conflicts that occur. Effective conflict resolution would be crucial to the functioning of any local landing site institution. Landing site institutions that are more representative in their authority structure may be better suited to this. Gear conflicts among fishers appear to be the most intense and persistent issue and one amenable to be addressed at the level of a landing site through arrangements among fishers.

Local Information-Decision Making Loops

A challenge to any form of fisheries management is how to use information about the fishery and changing conditions to flexibly manage fishing activity on a day-to-day basis such that it ideally results in the conservation of fish stocks. Local knowledge and information from fishers could be used to guide how and where fishing activity occurs. Such information-knowledge-management loops would be essential to the local landing site institutions. Mechanisms for monitoring the fishery on a day-to-day basis as well as over the long term by the fishers themselves are developing through participatory monitoring initiatives of CORDIO East Africa. Nonetheless, fishers in Diani-Chale have not embraced the use of this information for decision-making on their fishing activities. This may be due, in part, to the fact that fishers and their landing site do not feel responsible for managing their own fishing activities and do not see this as part of their role. This is an area that would require awareness and a formal recognition of the responsibilities that fishers have to play in resource management.

In addition, the Fisheries Department and other organizations have a continued role to play with regards to undertaking research and creating awareness among local institutions. There is also a need to better target the results of their monitoring and research to local levels and strengthen the links between monitoring and management. Currently, data on fish catch is collected by at least four different organisations that also conduct research in the area. They include the Fisheries Department, Kenya Marine and Fisheries Research Institute (KMFRI), Wildlife Conservation Society/Coral Reef Conservation Project (WCS/CRCP) and CORDIO. The changes in fishery policy and management resulting from research and monitoring activities are not apparent.

Clarifying Resource Rights and Tenure

The success of any management measures negotiated by fishers and the continued investment of effort by fishers in the process of creating and adjudicating rules can only be expected if fishers have an incentive to do so. Securing the benefits of management interventions (i.e. healthier fish stocks) can only occur if the tenure of fishing grounds is secure and access to them can be regulated and allocated to the membership of fishers utilizing that fishing ground. The recognition of the tenure of the fishing grounds by government is critical in order to exclude outsiders and those not abiding by local rules. In particular, the ability to sanction and prosecute violators from outside the community with government support has been attributed to securing tenure and the revitalization of many local level institutions (Ostrom, 1990; Johannes, 2002).

In order for the management interventions and actions of fishers to be fully effective, the government has an enabling role to play. In particular, the government needs to recognize the tenure of the fishing grounds and clarify who holds access rights to them. A few landing sites in the area have attempted to exclude beach seines using a variety of measures, resulting in mixed success (McClanahan *et al.*, 1997). The lack of follow up support and enforcement from the Fisheries Department has limited the effectiveness of this measure. Legal prosecution of outsiders who violate or break local rules for fishing would do a lot to make measures at the landing site/fishing ground more effective. Without this sanctioning of violators the benefits of management measures implemented will be diluted and, at the very worst, may lead to similar rule breaking within fishers of the landing site. Support for local enforcement units from amongst the community with government assistance should be considered.

CURRENT AND EMERGING INITIATIVES WITH IMPLICATIONS ON FISHERIES MANAGEMENT

Diani-Chale Management Trust (DCMT)

A recent development has been the formation of the Diani-Chale Management Trust (DCMT). This is an umbrella group of representatives from local community-based organisations, community leaders, local administration and government agencies working in Diani-Chale. It consists of a membership of 33 people, a number of sub-committees and a five-member executive drawn from the membership. The DCMT is perceived to be the body through which community development initiatives are to be developed and the primary body through which Integrated Coastal Area Management (ICAM) activities and issues will be addressed and resolved. This forum represents a local institution with an emerging mandate to address resource management and development issues. While there are representatives from fishers groups on the DCMT, there have also been recent efforts to organize local landing site chairmen into a group that can report and bring forward issues requiring intervention. Participatory fisheries monitoring work that was being undertaken by CORDIO has now been included under the DCMT and its sub-committee on research and monitoring and represents an effort to integrate activities that can support fisheries management at a more local scale.

While the exact manner in which the DCMT engages fisheries management still needs to be articulated by its membership, it operates at the appropriate scale and has the critical mass to engage in a number of measures that could make fisheries co-management operational. The DCMT, together with the landing site chairmen and Fisheries Department represented within it, could be the starting point from which a fishery management plan could develop. Its initial actions could target issues on which there is broad agreement amongst fishers. The development of a community enforcement unit that initially targets beach seiners could be a step in this direction. Another could be the facilitation of the development of a vision and future direction of the fishery that can be used as a basis for further activities.

Immediate challenges with the DCMT concern its capacity to undertake activities and to sustain itself and develop into a stable community institution. Fisheries are only one of the resources that the DCMT is concerned with and the efforts of the DCMT are going to have to be distributed between other resources and competing mandates for enterprise development.

Fisheries Development Initiatives

The Coast Development Authority (CDA), a governmental development agency, and community development non-governmental organisations (NGOs), such as Eco-Ethics International Union Kenya chapter (EEIU) and PACT Kenya, have been involved in renovating and building landing site structures and encouraging enterprise development. Of notable mention is the ongoing acquisition of fishing vessels and gears for the offshore fishery for some fishers. While the development of an offshore fishery presents an opportunity to reduce fishing pressure inshore, it would not be prudent to develop it without any arrangements or institutions in place that can regulate its use. Integrating fishery development measures with other aspects of fishery management is essential. In the inshore where there is already excessive effort, development measures need to focus on increasing its value rather than catches. Government supported, co-operative societies that should have been active in fisheries development in the area have largely failed and have been abandoned by fishers (King, 2000) and fishermen have formed self-help groups to provide their own small credit facility to members.

BARRIERS TO LOCAL LEVEL FISHERIES MANAGEMENT IN DIANI-CHALE

The socio-economic conditions of fishers and several issues that currently affect them pose a number of barriers to attaining a more local level fisheries management. For fishers, livelihood security considerations would be expected to feature prominently in any actions and management measures they choose to engage in. The current socio-economic condition of fishers and the low level of catch, pose a grave challenge to their participation in measures that are perceived to reduce their catches in the short term. In a fishery that is characterized by excessive effort, the improvement of fish stocks is not likely without the relief of excessive fishing pressure. This presents the greatest challenge to any form of management of the fishery.

In addition, the continuing loss of lands on which landing sites and their access routes are located has been the primary issue that has preoccupied fishers. With the advent of tourism development in the past few decades, community owned lands have largely fallen into private hands and most of the 12 landing sites in Diani-Chale and the access routes to them now sit on privately owned land. Fishers need some security of existence through arrangements that can guarantee their continued use of the landing sites, beaches and access to them. Fishers have cited the lack of such security as the primary issue that needs to be addressed before they can engage in discussions relating to other aspects of fisheries management. The DCMT is perhaps the best suited institution to take the lead and facilitate the collective negotiation any such arrangements.

A third issue that is historical in nature yields from the failed efforts of the Kenya Wildlife Service (KWS) to institute a marine reserve in the area. The community rejection of the proposal in 1994 and the events surrounding it have left a strong suspicion that such a reserve may be still be imposed through other means. As a consequence, discussions on any aspect of management have been treated with suspicion and often rejection for fear of it being associated with KWS. This has effectively limited the progress of any management initiatives that government agencies and other external agents have tried to develop with the communities. The current sentiments of the community make any intervention by the KWS a virtual impossibility. Nonetheless, in legal terms, the KWS still holds the mandate to manage the area. A productive intervention of KWS could be to publicly disengage itself from the management of the area. The official and formal delegation of authority from KWS to a local authority, such as the Kwale County Council, another government agency or perhaps even the DCMT, could be a step in this direction.

FISHERIES MANAGEMENT IN DIANI-CHALE: MULTIPLE PLAYERS AND LINKS

This paper has touched on several key players relevant to fisheries management in Diani-Chale (table 1). It has been noted that co-management can be considered as a mechanism to bridge institutions at multiple scales to improve the management of natural resources (Berkes, 2002). Thus, one may expect that the internal capacity of these individual institutions and the links and interactions between them will determine how effective fisheries co-management will be. At present, there does not appear to be a coordinated approach among players involved. It is important that the players at upper levels intersect and coordinate their efforts in a manner that is consistent with the development of local level management. Misguided policy and actions can erode social trust between local level organisations and agencies working at higher levels. The history in Diani-Chale between the community and others has always been one of suspicion and scepticism compounded by the failed in-

Table 1. Multiple institutions and scales pertinent to fisheries management in Diani-Chale.

	Institutions | Players		
Scale | Level	***Government Institutions***	***Community Institutions***	***Other Institutions***
Country	National Government; Fisheries Department ↓		
Coast Province	Provincial Administration; Coast Development Authority (CDA) ↓		Research & Conservation NGO's ↕
Kwale District	Local Administration ↓	South Coast Fisherman's Association (SCOFEC)	
Divisions, Locations			Diani Chale Management Trust (DCMT)
Village		Village Organizations	Other Stakeholders
			Community Development NGOs
Landing Site		Landing Site Organizations	
Fishing Ground		Fishers Self-Help Groups (Fishers + Traders)	

stitution of a marine reserve in the area in 1994. Frustration among fishers arising from the lack of fishery development measures or measures that were improperly implemented and, as a result, were detrimental or yielded insufficient benefits to them is already evident.

CONCLUSIONS AND RECOMMENDATIONS

At present, coral reef fisheries management in Diani-Chale is characterised by a combination of limited capacity for government based management and the lack of sufficiently developed and empowered local institutions that can play an effective role in fisheries management. Government policy is currently inadequate and not conducive to the development of more local level management. Specifically, it needs to recognise the landing site and adjacent fishing grounds as a socio-ecological unit and the role that these can play in fishery management. These units need to be empowered to be able to make decisions on the basis of information and local knowledge and accorded a formal role to play in fisheries management. Encouraging the development of arrangements among fishers, however simple they may be, may be an initial step towards according greater management responsibility to such local institutions. The Government needs to further clarify the tenure of fishing grounds and provide support to the actions of fishers that restrict access to fishing grounds to outsiders and those who have violated local regulations. Several barriers stand in the way of achieving a more local level fisheries management and the ability of fishers to fully participate in such management. These include the socio-economic condition of fishers, the unresolved loss of landing sites and access routes and the continued suspicion by fishers of interventions from the KWS. Addressing these issues can remove some of the current obstacles that hinder the committed participation of fishers in management. A coordinated approach involving all the players relevant to fisheries management is necessary and its absence may result in misguided actions that may further erode the trust between players at local and upper levels. The DCMT could effectively make fishery co-management in the area operational and needs to be supported to that end.

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A Diver and Diving Survey in Southern Mozambique

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ABSTRACT

Recreational SCUBA diving has grown tremendously along most of the southern Mozambican coastline in the last eight years. This growth was not managed, largely due to a lack of baseline information on various aspects of the industry, including diving intensity and socio-demography of the SCUBA diving community. These aspects of the industry were thus covered in this study to redress this shortfall. Information was collected on divers and diving pressure in southern Mozambique using questionnaires and dive log sheets distributed through local dive centres. Divers visiting southern Mozambique were found to be mostly educated South Africans with high levels of experience. They were committed divers, satisfied with their diving experiences in the area and sensitive to reef conservation issues. The diving intensity was estimated at 42 500 dives in 2001 and 62 000 dives in 2002 occuring at about 20 dive sites, which is not as high as previously thought. Nevertheless, there is potential for overuse of favoured dive sites, and recommendations are made to disperse divers among a greater number of sites and to undertake awareness programmes on sustainable diving practises.

INTRODUCTION

The southern Mozambique coastline between Ponta do Ouro and Cabo Santa Maria has been a focus of coastal tourism development since the end of the civil war in 1992 (Hatton, 1995; Massinga & Hatton, 1996). Around 115 000 tourists visit southern Mozambique annually (Saia, A., 2003, Ministry of Tourism, pers. comm.). Of these, approximately 10 000–13 000 visit the Ponta do Ouro and Ponta Malongane region (Bjerner & Johansson, 2001) to dive, fish and camp, the majority (60–72%) being certified SCUBA divers (Bjerner & Johansson, 2001; Abrantes & Pereira, 2003).

The high fish diversity in the area (Robertson *et al.*, 1996; Pereira *et al.*, 2004) contributes to the beauty and attractiveness of the reefs. Further, the occurrence of large, resident fishes such as potato bass (*Epinephelus tukula*), several species of sharks and marine turtles has resulted in specific localities such as 'Bass City' and 'Pinnacles' near Ponta Malongane becoming popular with divers (Robertson *et al.*, 1996). The diving intensity in 1995 was estimated at 30 000–40 000 dives per year and Robertson *et al.* (1996) stated that this dive rate was high considering the size of the reefs. Unconfirmed reports claimed that in 1998 this number increased to around 80 000–90 000 dives per year and it was suggested that the diving intensity was approaching unsustainable levels (H. Motta, WWF Mozambique, pers. comm.). Later, Bjerner & Johansson (2001), estimated the diving intensity in the area to be approximately 63 000 dives per year.

Despite the remarkable growth and economic importance of recreational diving in southern Mozambique (Bjerner & Johansson, 2001), its regulation and management are deficient and the existing legislation is obsolete (dating back to the late 1960s) and poorly enforced. Important demographic and socio-economic information on divers visiting the southern Mozambique reefs is generally lacking and management actions have been partially hindered by the lack of knowledge on the current diving pressure in the area. This paper reports aspects of an MSc thesis study of the demography, participation and attitudes of recreational SCUBA divers visiting southern Mozambique. Estimates of the diving pressure during the study period (February 2001–December 2002) and recommendations for management are also provided.

MATERIALS AND METHODS

An 8-page, 30-question, self-administered questionnaire was developed to collect data from recreational divers. The questionnaires were distributed to dive centres operating in Ponta do Ouro and Ponta Malongane and collected throughout the study period. The questionnaire collected information in four areas:

- demographic profile of recreational scuba divers;
- diver experience, activities and qualifications;
- diving activities and experiences in southern Mozambique;
- opinions on the condition and management of diving in southern Mozambique.

The number of recreational dives done during the study period at individual dive sites was estimated using two methods:

- pre-prepared log sheets filled out by dive centres;
- boat launch data extracted from resort log sheets and dive centres.

RESULTS

Diver experience

A total of 108 questionnaires were filled in and returned. Most (57.9%) of the recreational SCUBA divers that answered and returned the questionnaires were South African males and only three were Mozambicans. A total of 9 nationalities were represented, most of them European. Altogether, the average age was 34.9 years (S.D. = 8.8), with most (73%) between 21 and 39 years of age. Divers were highly educated; all divers had completed their secondary level of education (high school) and the majority (36.4% of females and 50.0% of male divers) had completed their tertiary education at university (B.A./B.Sc.). A number of female (27.3%) and male divers (21.6%) had undergone post-graduate education (B.Sc. (Hons)/M.Sc./PhD.).

On average, divers had been certified for 5.8 years, ranging from 0–27 years. The majority had been certified for at least 4 years and more than half of them had completed 51 or more dives. 35% of divers were 'newcomers' ('have dived for one year or less in southern Mozambique'), 48.5% had been visiting southern Mozambique for the past 2 to 5 years and the rest for more than 5 years. 63% stated that they have also dived at other locations in Mozambique, most notably Inhambane (31.3%) and Inhaca Island (19.3%). The majority of divers (65.1%) considered SCUBA diving to be their most important or second most important outdoor activity. Many outdoor recreational activities are primarily family-orientated, and recreational SCUBA diving in southern Mozambique does seem to be one of these activities. Most divers practised their sport frequently with friends (47.1 %) or a combination of friends and family (42.4%).

The diving in southern Mozambique compared favourably with other dive sites, as 84.2% of the divers considered the diving in southern Mozambique slightly or much better than other diving sites they have visited. The perception that southern Mozambique offers good quality diving is also reflected in the overall diving satisfaction expressed by the respondents. The great majority (93.4%, average rank of 4.5 on a scale of 1–5) stated that they were very or extremely satisfied with their diving experience in southern Mozambique, with none of them dissatisfied or slightly satisfied.

Diver Attitudes

The great majority of divers (91.6%) rated 'look at fish and other marine life' as a very important or extremely important reason why they came to dive in southern Mozambique. This was the highest ranked reason (4.7 on a scale of 1–5). Another important reason, with an average rank of 4.4 (83.7% of the divers), was 'to experience unpolluted surroundings'. Marine megafauna were the highest ranked attraction, especially dolphins, whales and whale shark. Following these, divers valued tropical reef fish (i.e. damsels – Pomacentridae, angels – Pomacanthidae and butterflyfishes – Chaetodontidae; 77.2%), other reef fish (74.2%) and small reef fish (72.9%) at higher levels (average rank of 4.1) compared with hard and soft corals, and most of the other reef fish categories (average rank of 4.0 by 70.9% respondents). Furthermore, 10.7% of the divers considered hard and soft corals to be unimportant or slightly important as opposed to only 7% for large reef fish or 6.9 % for small reef fish, which declared that these reef fish categories were unimportant for their diving experience.

The questions on the condition and management of the reefs was aimed at more experienced divers that have dived in southern Mozambique before 1999 (divers that potentially witnessed the effects of the 1998 bleaching event; Schleyer *et al.*, 1999). More than half of these (55.3%) stated that the reefs appeared the same and no changes were noted in the reef environment. Most divers also considered that the coral cover and the abundance of small reef fish had not changed. When asked about the abundance of large reef fish (rock cods, kingfishes), responses were mixed; a large proportion (44.4%) considered that there were less rockcod and kingfish, while 36.1% felt that the abundance of these fish had not changed. Those that noted changes in the overall reef environment were more experienced divers (highest level of diving qualification and mean number of logged dives). They also declared that both the coral cover and abundance of small reef fishes had remained the same, but they were unsure if the large reef fishes had decreased in abundance.

Attitudes towards reef conservation and the management of diving activities varied according to the nature and context of statements in the questionnaire (table 1). For example, the majority of respondents disagreed (average rank 2.3 on a 1–5 scale; 1 being strong disagreement) with the deployment of mooring buoys or with the idea that there is excessive diving in southern Mozambique (54.5% of the divers strongly disagreed or disagreed with the statement 'The reefs in southern Mozambique are too crowded'). Most divers agreed that excessive diving might damage reef communities (64.5%) and that a pre-dive briefing should emphasize environmentally friendly

Table 1. Percent agreement or disagreement of recreational SCUBA divers visiting southern Mozambican reefs, with attitude statements concerning management of the reefs. 1=Strongly disagree; 2=disagree; 3=neutral; 4=agree; 5=Strongly agree. (3Ts = don't Touch; don't Tease; don't Take).

	1	2	3	4	5	Mean rank
Emphasize 3Ts on pre-dive briefings	2.0	0.0	2.0	17.2	78.8	4.7
Can be damaged by excessive diving	5.1	10.2	19.4	27.6	37.8	3.8
Designated for specific uses	8.2	14.4	16.5	23.7	37.1	3.7
Artificial reefs should be deployed	19.4	7.1	20.4	27.6	25.5	3.3
Number of dives should be restricted	10.1	18.2	29.3	22.2	20.2	3.2
Mooring buoys should be provided	34.4	15.6	26.0	7.3	16.7	2.6
The reefs are too crowded	22.2	32.3	36.4	7.1	2.0	2.3

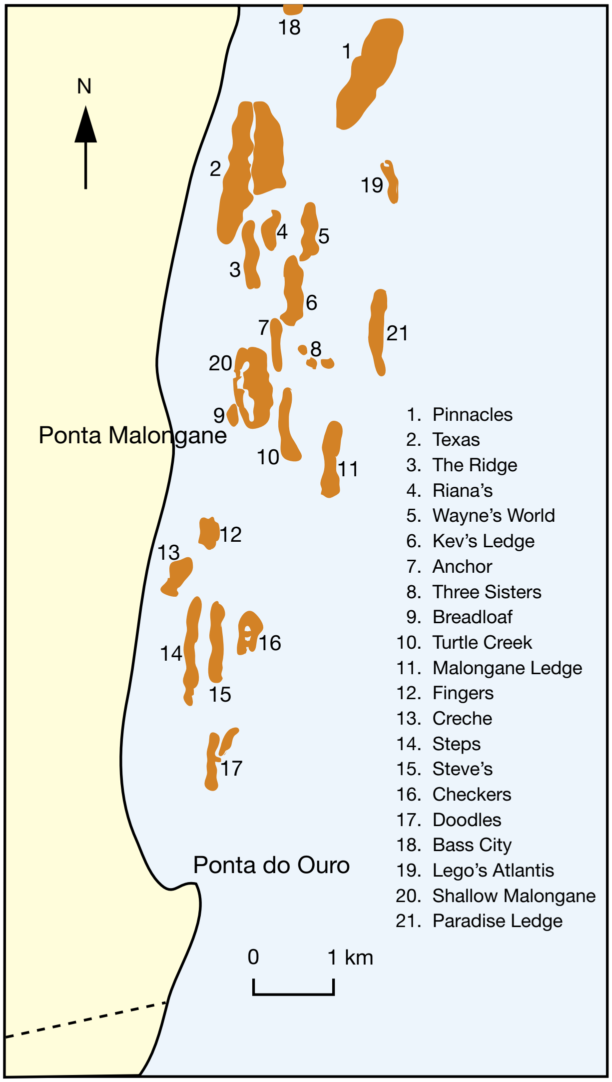

Figure 1. Schematic map of the most frequently dived reefs in southern Mozambique.

diving practices (96%), emphasising the 3T's ('do not Touch, do not Tease, and do not Take'). A clear-cut picture could not be drawn from responses regarding two management statements on restrictions on the number of dives per site and the deployment of artificial reefs, thus suggesting that these were not very popular among the respondents.

Diving Pressure

A total of 5 dive centres operated continuously throughout the study period (February 2001 to December 2002). Four of them were based in Ponta do Ouro and the fifth in Ponta Malongane. Two new operations initiated their activities in April (one based in Ponta do Ouro) and May 2002 (one based in Ponta Mamoli). The total number of dives for 2001 and 2002 was estimated at 104 500, with considerably more dives being executed in 2002 (62 000) when compared with 2001 (42 500).

A total of 1 526 launches (13 661 dives) were logged during the study period. Of the 23 reefs dived (see figure 1), 4 (Doodle, Creche, Kev's Ledge and Texas) were used the most, hosting more than 44% of the dives (table 2 on next page). This means that each of these 4 reefs was dived more than 7 000 times during the study period (February 2001 to December 2002) with over 12 000 dives at Doodles the most popular reef. Diving intensities are not presented for the reefs at Ponta Techobanine as they were not commercially dived for most of the study period due to the great distance from the dive centres at Ponta do Ouro and Ponta Malongane.

DISCUSSION

Virtually all the divers on the southern Mozambican reefs were South Africans. This is not surprising as the great majority of tourists (>95%) visiting the area originate from South Africa (Bjerner & Johansson, 2001; Abrantes & Pereira, 2003). Surprising, however, was the fact that a minimal number of Mozambique nationals participate in this recreational activity, probably due to levels of interest, and high cost.

Diving qualifications and experience were of a high standard and comparable to those previously found at Ponta do Ouro (Bjerner & Johansson, 2001) and in Texas, USA, (Ditton & Baker, 1999; Thailing & Ditton, 2001) but higher than those reported in Zanzibar and Mombasa (Westmacott *et al.*, 2000a) and Australia (Roberts & Harriot, 1995; Rouphael & Inglis, 1995; Harriot *et al.*, 1997). Divers were also committed to their sport, consid-

Table 2. Number of recreational dives conducted on southern Mozambican reefs during the study period. NA=refers to launches in which the number of divers was recorded but not the reef.

Reef	Dives logged	%	Estimated dives 2001	Estimated dives 2002	Total	Rank
Doodles	2 706	19.81	8 419	12 282	20 700	1
Creche	1 414	10.35	4 399	6 417	10 816	2
Kev's Ledge	980	7.17	3 047	4 445	7 497	3
Bass City	937	6.86	2 916	4 253	7 168	4
Texas	928	6.79	2 886	4 210	7 099	5
NA	818	5.99	2 546	3 714	6 257	6
Steps	817	5.98	2 542	3 708	6 250	7
Three Sisters	751	5.50	2 338	3 410	5 745	8
Anchor	699	5.12	2 176	3 174	5 347	9
Paradise Ledge	628	4.60	1 955	2 852	4 804	10
The Ridge	520	3.81	1 619	2 362	3 978	11
Breadloaf	461	3.37	1 432	2 089	3 526	12
Shallow Malongane	454	3.32	1 411	2 058	3 473	13
Checkers	419	3.07	1 305	1 903	3 205	14
Pinnacles	403	2.95	1 254	1 829	3 083	15
Malongane Ledge	244	1.79	761	1 110	1 866	16
Lego's Atlantis	215	1.57	667	973	1 645	17
Aquarium	92	0.67	285	415	704	18
Riana's Arch	88	0.64	272	397	673	19
Wayne's World	26	0.19	81	118	199	20
Padi	20	0.15	64	93	153	21
Fingers	15	0.11	47	68	115	22
Turtle Creek	14	0.10	43	62	107	23
Steve's	12	0.09	38	56	92	24
Total	13 661	100.00	42 500	62 000	104 500	

ering it an important outdoor activity. It might be argued that only experienced and more conscientious divers responded to the questionnaire, but similar proportions of experienced and novice divers responded to the questionnaire, suggesting that the survey data is representative of the recreational diving population of southern Mozambique. Diving experience in reef users is an important asset as far as the management and conservation of coral reefs is concerned. There is evidence that novice divers (<100 logged dives) cause more physical damage to corals than more experienced and conscientious ones (>100 logged dives; Davis *et al.*, 1995; Bjerner & Johansson, 2001).

'To look at fish and other marine life' was identified as the most important reason why divers chose to dive in southern Mozambique, with the most popular attractions being marine mammals (dolphins and whales), cartilaginous fish (sharks and rays) and marine turtles. These species enjoy worldwide popularity, being flag species for a number of marine conservation campaigns. Divers prefer reef fish (large or small tropical reef fish) when compared with benthic species (e.g. corals, sponges). Divers interviewed in Zanzibar and Mombasa by Westmacott *et al.* (2000a) and in the Caribbean by Williams & Polunin (2000) also regarded the variety and abundance of fish as the most important reef feature. This may be an impor-

Figure 2. Divers preparing to launch through the surf at Ponta Malongane, southern Mozambique. *Photo:* MARCOS A. M. PEREIRA.

Figure 3. Divers returning from a dive at Ponta do Ouro, southern Mozambique. *Photo:* ARTHUR FERREIRA/ÁFRICA IMAGENS.

tant issue to consider if diving pressure and fishing restrictions or zoning schemes are to be implemented.

Southern Mozambique seems to attract a loyal diver clientele. The percentage of respondents that have been visiting these reefs for more than four years totalled almost 40%. Despite the fact that tourism, and SCUBA diving in particular, were badly affected by the February 2000 floods in southern Mozambique, new divers are still attracted to this destination, with divers being 'very or extremely satisfied' with their diving experience.

This study also assessed divers' perceptions on reef condition and changes in coral cover and fish abundance, which can be used, with suitable care, as indicators of changes in reef condition and community structure (e.g. Hodgson, 1999; Uwate & Al-Meshkhas, 1999; Seaman *et al.*, 2003). Another important issue is that divers' personal perceptions as to whether reefs are changing or undergoing degradation may have an influence on the local economy. For example, Westmacott *et al.* (2000a, b) reported that coral bleaching influenced the choice of destination in 39% of the instances of divers visiting Mombasa who were aware of the 1998 bleaching event. They also noted that coral bleaching affected tourists' holiday satisfaction (with 47% of them considering dead corals the most disappointing experience), thus causing financial losses to the economies of Sri Lanka and the Maldives. Graham *et al.* (2001) recorded similar results in Palau, Micronesia.

In the present study, divers were in agreement regarding changes in the overall reef environment, with the majority of them noting no changes from before 1999 to the present. This concurs with findings that reefs in southern Mozambique were less impacted by coral bleaching in 1998 compared to reefs farther north (Schleyer *et al.* 1999; Motta *et al.*, 2000) and are likely to remain less vulnerable to climate change in the near future. It is quite worrying that the majority of divers (44%) stated that the large reef fishes (rock cods, kingfishes) had decreased since 1999. This could be attributed to fishing activity in the area, as bottom fishing or over-fishing on the reefs is widespread and illegal industrial vessels have frequently been seen around the reefs.

Some of the divers' attitudes towards the management of SCUBA diving and reef conservation in southern Mozambique were similar to those of divers in Texas (Ditton & Baker, 1999) and Bonaire Marine Park (Dixon *et al.*, 1993). They disagreed with the statement that the reefs were too crowded and agreed that the reefs should be designated for specific uses. The deployment of mooring buoys and artificial reefs (sunken ships) were not popular with divers in southern Mozambique, nor are they in South Africa, where rough sea conditions and relatively high costs preclude these interventions. Divers strongly agreed with the 3Ts (do not Touch, do not Tease and do not Take), suggesting they would accept and welcome awareness campaigns and pre-dive briefings (Medio *et al.*, 1997) on environmentally-friendly diving practices.

Previous estimates on the number of dives in southern Mozambique have varied greatly, from 30 000–40 000 in 1996 (Robertson *et al.*, 1996) to 80 000–90 000 in 1999 (H. Motta, WWF Mozambique, pers. comm.) and 50 000–63 000 dives in 2001 (Bjerner & Johansson, 2001). In the present study, the diving pressure was estimated at 42 500 dives in 2001 and 62 000 dives in 2002. The low number registered in 2001 is indicative of the impact of massive floods that occurred throughout southern Mozambique in February 2000, causing widespread destruction in the basic infrastructure with consequent bad publicity that resulted in a decline in tourism. In 2002, better marketing and a decline in the value of the South African Rand, causing more South Africans divers to dive 'locally' rather than travel overseas for their diving vacations, resulted in higher numbers. It thus appears that the diving pressure in southern Mozambique is not excessive, however it may have have reached its 'carrying capacity', as the present tourism facilities such as accommodation, roads, electricity and medical facilities appear to be saturated.

As noted above, most diving takes place on about 20 reefs with more than 50% of the dives being concentrated on 5 of them (see table 2). In nearby Sodwana Bay, South Africa, 85% of more than 100 000 dives per year (Schleyer, M., 2004, pers. comm.) are carried out on Two-mile Reef, the closest of four reefs used by divers, where significant diver damage has been noted (Schleyer & Tomalin, 2000). Reef features such as the abundance and diversity of fish, distance from the shoreline and depth are some of the most important factors in the selection of dive sites by both dive operators and divers, focusing most pressure on a small number of sites.

Interestingly, in spite of the high pressure at favoured sites, evidence of damage on similar reefs in South Africa, and the high levels of experience and awareness in the diver community, divers did not accept that southern Mozambican reefs are too crowded. As a result, they were reluctant to endorse management interventions to limit crowding and damage, such as placement of mooring buoys and artificial reefs, but were amenable to raising awareness about more environmentally friendly diving practices. The results of this study suggest there is a need to alleviate the diving pressure on the southern Mozambican reefs through a more balanced distribution of the diving intensity, better awareness programmes on sustainable diving practices and perhaps the deployment of artificial reefs (van Treeck & Schuhmacher, 1999; Wilhelmsson *et al.*, 1998).

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Resilience of Zooxanthellae to Bleaching Stressors:

An Experimental Study

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key words: coral bleaching, resilience, symbiosis, zooxanthellae

ABSTRACT

Resilience, in the context of the capacity for populations of zooxanthellae to recover after coral bleaching, is a little-studied but crucial aspect of coral responses to bleaching stressors. This study investigated resilience to experimental bleaching induced by elevated temperature and darkness in the scleractinian species *Porites cylindrica*. Resilience, as assessed by changes in densities of zooxanthellae on termination of the stressor, was influenced by the nature and duration of the stressor. Zooxanthellae in corals subjected to relatively long durations of darkness were more resilient than those in corals treated for shorter durations. The opposite trend was evident for zooxanthellae in corals exposed to elevated temperature. The basis for these contrasting results may lie in different endodermal processes occurring during treatment with the two stressors. Localised coral bleaching occurs in response to a range of stressors, and this study has strong implications for recovery of corals in the field after natural bleaching incidents. The relevance of these experiments on resilience to field bleaching events is discussed.

INTRODUCTION

Bleaching, the paling of zooxanthellate tissues resulting from the drastic decline in densities of zooxanthellae (e.g. Hoegh-Guldberg & Smith, 1989) and/or the loss of photosynthetic pigments (e.g. Kleppel *et al.*, 1989; Szmant & Gassman, 1990) has long been recognized as a generalised response of corals and allied marine Cnidarians to stress (Glynn, 1993; Brown, 1997). As such, it is elicited by a variety of environmental and laboratory stressors. Greatest emphasis has been placed on identifying the physiological determinants of bleaching in response to elevated seawater temperatures. This is due to the fact that elevated sea surface temperatures (SST), often combined with increased solar radiation (Glynn, 1993; Rowan *et al.*, 1997; Brown *et al.*, 2002), has led to the mass bleaching and mortality of reef corals after the 1980's (Glynn, 1993; Brown, 1997; Hoegh-Guldberg, 1999), with severe impacts to tropical coastal communities (Hoegh-Guldberg, 1999; Wilkinson, 1999). Nonetheless, localised bleaching in the field has been reported to occur in response to a range of stressors, including sedimentation (Bak, 1978), oil pollution (Guzman *et al.*, 1991), reduced salinity (Goreau, 1964), reduced water temperature (Kobluk & Lysenko, 1994) and aerial exposure (Yamaguchi, 1975). The underlying mechanisms of bleaching in response to the majority of known environmental triggers remain poorly defined (Douglas, 2003). For any given zooxanthellate symbiosis, the different triggers of bleaching are predicted to have different impacts on the zooxanthella, the animal host, and symbiotic interactions between the two partners (Douglas, 2003). Thus, the mechanisms and symptoms of bleaching are likely to vary with the specific trigger. Consequently, recovery processes are also likely to be influenced by the nature of the bleaching stressor.

Two bleaching-stressors that have been widely used to induce bleaching in laboratory studies are elevated seawater temperatures (e.g. Gates *et al.*, 1992; Warner *et al.*, 1996; Perez *et al.*, 2001; Ralph *et al.*, 2001; Dunn *et al.*, 2002) and prolonged incubation under darkness (e.g. Wang & Douglas, 1998; 1999; Titlyanov *et al.*, 2002; Lewis & Coffroth, 2004). Bleaching arising from exposure to elevated temperatures has most frequently been attributed to damage to the photosynthetic apparatus of the zooxanthellae (Iglesias-Prieto *et al.*, 1992; Warner *et al.*, 1996; Warner *et al.*, 1999; Jones *et al.*, 1998; Jones *et al.*, 2000). Laboratory investigations have also demonstrated damage to host tissues, particularly in the endoderm, during periods of exposure to elevated seawater temperatures (Gates *et al.*, 1992; Dunn *et al.*, 2002). These findings are consistent with reports describing the histology of corals in the aftermath of natural temperature-mediated bleaching incidents (Lasker *et al.*, 1984; Glynn *et al.*, 1985; Hayes & Bush, 1990). In contrast, prolonged exposure to darkness is not known to cause direct damage either to the photosynthetic machinery of zooxanthellae or animal tissues.

The onset of bleaching is thought to be a function of cumulative heat stress, i.e. not only is the magnitude of the stressor (e.g. positive SST anomaly) important in the incidence of bleaching, but so too is the duration for which it persists (Gleeson & Strong, 1995; Podestá & Glynn, 1997; Winter *et al.*, 1998). High values for indices assimilating duration and overall magnitude of the bleaching stressor, for example degree heating weeks (Gleeson & Strong, 1995) and degree heating days (Podestá & Glynn, 1997), were shown to correlate well with the incidence of bleaching. Critical values for such indices have been proposed as thresholds in excess of which bleaching may occur at the respective locations (Gleeson & Strong, 1995).

The major aim of the experiments described here was to investigate the influence of the nature of the bleaching stressor on recovery of populations of zooxanthellae in

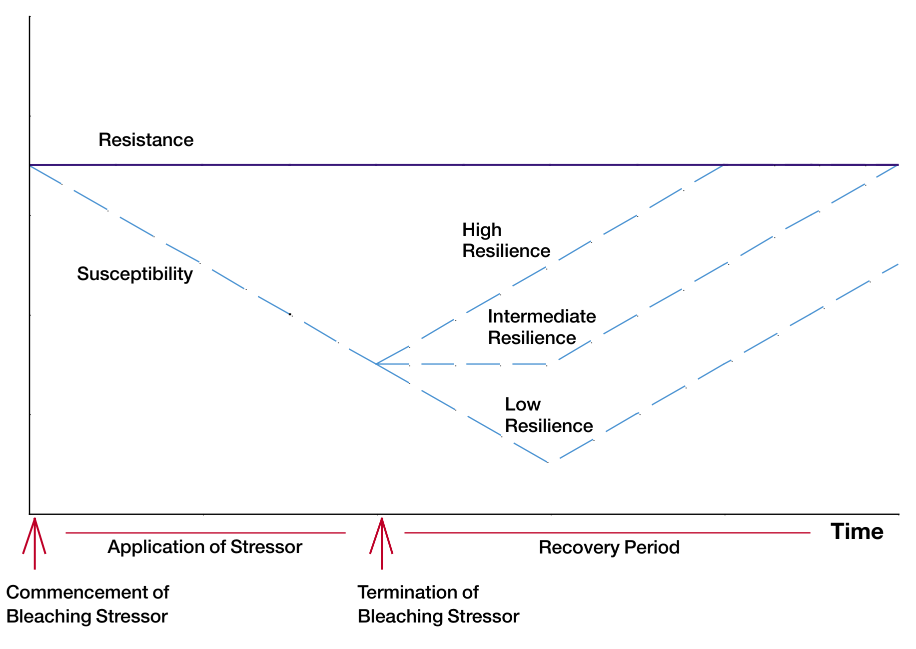


Figure 1. Key responses of the populations of zooxanthellae of coral colonies to bleaching stressors.

bleached corals. Specifically, does the nature of the bleaching stressor influence resilience, i.e. the capacity to recover from bleaching? For the purposes of this study, resilience is defined as the capacity of populations of zooxanthellae in a bleached coral colony to recover from a decline in population density after the application of an external bleaching stressor is terminated. Faster recovery is characteristic of greater resilience whereas slow recovery is a feature of diminished resilience. This is illustrated in figure 1. Elevated seawater temperature and prolonged darkness were selected as bleaching stressors based on the different impacts they have on zooxanthellae and animal hosts, and on their widespread use in laboratory studies on bleaching. A secondary aim was to establish whether the duration over which a stressor is applied influences resilience to bleaching.

MATERIALS AND METHODS

Coral Collection and Maintenance

Experiments were conducted in Mombasa, Kenya. The coral species utilised was *Porites cylindrica* Dana 1846, collected at low tide at a depth of 0.3 m from Kanamai Reef (3.97°S, 39.58°E). Colonies selected for study were separated by at least 5 m. Fragments measuring approximately 4–5 cm in length were broken off parent colonies and transported to the laboratory submerged in a shallow tub of seawater. Coral fragments were glued (Superglue, Alpha Techno Co., Japan) at their base onto dead coral stones. Fragments were maintained indoors, under natural light (12 hour dark/light cycle) in plastic seawater tanks, each with a capacity of 10–12 l. The seawater in the tanks was aerated continually and exchanged daily. Filamentous and turf algal growth were periodically scraped off the bases of coral fragment using a soft bristle toothbrush, and the walls and bottoms of all experimental tanks were similarly cleaned regularly. The positions of tanks were changed weekly. All fragments were maintained in these conditions for at least one week before experiments commenced, in order to allow corals to acclimate to laboratory conditions, and to identify any diseased or damaged fragments, which were removed.

Measurements of Zooxanthellae Density

The density of zooxanthellae, expressed as number of cells per square centimetre of coral skeleton, was determined using the 'aluminium foil' technique of Marsh (1970). The average number of dividing cells for two separate counts of 500 cells was made in order to determine the percentage of dividing cells. Measurements of the density of zooxanthellae and division rates commenced approximately two hours after dawn.

Experimental Designs

Experiment 1 was carried out in May–July 2003. Dark-treatments were commenced on different days, but terminated on the same day, allowing for simultaneous measurements to be made on designated days post-exposure to light on fragments from all treatment tanks. Eighty fragments of each of two *P. cylindrica* colonies were collected from Kanamai, and 10 randomly selected fragments of each colony were divided into 8 tanks. After an initial acclimation period of 7 days, 2 tanks were selected as 'controls', and 2 tanks were dark-treated for 21 days. Seven days and 14 days later, 2 tanks were dark-treated for 14 days and 7 days respectively. Dark treatment required enclosure in opaque heavy-duty black polythene, with no changes to aeration and seawater exchange. Immediately on removal of the polythene sheet (day 0), the density of zooxanthellae and the percentage of dividing cells in one fragment from each colony in each treatment tank was recorded and again on days 7, 21 and 42. One fragment per colony in each control tank was assayed at the start of the experiment, and at four-week intervals thereafter.

Experiment 2 was carried out in May–August 2003. Sixty fragments from each of 2 coral colonies were collected from the reef, and 10 randomly selected fragments from each colony were divided into 6 tanks. After an acclimation period of 24 days, 2 tanks were selected as 'controls', and the coral fragments in 2 'treatment' tanks were transferred to a water bath for 96 hours. The temperature in the water bath was gradually raised over 4–6 hours from ambient (approximately 28°C) to 32.5°C using a filament immersion heater. Aeration and seawater exchange was maintained throughout treatment. Two days after the experiment started, the coral fragments in the remaining pair of 'treatment' tanks were temperature-treated in the water bath at 32.5°C for 48 hours. Treatment was terminated simultaneously for both durations of temperature-treatment, and the fragments were transferred back to their respective 'treatment' tanks. Immediately on termination of temperature-treatment (day 0), the density and percent of dividing zooxanthellae in one fragment from each colony in each treatment tank was measured, and again on days 7, 21, 42 and 63.

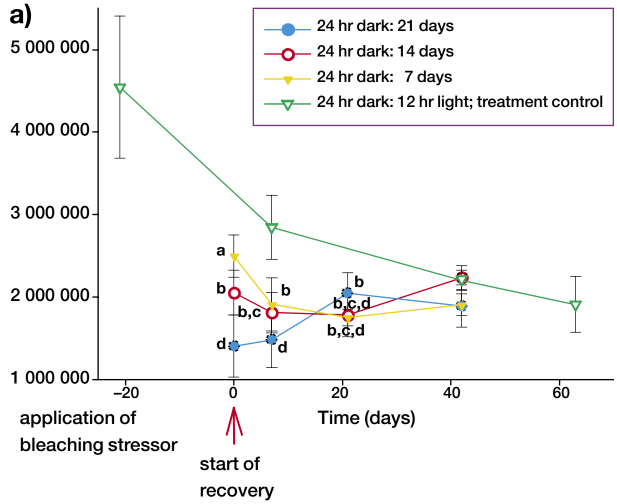
Statistical Analysis

Data were tested for assumptions of *normal distribution* and *homogeneity of variances* respectively, before applying ANOVA, followed by post-hoc analysis with Fisher's LSD test. Percentage data were arcsine-square root-transformed prior to conducting ANOVAs. Significant differences were tested for at the $p = 0.05$ level. Statistical analyses were performed using MINITAB (Version 10.1) software.

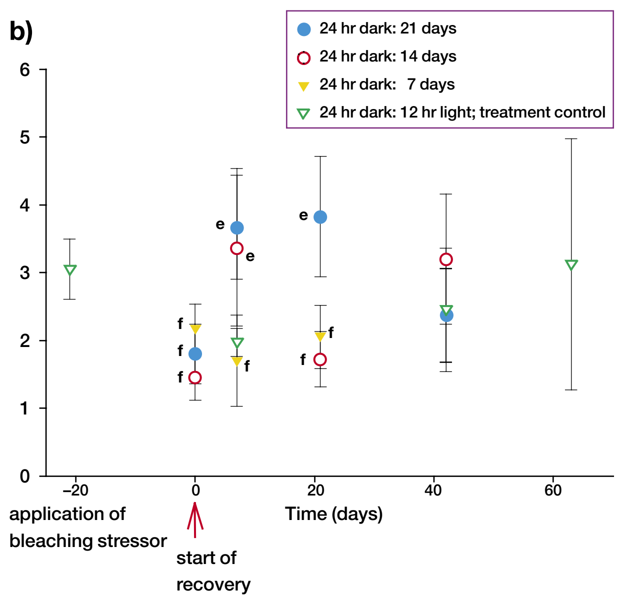
RESULTS

Experiment 1: Resilience of Zooxanthellae to Bleaching Induced by Darkness

Treatment corals underwent a progressive loss of zooxanthellae (and corresponding pigmentation), relative to control corals, with increased duration of darkness (figure 2). The density of zooxanthellae in corals that had been maintained in darkness for the longest duration (i.e. 21 days) was approximately 39% of that in control corals at the end of the dark period. Changes in the densities of zooxanthellae during the first 21 days of recovery were dependent on the number of days that corals were



Factor	D.F.	F Ratio	P value
Treatment	2	6.58	<0.01**
Time	2	2.47	0.103
Interaction	4	6.60	0.001***
Error	27		



Factor	D.F.	F Ratio	P value
Treatment	2	9.72	0.001***
Time	2	8.61	0.001***
Interaction	4	7.22	<0.001***
Error	27		

Figure 2. Densities of zooxanthellae (mean values ±1 SD) (a) and the percentage of dividing zooxanthellae (b) in corals recovering from bleaching elicited by varying durations of darkness (24 hr dark: 21 days, 14 days, 7 days) and in control corals (12 hr light: 12 hr dark, 21 days). Arrows indicate when the treatment was terminated. Results of a two-way ANOVA comparing changes in the density of zooxanthellae and percentage of dividing cells over the recovery interval of 21 days after corals were returned to ambient light are shown below the respective graphs. Measurements of the percentage of dividing cells in treated corals were arcsine-square root transformed prior to conducting the analysis. Letters indicate homogeneous subsets from post-hoc analysis with Fisher's LSD test.

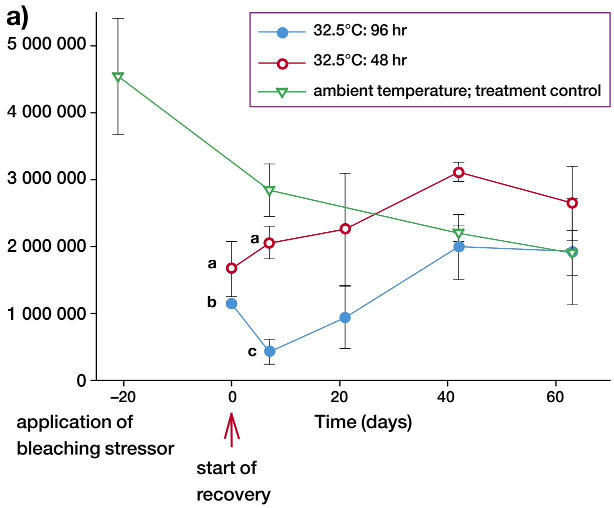
maintained in darkness (two-way ANOVA, interaction term p = 0.001). The least resilient zooxanthellae were those in corals maintained in darkness for 7 days. These underwent a further decline in zooxanthellae densities between recovery days 0 and 7 (2.50 x 10^6 cells cm^{-2} to 1.91 x 10^6 cells cm^{-2}, p<0.001), with no significant changes thereafter. Corals treated for 14 days did not exhibit significant changes in the densities of zooxanthellae over the recovery period analysed. Corals held in darkness for 21 days displayed significant increases in the densities of zooxanthellae between recovery days 7 (1.47 x 10^6 cells cm^{-2}) and 21 (2.05 x 10^6 cells cm^{-2}), showing the highest resilience of zooxanthellae populations of all treatments.

Percentages of dividing zooxanthellae, which varied between 1.5% and 3.8%, are shown in figure 2b. A two-way ANOVA was carried out on cell division data for the first 21 days of recovery. Results show that the rate of cell division over the period analysed was dependent on treatment (interaction term p <001). Corals maintained in darkness for 7 days did not display any significant changes in the percent of dividing zooxanthellae, remaining near control levels of approx. 1.5–2%. Those subjected to 14 days of darkness exhibited an increase in the percent of dividing cells at day 7 (3.4%), followed by a decline to 1.7% on day 21. Those subjected to 21 days of darkness exhibited an increase in the percent of dividing cells at days 7 and 21, to 3.7 and 3.8%, followed by a decline to <2.5% on day 42.

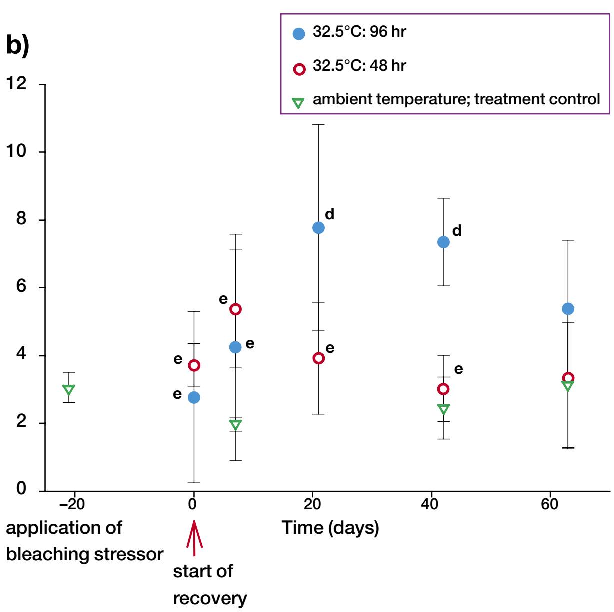
Experiment 2: Resilience of Zooxanthellae to Bleaching Induced by Elevated Seawater Temperature

At the start of recovery, treatment corals had densities of zooxanthellae that varied between approximately 47% (for 48 hour treatment corals) and 32% (for 96 hour treatment corals) of that in control corals (figure 3 on next page). There was a highly significant interaction for the first 7 days of recovery: zooxanthellae in corals treated for 96 hours displayed a significant decline in density between days 0 (1.15 x 10^6 cells cm^{-2}) and 7 (0.43 x 10^6 cells cm^{-2}), while there were no significant changes to the density of zooxanthellae in 48 hour-treated corals. This suggests that changes in the density of zooxanthellae in the initial period following exposure to ambient temperature was dependent on the length of time during which corals were exposed to increased seawater temperatures. However, over a longer recovery phase (days 0–21), two-way ANOVA showed non-significant interaction between treatment and time ($F_{2, 18}$ = 3.34, p = 0.058, data not shown). By day 42 of recovery however, the 48 hour treatment corals had significantly higher densities of zooxanthellae than either the 96 hour treatment corals or control corals, both of which did not differ significantly at that stage (one-way ANOVA: $F_{2, 9}$ = 15.86, p <0.01).

The percent of dividing zooxanthellae is shown in figure 3b. The interaction between treatment and time in the two-way ANOVA ($F_{2, 18}$ = 2.90, p = 0.081) was not significant for the recovery days 0-21. When data were analysed for recovery days 0–42 however, there was a significant interaction term. The percent of dividing zooxanthellae increased markedly for corals treated for 96 hours, from a mean of approximately 2.8% (± 2.5 SD) on day 0, to a mean of approximately 7.8% (± 3.0 SD) on day 21. These were more than double the maximum division rate observed for Experiment 1 (maximum mean of



Factor	D.F.	F Ratio	P value
Treatment	1	70.71	<0.001***
Time	1	1.72	0.215
Interaction	1	18.85	0.001***
Error	12		



Factor	D.F.	F Ratio	P value
Treatment	1	2.24	0.147
Time	3	2.24	0.109
Interaction	3	4.37	<0.05*
Error	24		

Figure 3. Densities of zooxanthellae (mean values ±1 SD) (a) and the percentage of dividing zooxanthellae (b) in corals recovering from elevated temperature-induced bleaching (32.5°C: 96 hr, 48 hr) and in control corals (ambient temperatures). Arrows mark the start of the recovery period, i.e. when treatment was terminated. Results of a two-way ANOVA comparing changes in the density of zooxanthellae in treatment corals during the first 7 days recovery after returning to ambient temperatures are shown below the respective graph. Percentage data were analysed for the first 42 days of recovery and were arcsine-square root-transformed prior to the use of ANOVA. Letters indicate homogeneous subsets from post-hoc analysis with Fisher's LSD test.

3.8%) for dark-treated corals. The division rates of 48 hour-treated corals did not change significantly over the period for which the analysis was performed.

DISCUSSION

Processes in Recovery from Bleaching

Corals that have undergone bleaching may recover their zooxanthellae through three mechanisms:

- an increased rate of cell division in zooxanthellae, as has previously been reported for bleached corals (Fitt *et al.*, 1993; Jones & Yellowlees, 1997), in combination with:
- the division of infected host cells and redistribution of their resident zooxanthellae to daughter cells (Berner *et al.*, 1993; figure 4a); and/or
- the expulsion by exocytosis of zooxanthellae from infected endoderm cells into the gastric cavity, and their subsequent uptake by uninfected host cells (Jones & Yellowlees, 1997). These could be vacant cells that had lost zooxanthellae during bleaching but that remain competent (i.e. can be reinfected), and/or newly differentiated from stem cells replacing host cells lost during the bleaching event (figure 4b).

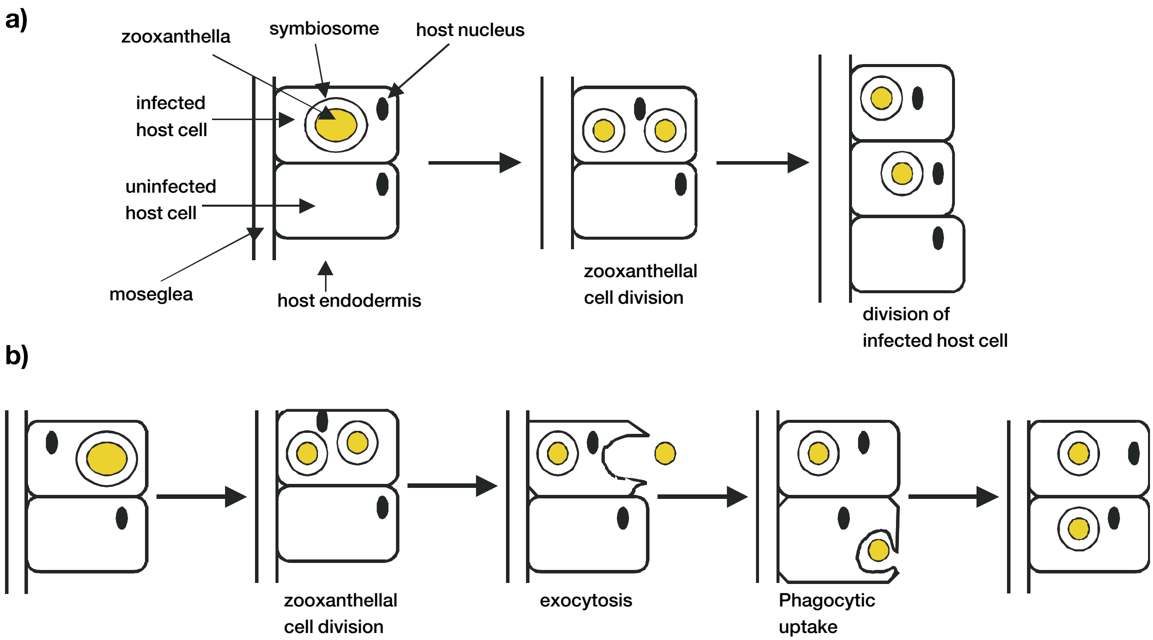


Figure 4. Processes occurring in the host endodermis during recovery from bleaching. a) The division of host cells and distribution of their resident zooxanthellae to daughter cells. b) The division, expulsion and subsequent uptake of zooxanthellae.

Recovery from Bleaching Induced by Darkness

An important consequence of prolonged exposure of corals to darkness is the reduction in cell division rate of residual zooxanthellae, without a corresponding decline in the growth and division of host cells. This is indicated partly by the variation in the rates of division of zooxanthellae in corals subjected to different durations of darkness, immediately on their return to ambient light. For instance, in Experiment 1, the zooxanthellae in corals treated with darkness for a relatively short period had a higher proportion of dividing cells on day 0 than those treated for longer periods (7 days: mean 2.2%;14 days: 1.5%; 21 days: 1.8%). The primary outcome of the contrasting effects of darkness on the division of host cells and zooxanthellae is predicted to be a change in the ratio of uninfected host cells to residual zooxanthellae. The longer the exposure of corals to darkness, the larger this ratio is likely to be (figure 5 on next page).

Factors that influence the rates of division of zooxanthellae include the availability of space (Smith & Muscatine, 1999), host-derived nutrients including nitrogen (Falkowski *et al.*, 1993; Muscatine *et al.*, 1998) and/or possibly carbon (Douglas, 1994), and light. These experiments were conducted indoors, where the light levels, albeit unmeasured, were low in comparison to that which corals are likely to have experienced in their natural environment. The extent to which these factors limit the division of zooxanthellae is directly related to the density of zooxanthellae in coral tissues. In turn, zooxanthellae density, as a consequence of the inhibitory effect of darkness on zooxanthellae division, was inversely proportional to the length of exposure to darkness. It follows therefore, that the rate of zooxanthellae division in corals subjected to relatively short durations of darkness (occurring at relatively high densities) would undergo a decline, thereby bringing about a *density-dependent* reduc-

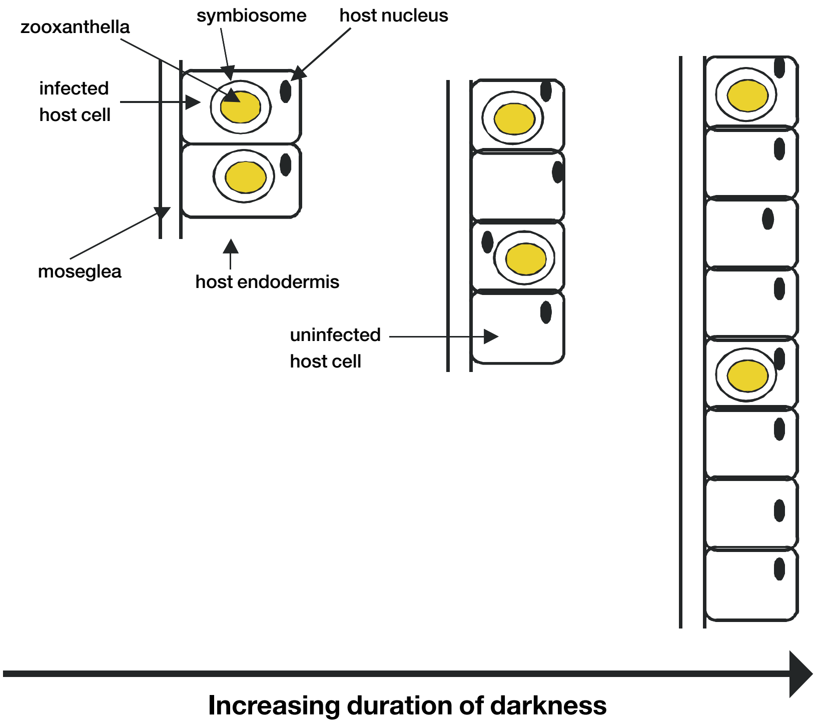


Figure 5. The predicted impact of duration of darkness on the ratio of uninfected host cells to zooxanthellae.

tion in zooxanthellae densities. Conversely, the above-mentioned factors, and in particular available space, i.e. the ratio of uninfected host cells to residual zooxanthellae, would not have limited the division of zooxanthellae in corals that were kept in darkness for relatively long periods (occurring at relatively low densities). Under these conditions, zooxanthellae would proliferate. Their release into the gastric cavity, and subsequent uptake by uninfected host cells would bring about the repopulation of bleached tissues, as would an elevation in the rates of division of infected cells. The observed data on the division of zooxanthellae during the early stages of recovery are consistent with this explanation. For instance, in Experiment 1, the percent of dividing zooxanthellae significantly increased between days 0 and 7 in corals subjected to treatment with darkness for 14 days (mean of 1.5% to 3.4%) and 21 days (mean of 1.8% to 3.7%), but declined, although not statistically significantly, for those in corals incubated under darkness for a period of 7 days (mean of 2.2% to 1.7%). In the context of the present study using darkness as a bleaching stressor, the observed changes in zooxanthellae density for the different levels of treatment would have been defined as elevated (21 days) or diminished (7 days) resilience. Resilience however, may not be an appropriate term to describe the *density dependent regulation* of zooxanthellae populations during exposure of corals to darkness, as the observed dynamics might not relate precisely to the capacity to recover from bleaching. This can be developed into a testable hypothesis.

Recovery from Bleaching Induced by Elevated Temperature

The responses of zooxanthellae populations to treatment with elevated temperature displayed the opposite trend to those of zooxanthellae subjected to darkness. Not only were the zooxanthellae in corals that were exposed to elevated temperature for a relatively short duration (48 hours) more resilient to bleaching than those exposed for a longer duration (96 hours), but they also exhibited an 'overshoot' of populations relative to treatment controls (see figure 3). In contrast, zooxanthellae in corals treated for 96 hours continued to undergo a decline in population density on their return to ambient temperatures. The zooxanthellae densities of corals exposed to increased temperatures for 96 hours did not exceed those in control corals at any time during the experiment.

Damage to the photosynthetic apparatus of zooxanthellae is widely believed to be the primary determinant of bleaching during exposure to elevated seawater temperatures (Jones *et al.*, 1998; Warner *et al.*, 1999; Jones *et al.*, 2000). Primary cellular mechanisms for the ensuing decline in zooxanthellae densities include the degradation of zooxanthellae *in situ* and the release of zooxanthellae into the gastric cavity by exocytosis (Brown *et al.*, 1995). Some laboratory studies have recently challenged this perspective. Notably, the study by Dunn and colleagues (2002) using the sea anemone *Aiptasia* sp., demonstrated that the swelling and rupture of host endodermal cells caused by tissue necrosis during hyperthermal treatment was a key factor mediating the release of apparently healthy zooxanthellae into the gastric cavity. The authors pointed out that an implication of necrotic damage (as opposed to programmed cell death, PCD) was that it was extrinsically mediated, and not under direct host control. Necrosis and PCD of zooxanthellae, resulting in their degeneration *in situ*, did however accompany damage to host tissues after prolonged exposures to elevated temperatures. Similarly, another laboratory study (Ralph *et al.*, 2001) indicated that the zooxanthellae released by the coral *Cyphastrea serailia* during temperature mediated bleaching (at 33°C) were photosynthetically competent, and only suffered from impairment to photosynthesis after the temperature was greatly elevated (to 37°C). The tissue necrosis of host endoderm indicated by laboratory studies on temperature mediated bleaching has also been observed during histological examination of corals that had undergone elevated temperature-mediated bleaching in the field (Lasker *et al.*, 1984; Glynn *et al.*, 1985). Zooxanthellae of normal appearance were observed in all but the most affected specimens (Glynn *et al.*, 1985).

An alternative mechanism by which the structural integrity of host endodermis can be compromised is the detachment and release of intact endoderm cells with their entire complement of zooxanthellae into the gastric cavity. This has been proposed, based on laboratory experiments, as a dominant mechanism for temperature-induced bleaching (Gates *et al.*, 1992; Sawyer & Muscatine, 2001). A combination of epifluorescence and electron microscopy were used to detect detached viable host cells enclosing symbiosomal membrane-bound zooxanthellae (Gates *et al.*, 1992). The host membranes surrounding zooxanthellae disintegrated shortly thereafter.

In the present study, the underlying mechanisms and symptoms of temperature mediated bleaching were not identified. However, immediately on termination of treatment, the zooxanthellae in corals subjected to increased seawater temperatures for 96 hours were dividing at a mean of 2.8%, not significantly different from those in corals exposed to elevated temperature for 48 hours. This rose sharply to 4.3% by day 7 of recovery, and further still to a maximum mean of 7.8% on day 21 (significantly higher than that of 48-hour treatment corals; see figure 3b). During the same period zooxanthellae densities in these corals significantly declined between days 0 and 7, before slowly increasing. This recovery profile is not consistent with damage to the photosynthetic machinery of the zooxanthellae, but is in line with the continued disruption of host endodermis and subsequent release of zooxanthellae into the gastric cavity in the period immediately after return to ambient temperatures. The exceptionally high proliferation rates of zooxanthellae on day 21 suggest that a large proportion of zooxanthellae counted were inside the gastric chamber and free of host suppression of their growth and division (Suharsono & Brown, 1992; Douglas, 1994; Jones & Yellowlees, 1997), although this was not established.

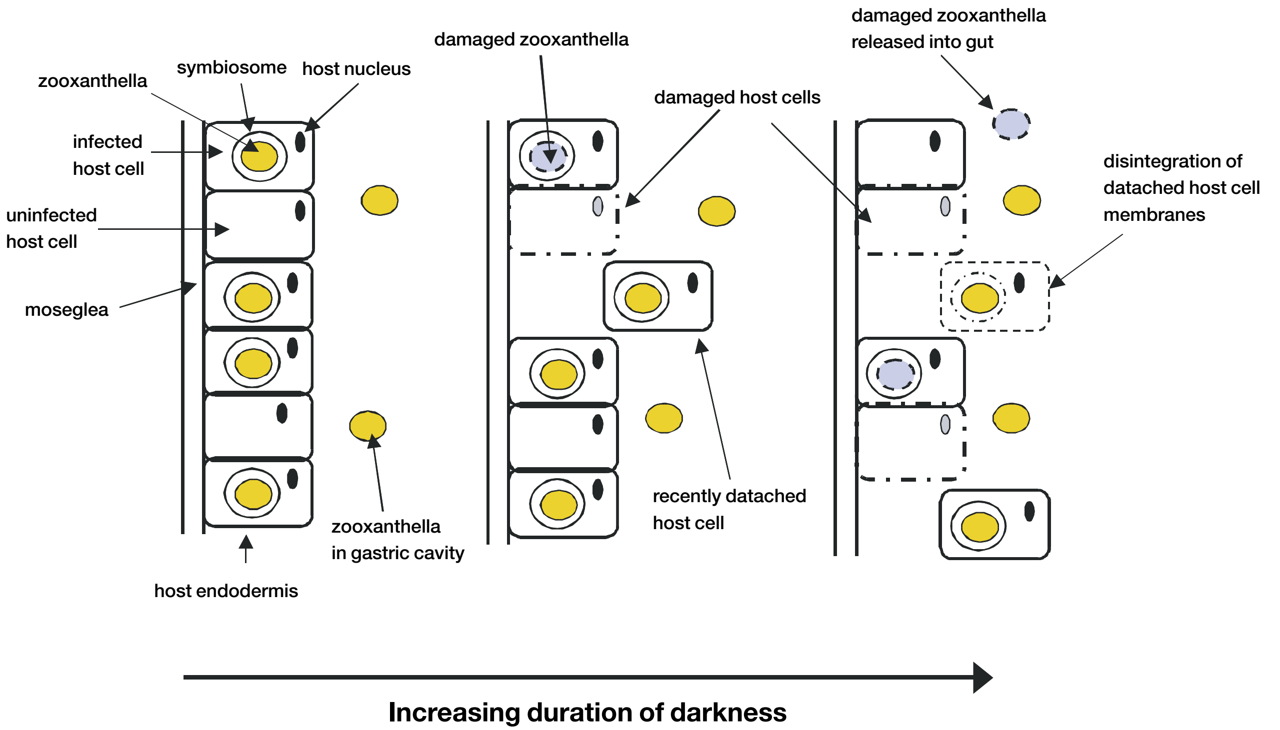


Figure 6. The theoretical impact of duration of elevated temperature on the availability of competent host cells and competent zooxanthellae in a section of coral endoderm tissue.

It is not disputed that damage to photosynthesis occurs when corals are subjected to elevated seawater temperature, especially during prolonged (Dunn *et al.*, 2002) or extreme (Ralph *et al.*, 2001) exposures. Incontrovertible too, is the fact that host tissues, particularly the endodermis, undergo damage during hyperthermic treatment. Frequently, inadequate consideration is given to repair processes in host tissues when attempting to understand factors that either promote or retard recovery of zooxanthellae populations after bleaching. These are almost certainly not instantaneous, and might take days and perhaps even weeks to occur under favourable conditions. Figure 6 is a diagrammatic representation of the theoretical impact of the length of exposure to elevated seawater temperature on host cells and the residual zooxanthellae in a section of the host endodermis.

After a relatively short exposure to elevated temperatures, not only are there a greater number of competent zooxanthellae to proliferate but there are also a larger number of competent host cells available to acquire the dividing zooxanthellae. On the other hand, the longer the period of exposure to elevated temperature, the more vulnerable the host endodermis is to structural damage, exacerbated by photosynthetic damage to zooxanthellae, and the greater the delay in recovery of zooxanthellae-populations, i.e. diminished resilience.

Localised bleaching of reef corals is known to occur in response to a range of environmental stressors, and these experimental studies provide indirect evidence that the resilience of zooxanthellae populations of bleached corals in the field are likely to be influenced by the nature and the duration of the stressor.

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Community-Based Monitoring of Coral Reef Resource Use

in Agatti Island, Union Territory of Lakshadweep, India

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key words: coral reef, reef fishery, resource use, participatory monitoring, Agatti Island, Lakshadweep

INTRODUCTION

Agatti is an atoll island in the Indian Union Territory (UT) of Lakshadweep, a coral archipelago off the west coast of India at the northern end of the Laccadive-Maldive-Chagos ridge. Located at 10° 51' N and 72° E it is the westernmost island in the UT Lakshadweep (Dept of Planning and Statistics, 2000). The island stretches 7.2 km in a roughly north-south direction, with a width varying from 1000 m at its widest point in the north to less than 100 m at its narrowest point in the south. A lagoon, which is wider and deeper (c. 2–5 m at low tide) on the western side than on the eastern side, is enclosed by a coral reef which surrounds the island (figure 1 on next page) (Hoon *et al.*, 2002). The total estimated land area is 2.7 km^2, lagoon area 12 km^2 and reef flat area 14.4 km^2 (Bahuguna & Nayak, 1994).

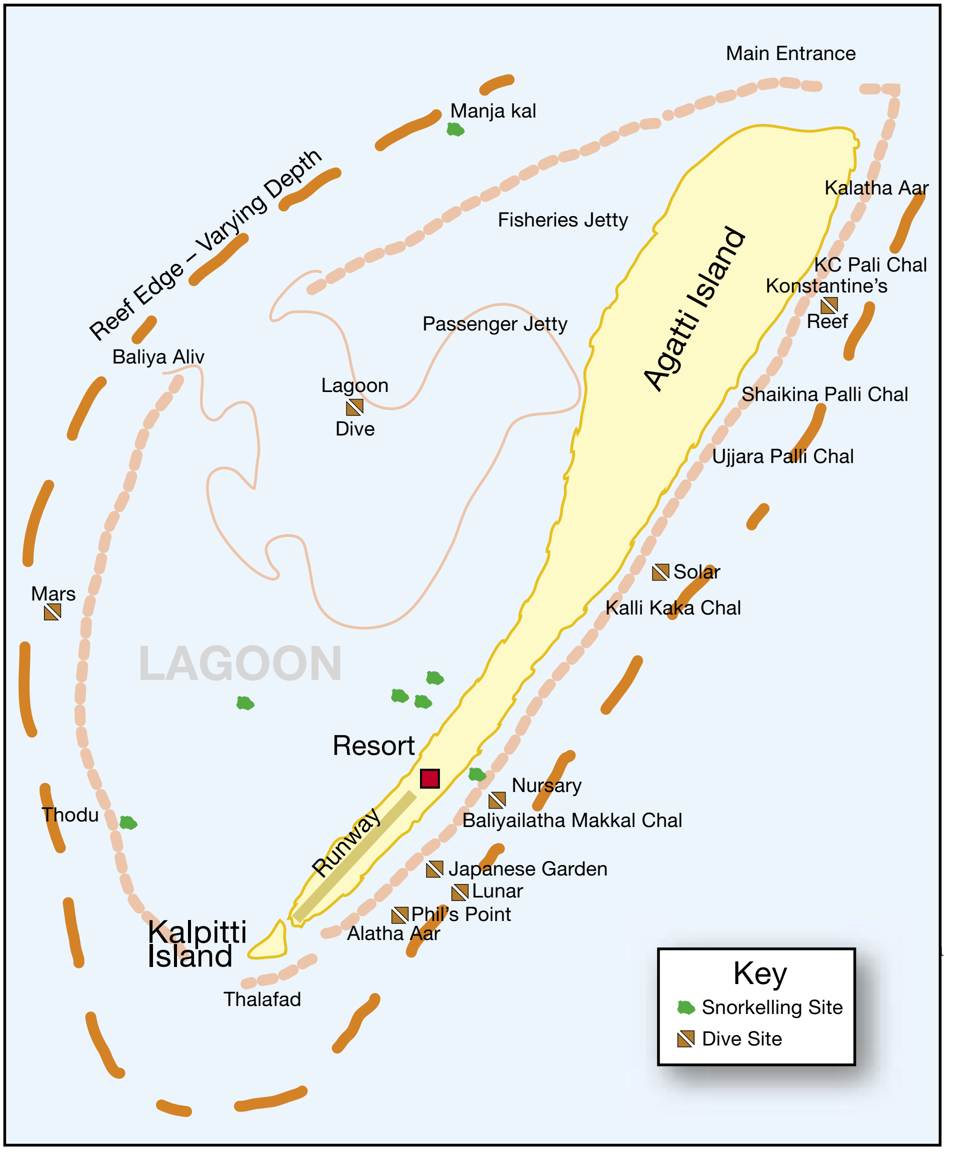
In the year 2001, Agatti had a total population of 7 072 and a population density of 1 842 km^{-2} (Dept. of Planning and Statistics, 2002)[1]. A detailed socio-economic assessment from the area, covering livelihood aspects, fishing methods, resource governance patterns, indigenous knowledge, site use and resource perceptions, shows that use of reef resources, such as reef gleaning and fishing, still constitutes a subsistence income for more than 50% of the population on the island and provides about 90% of the protein intake (Hoon *et al.*, 2002; Hoon, 2003). In addition to the reef around Agatti and Kalpitti, the traditional fishing and land rights areas of the people of Agatti include the submerged atoll Perumal Par to the northwest of Agatti, and the Bangaram lagoon, encompassing the islands Bangaram, Tinnakara, Parelli I, II, and III. Parrelli III was washed away during a cyclone in 1974 (Hoon *et al.*, 2002). All the areas are used extensively.

In an effort to conserve and protect coral reefs and reef resources, the Department of Environment and Forests of India and the Administration of Lakshadweep issued notifications in July and December 2001 restricting use of a number of marine species (Lakshadweep Gazette, 2001a, b). The July 2001 notification bans all extractive use of scleractinian corals, antipatharians, gorgonians, milleporids and *Tubipora musica*, and also several other key resource species such as all sharks and rays, 52 species of mollusks, and sea cucumbers which are listed as Schedule I species[2].

[1]The census data includes Kalpitti, Bangaram, Thinakara Parelli etc. in the total area of Agatti. This gives a total surface area of 3.84 km^2 and a population density of 1 842. However, because virtually all people live on Agatti Island itself the population density on the island is closer to 2 600.

[2]The wildlife protection act states that harming endangered species listed under Schedule 1 of the act is prohibited throughout India. Hunting or collecting other species requiring special protection (Schedule II), big game (Schedule III) and small game (Schedule IV) is regulated through licensing. A few species classified as vermin (schedule V) may be hunted without restriction.

Figure 1. Agatti Island and the surrounding lagoon. The map is drawn using information provided by Goa Diving (base map and dive sites) and from discussions with fishers regarding the location of Chals (Hoon *et al*., 2004).



This notification was amended in December 2001, returning some of the molluscs commonly collected to schedule IV, which allows licensed collection.

However, enforcement of the notifications is weak. The islanders value the reef and lagoon as a safety net and recognize that the reef provides vital protection against storms and waves, but consider replenishment of reef resources sufficient and thus do not support the restrictions issued by the administration. Many of the reef resources listed on Schedule I continue to be exploited. At the same time, fishermen admit that both catch size and the size of individual fish have declined (Hoon *et al.*, 2005).

There is considerable uncertainty regarding the sustainability of resource use in Agatti, as well apparent inconsistencies between opinions voiced and trends observed. Further, the many conflicting views and opinions means there is an obvious risk for increased conflict over resource use and access. At the same time, very little information on status and trends in reef resources and utilization patterns is available for the Lakshadweep. A survey on the distribution and abundance of corals, sea weeds, echinoderms and gastropods, conducted on the eastern reef flat of Agatti Island in 1992 and 1993, reports low coral abundance on the reef flat and classifies corals as endangered (Rodrigues, 1996). The Fisheries Department collects some fish catch data, focusing primarily on commercially important species such as Tuna, but information on most subsistence and lagoon activities is scarce.

In view of this, a monitoring programme was initiated in 2003, driven by local residents and stakeholders, that aimed to collect detailed information describing reef use, particularly the differences in resource use between the lagoon and reef area as well as within these; particular 'hotspots'; seasonality in different activities; spatial overlaps in resource use and conflicts that arise out of this; and, finally, illegal resource use.

This paper presents the results of one year of data collection and describes in detail the characteristics and patterns of resource use, with some additional data on resource extraction. In addition, this paper provides recommendations on further needs in reef resource and resource use monitoring in Agatti.

METHODS

Activity Descriptions and Estimated Resource Extraction

An inventory was made of all the reef related activities on the island using participatory resource appraisal methods such as focus group discussions, a variety of visualization tools, and interviews with practitioners (IIRR, 1998; Bunce *et al.*, 2000). Information describing a number of aspects of the activities, such as seasonality, location, importance ranking, value, and average catch size and composition was collected. Local taxonomy and terminology was used for the sake of accuracy and local relevance. Reef areas and sites used for different activities were located on a resource map and ranked according to preference by local stakeholders.

Estimates of the resource extraction by activity, such as average fish catch and catch composition using a certain gear, were obtained through observation and interviews. For each activity at least five separate interviews were conducted with practitioners, and where possible data recorders participated in the activities. Fisheries Department staff who collect fish landing data were also consulted. The data was validated through focus group discussion with 10 expert fishermen from Agatti. This method, while not precise, provided reliable indicative estimates of resource use and catch per unit effort.

Reef Use Monitoring

Reef use monitoring was carried out to estimate average daily pressure from human activities on coral and reef based resources, in different parts of the island and at different times of the year. The island was divided into eight zones as shown in figure 2 on next page. Beach-based data recorders made observations on the number of people carrying out each activity and taking notes on field datasheets listing common activities such as reef gleaning, octopus hunting, tuna baitfish collection, various forms of net and line fishing, and collection of boulder, shingle and sand for construction purposes. Data was recorded four times daily in each zone: at beginning of high tide; high tide; beginning of low tide; and low tide. This sampling strategy was developed through consultation with practitioners and was designed to capture all uses regardless of their dependence on tides. For example, the relationship between tides and the movements of fish means many fishing activities coincide with the change of tides (e.g. some fish are known to enter the lagoon with an incoming tide and leave with the start of low tide).

While this sampling strategy provides data on every type of reef related activity every day, it must be seen as an estimate of total number of reef users. However, it was viewed as appropriate for the objectives of this study, providing reliable information on the pressure on the

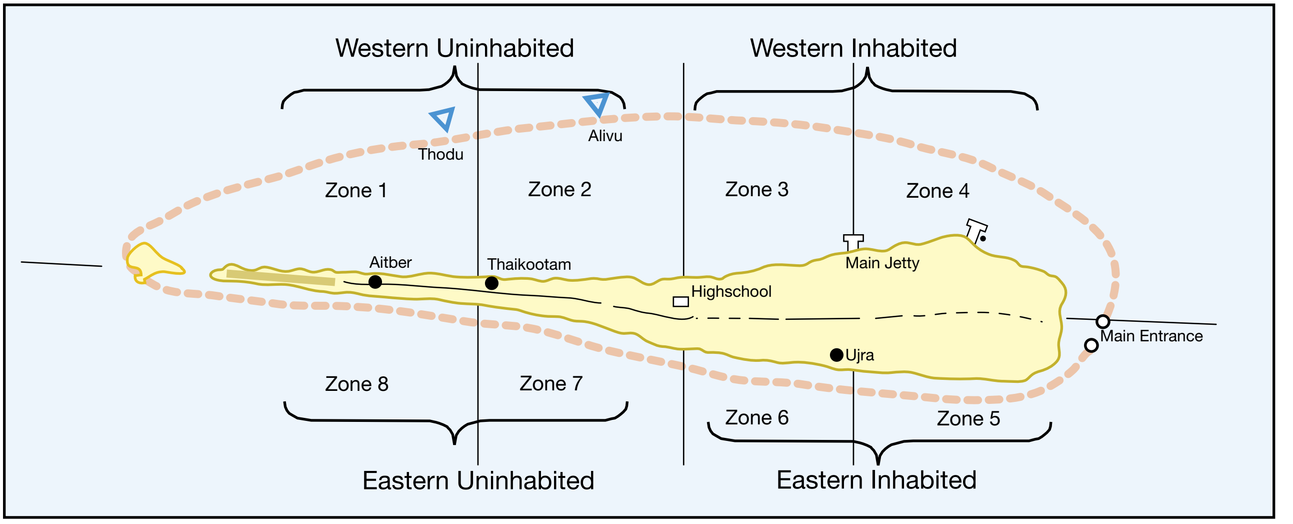


Figure 2. Monitoring zones on Agatti Island defined by the project.

reef and identifying potential problem areas, and it goes considerably further than any previous efforts on Agatti.

In analysing the data the eight original zones have been merged into four zones defined by location in relation to human habitation and lagoonal conditions. Thus zones 1 and 2 have been merged to become the Western Uninhabited zone; zones 3 and 4 became the Western Inhabited zone; zones 5 and 6 became the Eastern Inhabited zone and zones 7 and 8 became Eastern Uninhabited zone. Merging these zones was supported by the data, which did not exhibit significant differences in reef use between the zones that were merged.

Information describing non-extractive reef use in the form of scuba diving was obtained from the Goa Divers dive centre operating out of Agatti Island Beach Resort. The dive centre keeps a daily log of the number of divers they take out and sites visited. Dive site descriptions and locations were also provided.

RESULTS AND DISCUSSION

Most use of reefs and reef resources is carried out to fulfill basic needs. Activities can be classified into three major groups based on what the activity provides:

- collection of construction materials for houses;
- subsistence fishing, providing food and protein as well as some cash income for the household of the individual;
- dive tourism and snorkeling, which is a recently introduced category.

These different activities, their characteristics and use patterns are described and discussed in the sections below.

Collection of Construction Materials

Coral boulders, shingles (coralline rubble) and sand are, in addition to palm trees, among the few building materials available to atoll islanders. On Agatti they are still widely used, in spite of bans and/or restricted use and an increasing supply of materials from the mainland. It is important to note that construction materials imported from the mainland have a monetary cost, even when subsidized, as opposed to materials that can be collected locally.

Boulder Collection

Coral boulders are used for laying foundations of houses. They are normally collected for private use and not sold.

People wade through the shallow lagoon that separates the island from the reef and break off boulders, live or dead, with crowbars. Four to five people are involved in each operation, removing around 100 kg per person per day. If there is not enough manpower to haul whole boulders to shore they are broken into smaller pieces in the lagoon before transportation (figure 3).

Although this activity is prohibited, coral boulders are collected throughout the year all along the eastern side of the island, although at higher intensity closer to the human settlements to reduce transportation distances. Collection increases considerably during the fair season (especially December to March) as this is the season for house construction when the weather is more favorable (figure 4). The wide lagoon on the western side of the island restricts access to the reef and thus prevents extensive collection.

Figure 3. Coral boulders collected for construction. Both live and dead colonies are broken off the reef using iron rods. *Photo:* JERKER TAMELANDER.

Based on the data gathered an estimated 92 metric tons of live and dead coral boulders were collected between June 2003 and May 2004. When compared with the approximately 98 tons collected in a six-month period from July to December 2001 (Hoon *et al.*, 2002) it appears that there has been a reduction in boulder collection. This could indicate that the ban on coral boulder collection is having an impact.

However, there are also indications of bursts of increased boulder collection at times when periods of stricter enforcement of legislation is predicted or expected, illustrating that people are willing to break the laws in order to get the resources needed, when this can be done with a lesser risk of punishment.

Shingle Collection

Shingle is coral rubble that accumulates on the beaches and in lagoons. With cement as the binding material it is

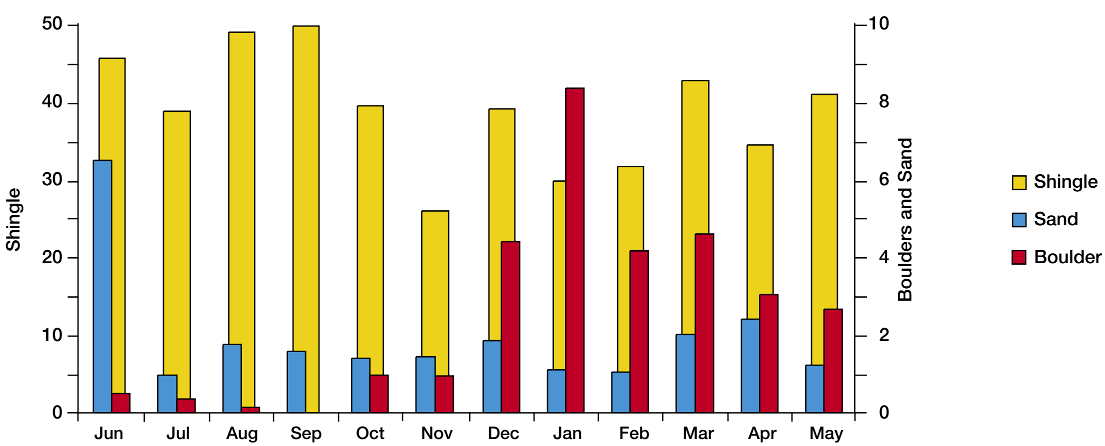


Figure 4. Boulder, shingle and sand collection, presented as average daily effort (man-days) by month. NB all zones have been merged.

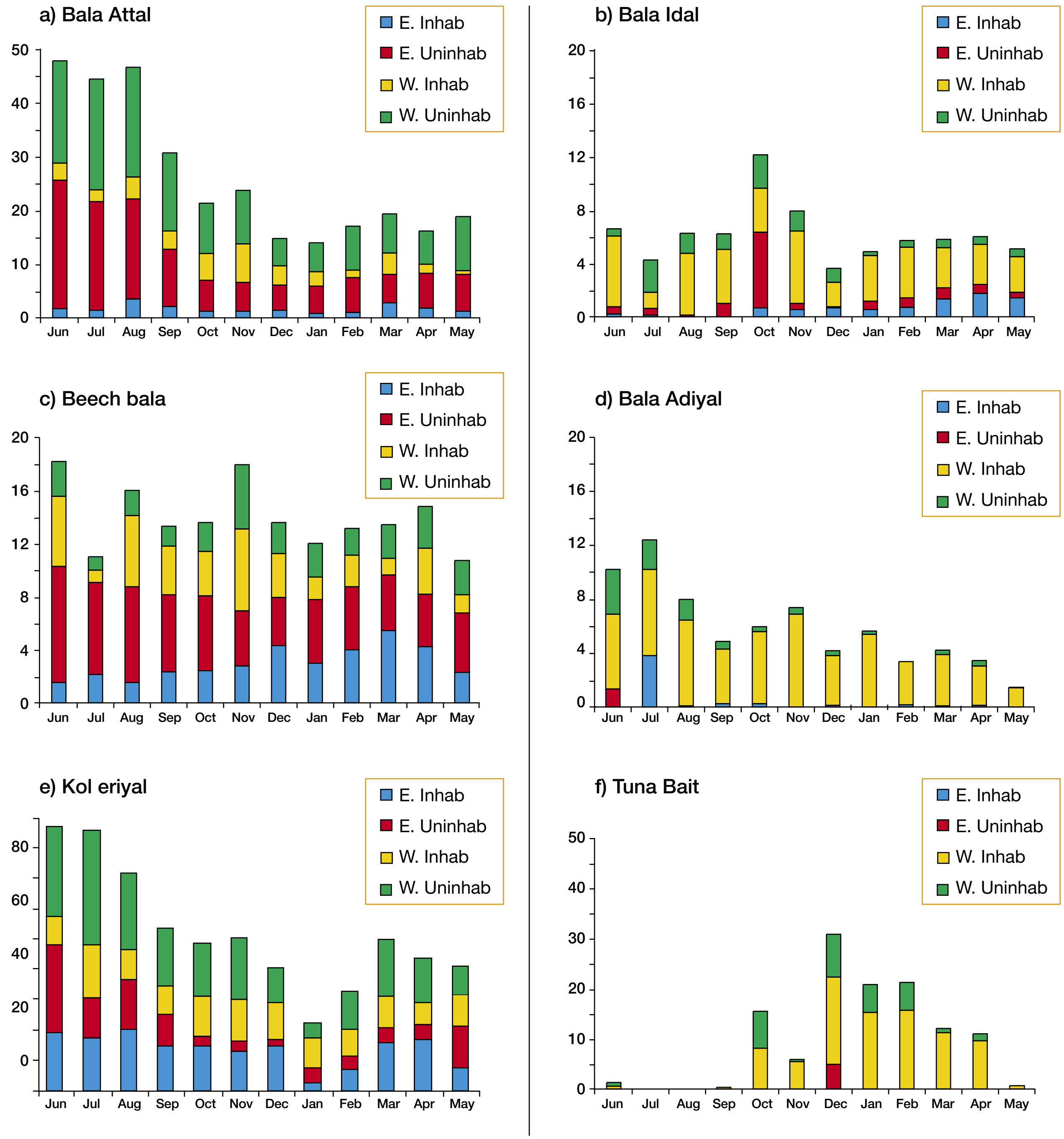


Figure 5. Average daily fishing effort in the four zones by gear and month. Effort is given as the number of people engaged in a certain activity during one day. a) Bala attal, purse seine; b) Bala idal, gillnet in lagoon; c) Beech bala, cast net; d) Bala adiyal, shore seine; e) Kol eriyal, handline; and f) Tuna bait. Note differences in scale on y-axis.

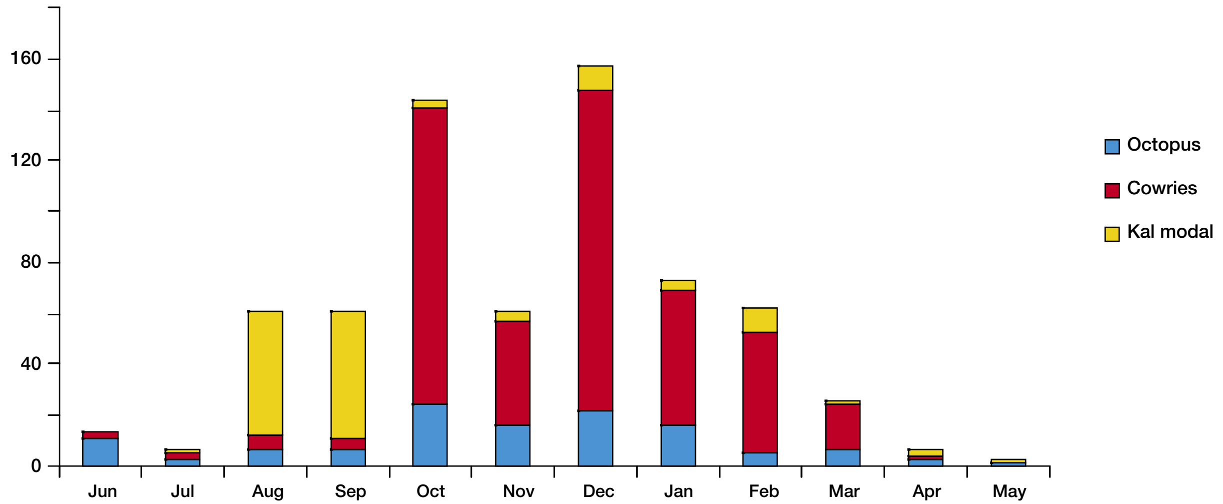


Figure 6. Gleaning pressure on the reefs in Agatti. Cowry collection and octopus and kal modal fishing presented as average daily effort (man-days) by month. *NB* all zones have been merged. Almost all gleaning takes place in the eastern lagoon.

used to make blocks for construction of house walls. It is also used in house foundations and floors. Shingle collection is a regulated activity under permit from the Environment Warden's Office. Those who have a permit must deposit a fee of five Indian Rupees (approximately 10 US cents) per bag of shingle collected.

The permit records show that no applications to collect shingle on Agatti had been lodged since 1998 (Hoon *et al.*, 2002).

In spite of this shingle is collected from all over the island both during the monsoon and fair season (figure 4). Most collection takes place in the inhabited part of the island on the eastern side, as well as in the Kalpitti area in the southernmost portion of the island. Based on the total number of shingle operations recorded and an estimated daily harvest of c. 15kg per person approximately 200 tons of shingle was collected during the monitoring period. This is at the same level as was recorded in 2001 (Hoon *et al.*, 2002).

Sand Collection

Sand, mixed with cement to make concrete used in building construction, is primarily dug out from low sand dunes along the shore, but also collected from the beaches. Collection takes place all around the island and throughout the year (figure 4). In the southern uninhabited part of the island tractors and tillers are used to collect and transport the sand, typically 1.5 and 0.5 tons per load respectively, while in the inhabited part sand is collected in bags, circa five 20 kg bags per person per day. The impact on beaches and dunes is obvious, resulting in loss of vegetation and loss in height.

Subsistence Fishing

Fish for household consumption is caught in the lagoon and on the coral reefs using a variety of gears. In the past the fish catch was shared between households and never sold. However, increasing demands as well as increased purchasing ability and refrigeration possibilities have meant surplus catch is now sold and reef based fishing is conducted for financial gains, in addition to supplying food for the family. Fishing methods range from single person gears such as hook and line or cast net, to large operations involving 30–40 people such as the *bala fadal* drag net. Gears and catches are described in some detail below, with graphs of average daily use (figure 5, 6 and

Figure 7. Local women gleaning the reef of cowries, octopii and other food items. *Photo:* VINEETA HOON.

7), catch compositions and information on average catches and catch per unit effort (tables 1, 2 and 3).

Shal Kakal

Shal kakal is a gill net with a mesh size between 12 and 14 cm, set at the *chals,* or channels in the reef. Used mainly during the monsoon season, nets are set at the time of new moon, i.e. during spring tide when tidal flushing is at its highest. The reported average catch is around four kilograms (table 1) and consists mostly of red snapper and some groupers. This is not a commonly used gear, with a total of 30 records during in the whole year. The activity is to an extent self-regulatory since it can only be carried out for six days per month around new moon,

Table 1. *Bala fadal* (drag net) catch composition expressed as a percentage of the total number of fish caught

English Name	Local Name	%
Snapper	Metti, Phulariyam	4
Carangids	Bangada, Kuluval	1
Parrot fish	Shandi	1
Others, each ≤5%		2
Unicorn	Karakam	
Surgeon fish	Neithala	
Trigger fish	Pallli	
Gar fish	Oola	

Table 2. *Bala adiyal* shore seine catch composition, expressed as a percentage of the total number of fish caught

English Name	Local Name	%
Carangids	Bangada, Kuluval	2
Half Beaks	Mural, Bacchala	2
Mojarra	Furachi	1
Goat fish	Manakkam	1
Others, each ≤5%		2
Mullets	Thithira, Balmeen	
Rabbit fish	Onam	
Gar fish	Oola	

Table 3. Main fishing gears used around Agatti (Gear), number of people involved in each operation (#fishers), average catch per operation (Avg catch), daily catch per person (CPUE), total number of times each operation has been recorded in the year (#events) and total annual catch in metric tons (Annual catch)

Gear (local name)	Gear (English)	# of fishers	Avg catch[1]	CPUE[1]	# of events	Annual catch[1]
Shal Kakal	Gillnet in reef channels	2	4	2	30	0.12
Bala Attal	Purse seining	2	4	2	2 266	9
Bala Idal	Gillnet in lagoon	2	4	2	9 560	38
Bala Fadal	Dragnet in lagoon	30	250	4	30	8
Beech Bala	Cast net	1	1	1	5 124	5
Bala Adiyal	Shore seine	4	8	2	2 161	17
Kol attikal/eriyal	Rod Fishing/Handline	1	1	1	23 313	23

[1]Data on catch and CPUE is based on reports from fishers and observation and is indicative only.

and is restricted to the limited number of natural sites that are available, which are located in the uninhabited section of the western lagoon.

Bala Attal

Bala attal, or purse seining within the lagoon, is a relatively common gear. It is used throughout the year and all around the island, but at higher frequencies during the monsoon months of June, July and August. The zones on the uninhabited southern side of the island are favored, apparently due to availability of suitable sites. Average catch reported is around 4 kg (table 1), consisting mostly of carangids, snappers and garfish (figure 5a).

Bala Idal

Bala idal is a gill net with a mesh size of 12–14 cm. The net is set and anchored in the lagoon close to coral boulders and checked for catch every two or three hours. The gear is used mainly in the inhabited section of the western lagoon, although at low levels in all zones. It is used at similar levels throughout the year (figure 5b). Bala idal nets are owned by 150 families, but used by only around 30 families on a regular basis. The average catch is around 4 kg and consists mostly of carangids and snapper (table 1).

Bala Fadal

Bala fadal is a drag net operation involving 25–30 persons. The team is divided into two groups. One group stays on the shore spreading out the *chandalibala*, a rectangular net 20–40m long and 2–3m high, with a mesh size of 5–6 mm. The other group lays a 100 m long rope with coconut fronds tied to it (the *olabala*) over the reef forming an arc. This aggregates the fish, which follow the *olabala* as it is pulled towards the shore. The *chandalibala* operators then quickly circle the fish with the net and haul them up. The gear is used only during the monsoon, two to three times per week, and almost exclusively in the uninhabited zone near Kalpitti, although occasionally in the northern end of the lagoon. There are two *bala fadal* units on the island, but only one operates at a time. The estimated average catch per operation is around 250 kg, including many juveniles. During the monsoon season in 2003 the drag net operation took place 30 times (c. twice a week between May and August). This means approximately 7 500 kg of reef fish were caught in four months using this gear alone (tables 1 and 2).

Beech Bala

Beech bala, or cast netting from the shore, is a one-person operation (table 1). It takes place throughout the year and in all the zones with only limited variation, although slightly more frequently in the eastern lagoon (figure 5c). The gear is primarily operated from the shore and thus not in the immediate vicinity of coral patches. Fish caught are primarily shallow water and near shore fish such as carangids, goat fish and half beaks.

Bala Adiyal

Bala adiyal, or shore seining, is a popular fishing method used around the year mainly in the western lagoon (figure 5d). Primarily used as the tide changes, it targets fish that aggregate in shallow water at these times. The nets, 15–20 m long and 2–3 m deep with a mesh size of 15–25 mm, are usually operated by four people. The net is laid in a broad arch and hauled back to the shore. Towards the final stages of hauling the footrope is manipulated in such a way that it reaches the shore prior to the head rope without rising from the bottom. The catch size is around 8 kg per operation (table 1), with carangids making up around a quarter of this (table 2). A total of c. 2 000 operations were observed during the one-year monitoring period, meaning approximately 16 tons of fish were caught using this method (table 3).

Kol Attikal and Eriyal

Kol attikal and eriyal, fishing with rod or hand line, is a common practice and pastime for the male population of Agatti. Used mainly as a leisure activity in the free time throughout the year, the intensity of hand line fishing increases during the monsoon when many other activities are reduced (figure 5e). Simple hand lines, monofilament with a hook and a sinker, rolled around a piece of wood, are used about four times as frequently as rods. While the most popular rod fishing areas are in the inhabited areas, from the jetties in the western lagoon as well in the eastern lagoon, geographic patterns are less clear for hand line, reflecting the impromptu and opportunistic character of the operation (figure 5e). Popular areas include the north shore, jetty areas, Thodu and the bar area around the reef. Fish caught are mainly red snapper and other snappers, carangids, emperors and goat fish.

Chadum Pork

Chadum pork, or harpooning, is carried out in the outer reef area along the eastern side of the island, predominantly in the uninhabited zone, as well as to a certain extent in the inhabited section of the western lagoon. It is mainly a fair season activity although practiced also on clear days during the monsoon period. Fishers go out in traditional boats generally fitted with outboard engines. There are 8–10 groups of one to three members each, depending on the craft. No powered spear guns are used. Large fish such as seer and rays are targeted. While fish are consumed fresh rays are cut into small pieces that are sun dried.

Chala Pidika

Chala pidika, fishing bait for the tuna fishery, is carried out using fine mesh nets on sandy bottoms in shallow lagoon areas. Collection of baitfish is limited to the times tuna is fished and so almost exclusively collected during the fair season, although there are instances of bait collection and tuna fishing during the monsoon (figure 5f). For example, it is known Agatti fishermen started tuna fishing in August in 2001, which falls within the monsoon season. On Agatti, baitfish are collected only in the western lagoon, primarily in the inhabited portion. However, it seems likely this is minor compared to the collection that takes place in other areas, such as Perumal Par, in association with tuna fishing trips. Another type of bait collection on Agatti includes digging out worms and crabs from the seashore and from the sand shallow areas within the lagoon for the rod and hand line fishery.

Reef Gleaning

Reef gleaning is both an important past time and subsistence activity for the Agatti islanders. Traditionally carried out by women as a means to obtain a disposable income, it now involves women as well as men and children. People walk on the exposed and shallow reef areas looking for cowries and other resource shells as well as octopi (there is also a target fishery for octopus). Iron rods are used to prod, break and overturn coral boulders. Fish are caught by placing nets around small coral boulders, which are then shaken or beaten to drive the fish out and into the net. While there is some specialization gleaning is an opportunistic activity and any reef gleaner will take any target species found. Reef gleaning is carried out monthly throughout the year during the six to seven days of spring tide (figure 6). At its peak over 400 reef gleaners have been counted on the eastern reef flat in a single day (figure 7).

Scuba Diving and Snorkeling Tourism

The dive industry is still in its infancy in Lakshadweep. Commercial/tourist scuba diving at Agatti Island was introduced with the opening of a dive center in September 2003. Dive sites have therefore only recently been explored, but tourists are taken to both lagoonal and outer slope sites, the most frequently used being a site for introductory dives within the lagoon and 'Japanese garden' on the eastern reef. As most of the guests staying at Agatti Island Beach Resort, the only tourist hotel on the island, stay only 2–3 nights few end up doing more than 2 dives. However, there is a lot of potential for development. While the 1998 coral bleaching and mass mortality reduced coral cover by an estimated 70–90% recovery is now seen in several areas, although it is patchy (Rajasuriya *et al.*, 2004). Abundant recruits indicate there is a sufficient supply of larvae. The fish populations are less depleted than many mainland areas, turtles are ubiquitous and reef sharks are seen frequently, all factors that attract recreational divers.

SUMMARY AND DISCUSSION

Monitoring the different types of reef related activities carried out on Agatti Island provides information on both the frequency of efforts and average harvest, as well as on trends in the use of traditional gears, adaptation or development of gears and practices, and on the importance of reef related activities for food, livelihoods and island culture.

Fishing, whether as a commercial activity or a hobby, is ingrained in the culture and people of the islands. Men take 'leave' from regular jobs to join in fishing activities, and young boys spend their vacations fishing during the fair season. This is reflected in the average daily number of reef users (i.e. number of people involved in direct extractive activities on any given day), which is around 300 and slightly more during the fair season than during the monsoon. Despite many developments and modernization, several of the traditional and indigenous methods of subsistence reef fishing are still used and constitute an essential part of people's lives. Indigenous knowledge of reef resources is still prevalent in Agatti, and with so many practitioners knowledge and skills can be passed down to future generations.

The data gathered during one year provided an estimate of the amount of fish caught through subsistence or recreational reef based fisheries. During the sampling period more than 100 metric tons of fish were caught using these methods, a significant catch that is not recorded in other data systems, such as that being maintained by Fisheries Department. Thus this study provided the only information obtained to date on the size of reef fisheries and their importance to the island, and provides a baseline for studying future trends.

While the eastern lagoon and reef in the inhabited zone is the most utilized, with high levels of harvesting of all types of reef resources, trampling, breakage and overturning of coral boulders and so on, the entire reef and lagoon area is under considerable stress and there are signs of over exploitation and resource depletion. The main local driving force is the increase in human population on the island and continued high dependence on extractive uses. In 1951 the population of Agatti was less than 2 000. In 2001 the population had increased to over 7 000, more than tripling in half a century. This growth coupled with modernization of the society and equipment used has put great pressure on the limited land, fresh water, and lagoon-reef resources. For the long-term sustainability of the area it is therefore extremely important that the reefs and reef uses are managed well. Reliable data on resource use and resource abundance is therefore essential, and the activities reported here will be revised accordingly.

Given the scarcity of information available on reef related activities and the lack of studies describing and quantifying reef fisheries and other resource use in Agatti, the method and approach used have been both appropriate and necessary. However, for more detailed statements and analyses of trends in both resource use and resource abundance a more targeted sampling strategy is needed. This will be developed during early 2005, field-tested and put into operation with the involvement of the local monitoring team, including fishermen and other resource users, during a phase-in period.

Development and expansion of protocols will benefit from the data collected thus far, which can be used to identify where sampling effort should be placed to best reflect the situation on the ground and to provide more rigorous data with higher statistical significance on aspects that currently can only be described in a cursory way. A higher resolution can be attained without losing sight of overall patterns and without increasing the actual sample size. For example, the existing data provides indications of seasonality, which can be used as justification for focusing sampling on one or a few intense periods in each season rather carrying it out continuously throughout the year.

The zones, initially defined arbitrarily and only to a certain extent based on natural or physical character-

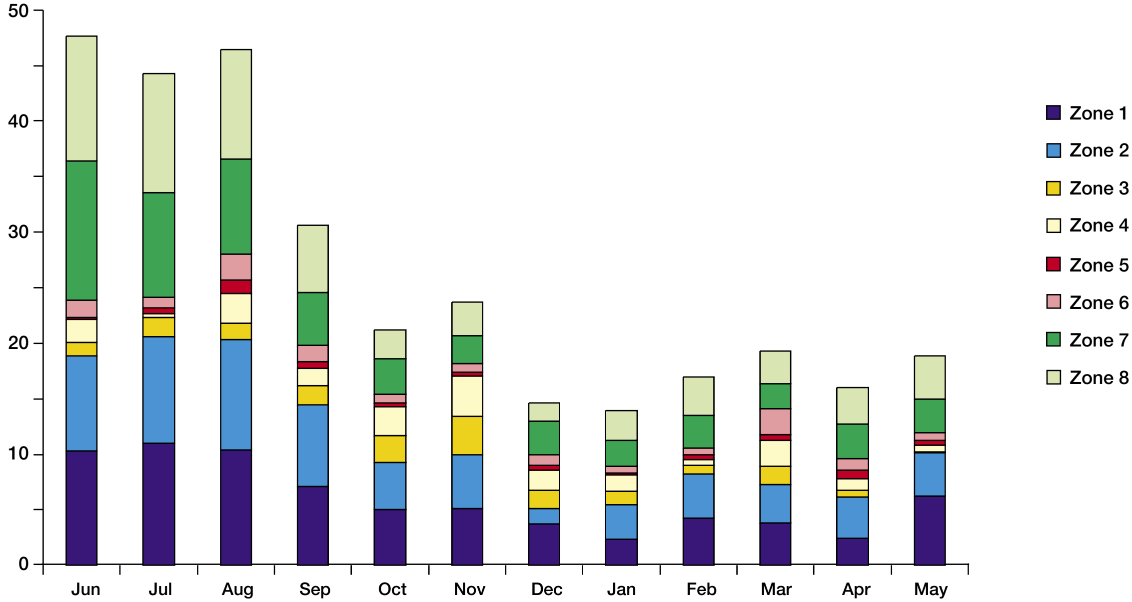


Figure 8. Example of resource use (Bala attal, purse seine) in the originally defined eight zones. Zones that were merged are illustrated in similar colors, e.g. zones 1 and 2, which were merged to become the western uninhabited zone are presented in shades of blue.

istics, were already redefined as observed patterns provided a justification for this. Field observations indicate that while there is a marked difference between the western and eastern lagoons in terms of hydrography and structure etc., they are quite homogenous internally. This is supported by the resource use monitoring data. However, the resource use monitoring data further indicates there is a clear difference in use between the lagoon area adjacent to the inhabited portion of the island and the area adjacent to the uninhabited area within a lagoon (figure 8). Thus differences in resource use patterns between lagoons reflect lagoon characteristics, structure, accessibility and availability of target species, whereas differences in resource use patterns within the lagoons primarily reflect proximity to human settlement, although certain features such as reef channels also play a role. Seasonal rather than monthly variation in most gears indicates using sampling periods (fair, monsoon and the two transition seasons) might be sufficient to show patterns of use and record changes in catch and effort.

The participatory approach taken in setting up the activities means stakeholders benefit both from their direct involvement in the activities and from the monitoring data, which is collected with needs of the local population in mind and presented to them and discussed through regular seminars. This partnership with local resource users is constantly evolving, as are the issues identified by them as important to include in the monitoring activities. In particular, linking ecological and resource monitoring with resource use and catch monitoring will help to illustrate the relationship between destructive reef use or over exploitation of resources and reef health, how multiple stresses such as resource use, coral bleaching and cyclones affect the environment, as well as how this impacts on resource availability. This is an important awareness tool, and will also be used to strengthen the capacity of stakeholders to increasingly take part in management of the resources on which they rely. Further, the project will continue to organize regular awareness raising activities among fishers as well as other stakeholders such as children (Hoon & Kanvinde, 2005).

The only obvious source of conflict relating to resource use identified during the monitoring is between government and legislation on the one hand and local populations on the other, primarily due to differences of opinion regarding resource management. However, as legislation is rarely enforced, this conflict has been largely dormant. The data gathered does not indicate there is conflict between different resource users, e.g. between tuna bait collectors and cast net fishers or between different groups gleaning the reef area. However, should current legislation be enforced strictly without considerations to livelihood options for the islanders, it seems obvious conflict between resource users and government will become more heated, and could possibly also increase conflict between reef users. In particular, introduction of new reef uses that are seen to benefit outsiders more than local populations may aggravate the situation. This highlights the importance of reliable information on changes and trends in reef ecosystem health and resource abundance, as well as the importance of awareness of these issues among local stakeholders and a willingness and capacity to participate in resource management.

For example, there are indications a grouper fishery in the archipelago will develop further, selling chilled and frozen fish to the mainland and foreign markets (Fisheries Director pers. Comm.). The grouper population in the Lakshadweep appears healthier than in many other parts of Asia, where overexploitation has reduced abundances considerably (e.g. Bentley, 1999). The high market value of the fish is a driver for repeating this pattern. Reliable data can help identify risks for population crashes and stakeholder participation in resource management can help prevent them from occurring. Similarly, increased collection of ornamental fish seems a likely development. A fish hatchery is about to start operations on Agatti, and while this could in the longer term reduce exploitation of target species it will need initial stocks as well as regular replenishment, which will be obtained from the area. Further, it will only have a capacity to breed a certain number of species, but the infrastructure and logistics surrounding it may promote harvesting and export of additional ones, thus introducing a new reef activity that can be destructive to the area. However, if carried out in accordance with sound principles, following e.g. standards set by the Marine Aquarium Council (www.aquariumcouncil.org), it can provide a sustainable source of income for the island. The institutions behind the initiative have indicated they wish to take this path.

The indiscriminate collection of coral boulder, shingle and sand from all around the island and particularly on the eastern side of the inhabited area is a cause for concern. There are indications of increased shoreline erosion, and through a government-led initiative cement tetra-pods have been deposited in huge numbers to reinforce shoreline stability. The efficiency of this intervention is questionable as it does not address the causes of erosion. Further, with each tetra-pod unit costing 1 200 Rupees (~20 Euros) the monetary cost is enormous. The actual sand and rubble budget of the island is unknown, but it seems unlikely the island can sustain the present rates of extraction, especially given the degraded state of the surrounding coral reefs. This issue requires additional and sound information, and a concerted effort from both government and local populations to reduce the drivers behind increased shoreline erosion, while minimizing erosion that is already taking place (figure 9 on next page).

Lastly, the monitoring has identified that a number of activities are carried out illegally, either targeting species under Schedule I protection, or harvesting resources without necessary permits. While the restrictions put in place by the government are designed to protect key species and resources, they have had little impact in Lakshadweep as they are not actively enforced. At the same time strict enforcement would deny islanders use of traditional resources that are still important for their sustenance. A process where resource use is regulated and supplemental sources of income developed can help en-

Figure 9. Cement tetrapods and other modules deployed to prevent erosion. A cyclone in 2004 caused significant loss of beach sand and infrastructure damage. *Photo:* JERKER TAMELANDER.

sure preservation of both key resource species and of cultural practices in the archipelago, for the benefit and enjoyment of future generations. The islanders, the stakeholder group most dependent on the reefs, and partly but not solely responsible for their degradation, must be seen as central in any such efforts.

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Alternative Livelihoods as a Tool for Sustainable Coral Reef Management in Sri Lanka

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key words: Coral reefs, Sri Lanka, Alternative Livelihoods, Sustainable Management

INTRODUCTION

As an island nation, Sri Lanka's economic development has always been closely linked with the coast and the marine environment. Coastal ecosystems such as coral reefs, mangroves and seagrass beds provide significant socio-economic benefits, especially in the form of food security and livelihood options for over one million people in the country. The coral reefs of Sri Lanka have not been comprehensively mapped, but three types of reef habitats have been identified: true coral reefs; consisting of fringing and patch reefs, and sandstone and rocky coral communities. The major reef formations are found on the continental shelf within the 30 m depth contour. An estimated 2–3% of the coastline has fringing reefs, with larger reef areas occurring offshore in the Gulf of Mannar and west of the Kalpitiya Peninsula (Rajasuriya *et al.*, 2002; Bakus *et al.*, 2000) (figure 1).

The main economic use of coral reefs in Sri Lanka is reef-associated fisheries, constituting up to 15% of the total fish landing (Rajasuriya *et al.*, 1995). The country also provided 5% of the marine ornamental fish and 8% of the invertebrates exported worldwide during 1997–2002 (Wabnitz *et al.*, 2003). Spiny lobsters, groupers, sea cucumbers and shark are the other coral associated species with high export demand (Perera *et al.*, 2002).

Tourism, which is the fifth largest income earner in

Figure 1. Recorded Coral Reef Locations in Sri Lanka (White & Rajasuriya, 1995).

Figure 2. A fishing net entangled on a reef.
Photo: NISHAMANI JINADASA.

Figure 3. Mined sea coral piles at Rekawa beach.
Photo: NISHANTHI PERERA.

Table 1. Major types of direct and indirect stresses on coral reefs in Sri Lanka (modified from White & Rajasuriya, 1995.)

Factors and Examples	Total Relative Impact at National level*
Direct	
• Live coral reef mining: Direct removal of live coral from shallow coastal areas for the lime industry.	**5**
• Direct smothering by sediments, solid wastes and oil: Shallow reefs on the south-western coast experience high sediment loads during the monsoon season.	**5**
• Anchor damage: Encountered in areas of intense fishing (e.g.Weligama and Madiha-Polhena), intense tourism (e.g.Hikkaduwa and Pigeon Island) and ship anchorages (e.g.Pitigala Reef, located near Colombo harbour).	**4**
• Blast fishing: Continuous blasting have severely damaged Rumassala Reef and is a serious problem in the Eastern Province.	**4**
• Storms and cyclones: Coral reefs at Pigeon Island were severely damaged by a cyclone in 2000.	**2**
Indirect	
• Global Warming: Live coral cover is reduced due to coral bleaching and subsequent mortality (during the 1998 El Niño event coral cover was reduced zero in some areas – e.g. in shallow areas of Bar Reef Marine Sanctuary). There are indications of a shift toward algal domination in many areas.	**5**
• Over-exploitation of species and use of destructive fishing gear: The destruction of Kandakuliya Reef was accelerated with the introduction of bottom-set gill nets to harvest spiny lobsters.	**4**
• Predation and diseases: Predation by *Acanthaster planci* has been recorded at Bar Reef, Kandakuliya and Rumassala.	**3**

*=5 high to 1=low

the country, also depends on clean sandy shores and the attraction of healthy coral reefs.

The coral-based lime industry provides another livelihood to poor coastal communities in the south-western, southern and eastern coastal belts, where there is easy access to near-shore fringing reefs. The minimum economic value of coral reefs in Sri Lanka has been estimated to be between US$ 140 000 and US$ 7 500 000 per km^2 of reef over a 20 year period (Berg *et al.*, 1998).

Yet in the past few decades, many coral reef ecosystems that have taken thousands of years to develop have been severely degraded, and some have been destroyed entirely. According to the Reefs at Risk Assessment (Bryant *et al.*, 1998), 86% of Sri Lanka's reefs are at risk due to human activities such as near-shore live coral mining, destructive fishing practices, uncontrolled harvesting of reef biota, increased pressure from tourist-related activities and land-based source pollution (table 1). High coral mortality was recorded during the 97–98 El Niño-related bleaching event and as a result some reefs are now covered by dense algal growth (Rajasuriya, 2002).

The country has adequate laws to protect its coral reefs, and legislation seems to provide a solid framework for prevention of physical breakage of corals, over harvesting of fishery resources and pollution. Also, the marine protected area (MPA) concept has been in use in Sri Lanka since the 1940s (De Silva, 1997). However, management of the nation's coral reef areas has been poor as policy makers and ground level managers rely on incomplete knowledge of the status and ecology of the reefs. Enforcement of regulations remains weak and complicated. For example, reef-based fishing and live coral mining activities are done mainly on a small scale and are widely scattered along the coastline. Table 2 summarizes some weaknesses in existing regulations and socio-political aspects affecting the implementation of existing laws and policies.

Policy makers are now realizing the importance of a strong commitment from the local community for effective management of reefs. In order to motivate a community to protect resources, the management strategies implemented should be able to provide direct benefits to them. One such management option is the provision of appropriate alternative livelihoods, which can financially compensate for income lost when populations are giving up destructive resource use patterns (ICRI, 1999).

Sri Lanka's Coastal Zone Management Plan (CZMP) has evolved since 1990 to include greater levels of com-

Table 2. Summary of reasons for management failures in Sri Lanka.

- In Sri Lanka, both inland fossilized coral as well as live coral from the sea are used in the lime industry. Mining of coral from the sea is prohibited under the Coast Conservation Act (CCA), the jurisdiction of which is limited to the coastal zone. However, implementation requires close coordination between Coast Conservation Department (CCD) and Geological Survey and Mines Bureau (GSMB), which issues permits for inland coral mining (CCD, 2003), as both fossil and live coral is burned in kilns located far from the coast.
- Sustainable management of a resource should be a process, not a project, which is often the case in Sri Lanka. For example, at the end of a donor-funded project, implementation of Special Area Management Plans at Hikkaduwa and Rekewa ceased due to lack of government commitment. People quickly returned to destructive activities and now a new donor funded project is addressing the same issues (Rajasuriya *et al.*, 1998).
- In order to address destructive fishering practices, the government recently established Fisheries Management areas at the Great and Little Basses Reefs off the south coast. Due to political interference, there was partiality in the issue of permits for harvesting of chanks (*Turbinella pyrum*) in this area, which resulted in the collapse of the management regime (Rajasuriya, 2003).
- An attempt by the government to ban the export of live fish was abandoned due to protests by exporters who claimed that around 50 000 people would loose their livelihoods if the ban was implemented (Öhman *et al.*, 1993).

munity participation in resource management. The 1997 CZMP highlights the importance of developing alternative and lucrative economic opportunities in the coastal area as optional employment for those dependent on depleted fisheries and coral mining. This was tested at a pilot scale through the implementation of Special Area Management (SAM) Plans, a community-based collaborative process involving residents and government departments that allows for comprehensive management of coastal resources in a defined geographic area. The SAM Plans for Rekawa and Hikkaduwa highlight the links between poverty, lack of livelihood opportunities and illegal livelihood activities such as live coral mining, cutting of mangroves and collection of turtle eggs. The third iteration of the country's CZMP is in its final stages of development and the SAM process is set to remain a central element (CCD, 2003; Anon., 1995; Anon., 1996; Aeron-Thomas, 2001).

In view of the above, a study was carried out to assess the practicalities of using alternative livelihoods as a

Table 3. Synthesis of reasons for turning to and continuing destructive activities in selected coastal areas

Destructive activity and Location	Reasons
Sea coral mining at Rekawa (Banda, 2002)	By the late 1940s, with the transition to market economy, people of the Hunu cast traditionally involved in the lime production industry were completely replaced by the dominant Karawa cast, who had previously considered lime burning as an inferior occupation. During the 1970s to mid 1980's, prolonged droughts drove poor traditional farmers into coral mining and lime production to earn a living.
*Sea coral mining at Passi-***kudaha** (Dharmarethanam & Kirupairajah, 2003)	Civil unrest restricted movement of migratory fishermen and farmers, who instead turned to coral mining and exploiting lagoon resources for their livelihood.
Dynamite fishery at Rumassala (Weerakkody, 2002)	Two influential local residents control the activity, supported by several spotters and collectors. They are fully aware of the long-term effects of their actions, but high financial gains and the maintenance of social hierarchy motivates the continuation of the activity.
Overharvesting of ornamental fish at Unawatuna (Ranasinghe, 1996)	Collection has increased due to the expanding export market and the good income earned. Around 72 divers are involved in collection and earn an average of Rs. 500/– per day
Overharvesting of sea cucumbers on the eastern and northwestern coasts (Brown, 1997)	Traditionally, harvesting was limited to estuarine environments, but external market demand has lead to divers engaged in the collection of ornamental fish to also collect sea cucumbers from coral reef habitats using SCUBA. Presently there is no monitoring of catch or exports.
Overuse of reef resources for tourism at Hikkaduwa National Park (Anon., 1995; De Silva, 1997)	Considerable damage is caused by the large number of glass-bottom boats running over shallow coral patches. Food such as bread is also used indiscriminately to attract fish. There is no demarcation of park boundaries and no restriction of entry of boats.
Visitor Pressure at Pigeon Island National Park (MENR, 2002)	Free movement of people due to the cease-fire agreement signed in 2002 has resulted in around 3000 people visiting the 4.6 ha Pigeon Island every weekend. It is estimated that around 15–20 boats are operating in the area, often damaging the shallow coral reefs. Due to lack of awareness and enforcement, live corals are often collected as souvenirs.

management tool to mitigate coral reef and other near-shore resource degradation. The main objective of the review was to synthesize experiences gained in the past in providing alternative livelihood options for coral reef resource users (miners, fishers, etc.) to minimize reef degradation and to develop a set of recommendations specific to the Sri Lankan context. The review and recommendations were compiled in a book entitled *Alternative Livelihoods Through Income Diversification: An Option for Sustainable Coral reef and Associated Ecosystem Management in Sri Lanka* (Perera, 2004). The book will act as a resource guide for policy makers and ground level managers on factors to be considered when introducing new livelihood options to coral reef and other coastal resource users. The project, funded by CORDIO and the South Asian Cooperative Environment Programme (SACEP), was initiated in April 2002 at the inaugural session of the Sri Lanka Coral Reef Forum, a joint venture of SACEP, CORDIO, the Global Coral Reef Monitoring Network (GCRMN) and the National Aquatic Research and Resources Development Agency (NARA). The main findings of the study are discussed below.

FINDINGS AND DISCUSSION

Reefs and livelihoods

The reliance on reefs for livelihood and food vary between locations, depending on the accessibility of reef resources and the socio-cultural background of the user community (Ranasinghe, 1996). The present review revealed that the actual number of people involved in destructive activities and their level of dependence are either not well documented or the data are outdated. For example, comprehensive studies on coral miners were conducted between 1980 and 1995 and therefore do not capture or address more recently emerging issues. However, studies have indicated that poverty, lack of other employment opportunities and short-term financial gains drive people to unsustainable methods of harvesting or illegal mining of the reefs (table 3). Another important factor is the fact that coral reefs are open access resources except in protected areas. Thus, people tend to turn to them for food and income when they are displaced from other traditional livelihoods, e.g. due to civil conflicts, loss of arable land or loss of jobs. Further, at times, local communities become victims of unsustainable activities by tourism developers and external fishers, often with conflicting interests, which may drive them towards unsustainable resource use. The stress on coral reef resources caused by this situation has become more apparent as the population increases.

As shown in Case Study 1 on next page, a community's opinion on how a coral reef should be managed depends on the perceived benefit of the reef, whether it is directly and immediately affecting income and survival, as well as on policy implemented by the government.

Successes and failures of alternative livelihood projects

Situations under which alternative livelihoods have been introduced as a management tool can be categorized under four headings: when certain activities are prohibited under new laws and regulations (e.g. illegal sea coral mining, use of certain types of destructive fishing gears etc); when an area is legally designated as 'protected'; to reduce pressures on natural resources that are not legally protected; and to empower communities in decision making process. The following sections will briefly discuss findings of several initiatives targeting different resource users under the above conditions.

Prohibition of activities under new regulations

In Sri Lanka, the legislation surrounding coral mining has had a difficult and complex history. A total ban on live coral mining was imposed under the provisions of the Coast Conservation Act No. 57 of 1981 and its Amendments of 1988 and 1996. These bans were selectively enforced, especially in areas with a multiplicity of reef use, such as tourism-related activities (Brown, 1997). Prohibition of live coral mining in the coastal zone led to

Case Study 1

Tale of two cities: Unawatuna and Kandakuliya (adapted from Weeramunda, 1999)

The two communities Unawatuna and Kandakuliya, located on the southern and northwestern coast respectively, represent contrasting demographic and economic situations. Unawatuna is highly urbanized, has a heterogeneous social composition, and depends principally on tourism for its economic survival, having given up traditional fishing to a large extent. Kandakuliya, on the other hand, is rural, has a relatively homogenous social composition and still depends on fishing.

A crucial factor influencing the perceptions of coral reef conservation needs among these communities is the importance attributed to the coral reefs for the local economy. The people of Unawatuna have identified reefs as a resource bringing direct financial returns through tourism, and have taken steps to protect the reefs by setting up two conservation societies and even openly opposing visitors who harm the reefs, especially when they are collecting reef biota as souvenirs. People in Kandakuliya do not consider the reefs to play such a important role, suggesting that they do not perceive the direct connection between fish catch and reef health. This can largely be attributed to social context. Economic backwardness and poverty in Kandakuliya, with minimal education, female unemployment, gender imbalance, and indebtedness during the fishing off-season are important factors influencing people's perspectives on resource management. It was also noted that the economic value of a natural resource alone is not sufficient to guarantee management with a long-term perspective. The resource will not be well cared for by those who profit from unsustainable use in the short-term unless good policy decisions on realistic alternative livelihoods are taken, such as promotion of ecotourism.

the loss of livelihoods of several thousands of people, and the CCD, the implementing agency, was responsible for providing alternative livelihood options to those affected. As a consequence, the south-western coastal zone has been the geographical focus of CCD's activities since 1978. Undoubtedly, the most popular solution was the proposal that the miners should turn to fishing. However, experience has shown that this is not a good alternative as in many cases when miners were given boats to earn more income from fishing, the boats were instead used for more efficient coral mining (Hale & Kumin, 1992; Premaratne, 2003). Another strategy used was to relocate the miners to new geographical locations and encourage them to earn a living through agriculture. Case Study 2 describes a relocation programme in Hikkaduwa Divisional Secretariat in 1989.

Studies have revealed that finding alternative employment for people involved in the lime industry depends on several factors, including level of occupation (i.e. miner, kiln operator, kiln owner, etc.), skills and experience of individual workers, the socio-economic viability of the proposed livelihoods and acceptance among target communities (Hale & Kumin, 1992; Ginige, 1997; Premaratne, 2003). Coral mining can be either a primary or a supplementary income generating activity. Thus, where coral mining is a primary income source, new employment ventures must be as financially rewarding as coral mining, or more, in order to be viable and success-

Case Study 2

Provision of agriculture lands for miners in the Monrovia Estate, Hikkaduwa (Hale & Kumin, 1992; Wickramasuriya *et al.*, 1999; Andrahennedige, 1995)

In 1989, the Government initiated a pilot relocation programme targeting 100 coral mining families (33% of the coral mining families in the area) of Seenigama, Totagamuwa and Werallana areas of the Hikkaduwa Divisional Secretary's Division. The project was aimed at providing beneficiaries with agricultural land in Monorovia Estate, located about 16 km away from their native place. Other facilities such as housing loans, food stamps, seedlings and agricultural training were also included to assist the families to adjust to their new living conditions. The funds and other inputs for the project were provided by several government and semi-government organizations such as Hikkaduwa Assistant Government Agent's (AGA) Office, the Land Commissioners Department, Department of Agriculture, National Housing Development Authority (NHDA), Coconut Development Board, Department of Education, Deutsche Gesellschaft für Technische Zusammenarbeit GmbH (GTZ) and the Coast Conservation Department (CCD).

Out of 386 applications received, 93 families were selected as beneficiaries by Grama Seva (GS) officers of the respective divisions, and final approval was given by the AGA Hikkaduwa. As a result of the absence of clear selection criteria and due to political interference, some non-eligible families (e.g. businessmen and farmers) initially received land, which then had to be re-allocated when the irregularity became known. The entire land area of the estate consisted of 97 blocks (acres), out of which 42 contained coconut, 40 rubber and 15 consisted of bare land. The coconut and rubber lands were distributed among 82 families while 11 families received one acre of bare land each. Two acres of bare land were designated as a cemetery. At the time of programme initiation, 80% of the coconut palms were bearing nuts and most of the rubber trees were at the stage of tapping.

A study conducted in 1995 revealed that 48% of the people joined the programme due to fear of a total ban on coral mining while 10% joined to obtain land as they did not own a permanent homestead and their income level was also lower than that of other coral miners (as they were collectors of coral debris from the beach or workers in the lime kilns). After five years, only 22 families remained on the estate, 12 of which on coconut lands and 3 on bare lands. Among those resettled, only 12 families have abandoned coral mining as an income generating activity and were engaged in activities such as agriculture, fishing, day labour and self-employment. Around a third of the beneficiaries that remained on the estate continued coral mining while also receiving additional income from activities such as small businesses, carpentry and hired labour. Of those families who returned to there original homes, around 27% went back to coral mining as the sole income generating activity. Four families leased out their lands to non-coral miners living in the vicinity of Monorovia Estate before returning.

The following factors contributed to the low success of the programme:

- Conflict: The relationship between settlers and villagers in the estate area was damaged as the villagers felt the settlers deprived them of benefits such as pasture land and a source of firewood (the estate was previously used for these purposes by the villages).
- Insufficient income: The income from agricultural activities at the estate was far below the anticipated

level (less than Rs. 2 500 per month) and around 26% of the beneficiaries discontinued the programme as they earned no income from the land.

- Lack of training: Settlers on bare lands could cultivate according to their preference, but settlers on coconut and rubber lands had no choice but to take up these activities. Settlers on rubber lands suffered due to lack of experience in latex tapping and processing and therefore out of the initial 40 only 7 families remained. The two-day training in agriculture and one-week training in skills for rubber tree tapping provided before the resettlement was not sufficient for the settlers to acquire the necessary skills.
- Lack of facilities and funds: Basic facilities such as transport (the estate was located 4 miles away from the bus route), health and schooling were not sufficient.
- Lack of capacity: Most government organizations involved in implementing the programme faced difficulties in undertaking activities allocated to them as they lacked the necessary financial and human resources. For example, the NHDA could provide housing loans for only half of the beneficiaries and the loans were not sufficient to construct houses. Regular monitoring of the programme was not possible due to lack of staff.

ful. Where mining is a supplementary income generating activity, people must be encouraged and assisted to develop their primary income sources (such as fishing, self employment in small businesses, etc.), or to take up alternative strategies on a smaller scale. Kiln workers who are poorly paid tend to be more willing to accept new livelihood ventures, while providing alternative income options to kiln owners is more problematic as their income is significantly higher.

Another example can be drawn from the protection of the turtle nesting area in Rekawa. Turtle egg collection is prohibited in Sri Lanka under the Wild Flora and Fauna Protection Ordinance, section 30 B. In order to involve local communities in the implementation of a law that is difficult for the authorities to enforce, the Turtle Conservation Project (TCP) employed 17 former turtle egg poachers as nest protectors, who were later trained as nature tour guides with the support from the Ceylon Tourist Board and the Sri Lanka Hotel School. The aim of this programme was to provide a valid tourist guide license to the trainees so that they could make an income from their natural resources in a manner that was not destructive. In a rural poor community like Rekawa where there is a lack of services and facilities, a conservation project can increase the commitment to conservation among the community by also addressing socio-economic issues. Therefore, activities such as English classes, health clinics and maintaining a library has assisted the TCP to achieve high community involvement in the programme while also assisting to increase the well-being of the community as a whole. This project also highlights the need for partnership building, collaborative management efforts that involve the community and the key departments and institutions for long-term support and wider outreach (Kapurusinghe, 2001).

Declaration of Marine Protected Areas

One aim of MPAs is to reduce pressures on coastal and marine resources by restricting extractive and other uses by legal means, allowing the habitats to regenerate and thrive in perpetuity. Although still in its infancy in Sri Lanka, many countries use alternative livelihoods through economic diversification as a fisheries management tool or for the conservation of biodiversity within MPAs. For example, at Komodo National Park (KNP) in Indonesia, new livelihood options such as fish culture, the use of fish aggregating devices and the promotion of ecotourism has created many opportunities to engage and educate local communities and private sector industries on best practices and ecological and economic sustainability of well-managed MPAs. Experiences from a KNP fish culture project shows that full-cycle farming (i.e. which does not require the capture of wild brood stock) of some high value reef fish (such as groupers) is possible, but for many species the technology and knowledge is still lacking. This programme has also realized the importance of educating policy makers on the necessary shift in perceptions regarding aquaculture. Rather than simply producing large quantities of fish, a well-designed mariculture venture can create maximum community involvement and benefits with minimal ecological impact (Sinhleton & Sulaiman, 2002; Pet-Soede, 2003).

In Port Honduras Marine Reserve of Belize, a grassroots community-based organization has been granted co-management of the MPA. Here alternative livelihoods such as fly-fishing, micro-enterprise and ecotourism training are provided to overcome the immediate concerns of the villages have about making an income after sacrificing fishing areas (Wil Maheia, pers. comm.). In the Tubigon Municipality, Philippines, grouper culture was successfully introduced as an alternative to unsustainable fishing methods, such as use of cyanide and dynamite. There are now around 141 grouper culturists in the region. However, two key factors impacting on the ability of fishers to adopt aquaculture are the limited supply of wild brood stock and trash fish for food (Haylor *et al.*, 2003).

Reduce pressure on natural resources that are not legally protected

In 1993, a micro-credit scheme was introduced in Sri Lanka under the Asian Development Bank (ADB) funded Fisheries Sector Development project to strengthen fishery management and reduce pressure on the resource, by diverting the fishing community to land-based income generating activities. It provided around 1590 employment opportunities combined with loans, out of which 71% were non-fishery based enterprises such as production and sales of consumer goods and services. These included bakeries, beauty parlors, tailoring, day care centers and fish processing and trading. Of the borrowers, 465, or 36%, were female, which is higher than past credit schemes. The scheme was operated by the National Development Bank through a wide network of participating credit institutions (PCI). Due to low disbursements recorded at the beginning of the project the ADB and the Government pressurized the PCIs to improve the disbursement ratios and activate the programme, with the result that large-sized loans were given to the best customers. Credit demand, however, was mainly for small loans, and even with small loans most people in the fishing communities were unable meet the collateral requirements of commercial banks and, as a result, defaulted on payments. Therefore, micro-credit institutions with grassroots level links are better suited to serve poor fishing communities (ADB/MFARD, 1999).

Another option in aiding recovery of a depleted resource is reduced harvesting pressure in combination with rehabilitation. The WorldFish Centre is developing and testing a model that links farming of giant clams and restocking of reefs in collaboration with 30 small-scale farmers in the Solomon Islands. The farmers are given 2–3 batches of about 1000 seed clams each year. When the clams reach market size, the farmers set aside 2% of their produce for restocking the reefs. Placement of clams on coral reefs is done to maximize survival, growth and reproduction. Thus, pressure on the reef resource is reduced through farming and recovery is aided by restocking (ICRIForum, 2004).

Empower communities in decision-making processes

The impacts on resource stability can come from external sources, such as through investors who do not live in the area concerned and who may not be sensitive to local traditions regarding access, tenure and resource use. In such instances, it is important to empower communities to manage their own resources. For example, in Rekawa, a low-income traditional coastal community was motivated to unite and self-regulate fishing pressures in the lagoon, so that the whole community could benefit.

United and coordinated action prevented outsiders from encroaching on the lagoon for prawn farming (Ekaratne *et al.*, 1998).

Community empowerment can also address gender issues. Under the Small-scale Fishery Project of the Bay of Bengal Programme, three pilot projects were initiated to promote the skills of women in a fishing community and thereby improving their social and economic conditions. Coir fiber processing, tailoring and lace (beeralu) making at Ulhitiyawa, Mirissa and Kudawella respectively, were selected after a stakeholder workshop revealed that the small-scale rural industrial sector provides scope for promoting women's skills and employment. Initially, many women in the community showed a reluctance to participate in coir processing as this enterprise, like fish drying and vending, has traditionally been associated with poverty and lacks social and economic status. However, a later study revealed that the Ulhitiyawa coir fiber processing centre was functioning well and the earnings had increased due to the improved market demand, while the Mirissa tailoring centre, on the other hand, faced difficulties due to high availability of cheap imported factory made garments in the local markets (Drewes, 1985). While this has strengthened the role of women in society, it also illustrates that economic realities can supersede common perceptions regarding livelihoods.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE INITIATIVES

Introduction of new alternative livelihoods is an activity that is embedded within a complex system comprised of social, ecological, economic and technological dimensions. For new livelihood options to be adopted by the target communities and continued in the longer term, it is essential to identify the factors that threaten sustainability and to address them in an integrated manner. An activity promoted as an alternative livelihood option must, in addition to being environmentally sustainable, also be financially feasible from the perspective of the target community as a whole as well as the individual. For example, this is an important factor to consider when addressing the dynamite fishery or sea coral mining, where a person can earn a very high income within a day compared to many other locally available livelihood options such as agriculture. Therefore, if the introduced option does not make financial sense, participation will be poor unless some other financial incentives, such as direct subsidies (e.g. Food stamps), are offered.

However, it must also be noted that target communities often have highly unrealistic expectations in terms of income and other benefits from donor funded projects, and therefore, the benefits from projects have to be estimated at a conservative level and expected outputs should be clearly explained to the community. Managing the expectations of communities is as important as managing the resources they rely on. Contributions, inputs and efforts expected from the beneficiaries need to be explained and agreed on at the start of any intervention, and non-participation of individuals for whatever reason in any given intervention should not be seen as a loss of economic opportunity within the community. Social mobilization at the community level should be ensured to enable participants to understand that pilot projects initiated with a limited number of clients, when successful, could be more equitably distributed throughout the community (e.g. CEA/ARCADIS, 2003).

Some of the main recommendations for future alternative livelihood ventures, as identified by the review, are summarized here. For further detailed information, see Perera, 2004.

- Strong commitment from the central government is vital to end any destructive activities that are degrading coral reef resources. The government should support and promote economic diversification as a management option while firmly implementing the existing laws.
- The introduction of new livelihoods should be a part of a wider programme of intervention in coastal resources management (e.g. SAM plan), involving resource users and all other relevant stakeholders. Small-

scale income diversification approaches should be linked with national poverty reduction strategies such as the Samurdhi Programme, or with line agencies such as the National Design Centre to achieve better results.

- More than 30 government agencies have sectoral responsibilities for coastal resources management in the country. If each agency acts in isolation to implement their own work programme without consulting the other agencies, long-term sustainability of a resource will be compromised. For example, in Rekawa, the number of sea coral miners increased due to decreased agricultural productivity caused by poorly planned irrigation. Therefore, cooperation between seemingly unrelated departments such as Irrigation, Agriculture and Coast Conservation, as well as the farming community, is necessary for the rehabilitation of agricultural activities.
- When introducing new technologies through training programmes, educational backgrounds of the participants should be taken into consideration. The younger generation living in the coastal belt has a reasonable level of education and aptitude to learn. Presently, many are employed in activities such as repairing boat engines and diving equipment, but without any technical training. These capabilities can be improved by providing opportunities to enter into vocational training centres, in which enrolment standards should not depend on formal education alone. This will increase the chances of finding jobs, but also improve the quality of work and safety. Training in fields such as electronics, motor mechanics and computing would also put people in a position to venture into 'modern' livelihood options that are not directly depended on natural resources. Skills development in areas such as carpentry and masonry can be promoted to meet market demand for trained personnel.
- The process of obtaining an agreement from a community regarding the possible types of alternative livelihood schemes requires enough time to allow people to discuss different options, negotiate disputes and develop the necessary level of consensus. Effective implementation of the scheme also depends on the process of information exchange, building of rapport and trust between the intervening agency and various stakeholders. Non-governmental agencies and community-based organizations such as fisher folk organizations and women's groups can play a vital role in this. Before an alternative livelihood programme is introduced to an area, such organizations should be identified and strengthened.
- A good understanding of the demographic and social dynamics of coastal communities is needed before introducing a new employment venture. For example, in situations such as Rekawa where women mainly carry out the near shore illegal sea coral mining, it is essential to be aware of gender specific roles in designing projects.
- Similarly, natural or political externalities that may affect a project need to be assessed and taken into consideration. These could include, for example, seasonal weather patterns and infrastructural development plans.
- Rather than trying to introduce new concepts, promoting and upgrading economic activities that already exist within that area is more sustainable. For example, the coconut industry is well established in a few coastal areas. Various coconut-based activities such as production of copra, oil, fiber and arrack distillation, and small-scaled traditional industries such as coir rope, toddy, and mat production, are already well established within rural households. These ventures can be made more economically viable through introduction of new technologies for increased quality and quantity of the final product and by assisting in identification of existing or new markets. Local products can be promoted in the international market by value added approaches such as using attractive packaging to highlight the fact they are locally grown or made. At the same time, new products such as bricks and flowerpots using coir can be promoted.
- Provision of financial services such as revolving funds,

micro-credit facilities and community development funds especially designed for poor communities is essential for long-term sustainability. These financial mechanisms should be flexible to changes occurring in the economic ventures they support as well as market forces.

- Constant monitoring and periodic evaluations of progress of new livelihood ventures with the assistance of independent evaluators is essential to appropriately respond to changing conditions, solve problems, and manage environmental impacts.
- Experiences and lessons learned from projects should be documented and disseminated to policy makers and ground level managers. As the principles of community based management of natural resources vary from case to case, it is important to ensure that policy-makers can and will consider each new venture as a different entity, but based on previous experience. This will also assist them to make relevant changes in legal frameworks and supporting policies. In some instances, institutional reforms should take place, giving more authority to local agencies to manage resources. Also, networking among similar ventures carried out nationally or internationally will assist in duplicating positive results and evading the negative impacts.
- Public awareness programmes should go hand in hand with the implementation of alternative livelihood ventures to ensure success. It is important to make the public aware of the values of coral reefs, the factors affecting them and the ways they can be protected and used in a sustainable manner. Both primary and secondary resource users may damage coral reefs inadvertently if unaware of the long-term importance of healthy reefs, but through outreach they can become partners and key players in management initiatives.
- Many alternative livelihood approaches are primarily based on existing natural resources, and therefore the sustainability of such ventures depends on both environmental factors as well as the level of resource use induced by the alternative livelihood venture. Tools such as certification for environmentally sound practices and green labels for products can be introduced to manage this, as well as to aid marketing.

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Bandaramulla Reef of Southern Sri-Lanka: Present Status and Impacts of Coral Mining

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key words: Sri Lanka, coral reefs, coral mining

ABSTRACT

Bandaramulla Reef is an isolated reef on the southern coast of Sri Lanka where the activities of tourists, fishermen and coral miners are completely unregulated. As a result, the overall health of the reef is gradually becoming degraded. This paper describes the present status of the reef and highlights the impacts of mining activities. At present, the coral community is dominated by *Pocillopora, Goniopora* and *Podabacia*, which are known to thrive in highly turbid waters, while the reef fish community is comprised primarily of herbivores. Questionnaires and direct interviews determined that 81% of coral miners were between 15 and 25 years old and that each miner earns Rs. 375 per hour. In total, these miners remove approximately 60 tons of coral each month, averaging 50 coral bags per day. In order to find sustainable solutions to the degradation of Bandaramulla Reef, recommendations for awareness programs, alternative livelihood options, alternatives for coral lime production and improvements in law enforcement are proposed.

INTRODUCTION

Sri Lanka is a tropical island situated between 5° 55' and 9° 55' N latitude and 72° 42' and 81° 52' E longitude and south of the Indian sub-continent (figure 1). Sri Lanka

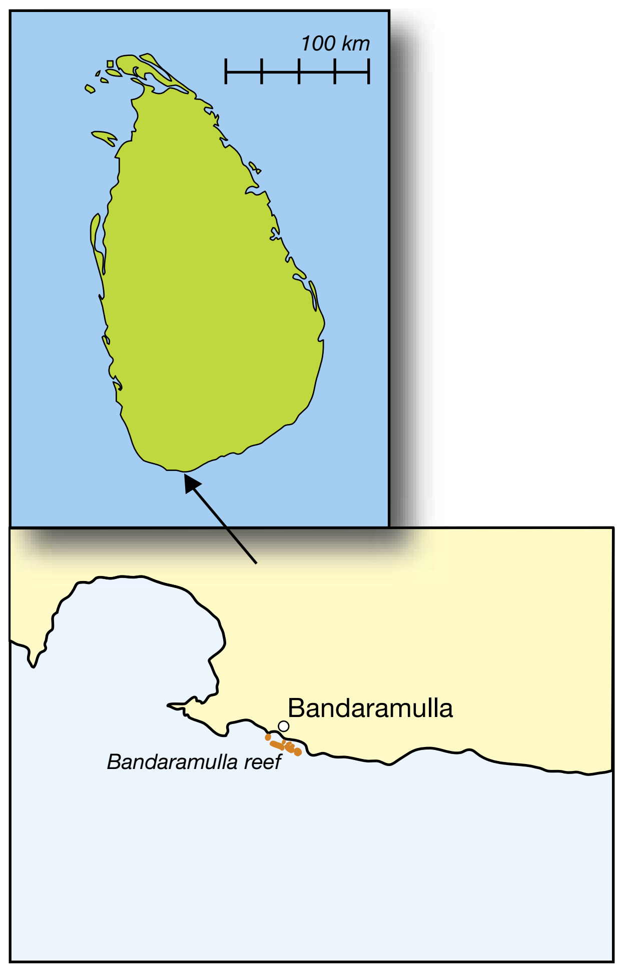

Figure 1. Map of Sri Lanka showing the location of Bandaramulla Reef.

has 1 740 km of coastline and a relatively narrow continental shelf, particularly along the southern coast. Fringing reefs that have formed on rock or limestone substrate abound in the coastal waters off the western, south-western and southern coast of Sri Lanka. In addition, there are a few true coral reefs which tend to be small and isolated fringing reefs (Rajasuriya & De Silva, 1988). During the 1998 El Niño event, corals on about 90% of the reefs in Sri Lanka bleached (Wilkinson *et al.*, 1999) causing considerable mortality. Recovery since the 1998 El Niño has been very slow, moderate or patchy and has been retarded by destructive anthropogenic activities such as dynamite fishing, coral mining, pollution, human settlement, mineral mining, shipping activities and intensive fish collection for the live fish and the aquarium trade. Although coral mining is illegal in Sri Lanka, mining of corals for building materials (Souter & Lindén, 2000) and to produce lime for agriculture and industry still occurs and the resulting degradation of Bandaramulla Reef from intense coral mining is alarming to local fishers.

Coral reefs around the world are incredibly diverse hosting a large proportion of known marine animals and plants. In 1998, it was estimated that the minimum economic value of coral reefs in Sri Lanka was approximately USD 140 000–7 500 000 per km^2 over a 20 year period (Berg *et al.*, 1998). The economic value of coral reefs can be divided into two major components, namely the extractive value and the non-extractive value. The extractive value is derived from the sale of resources harvested from coral reefs such as corals from coral mining, ornamental and food fish and sea cucumbers. Although these extractive activities can cause irreversible damage to coral reefs when conducted in an uncontrolled and unsustainable manner, they provide a short-term profitable source of income for the people involved.The non-extractive value includes the aesthetic qualities of the reef and the white coralline sand beaches that attract thousands of tourists annually and also their essential role in protecting coastlines from erosion by waves (Souter & Lindén, 2000).

Coral mining of living reef is an age-old activity in Sri Lanka, particularly along the southern coast. For centuries, these mined corals have been used for building houses, temples, tombstones and parapet walls to demarcate boundaries. However, these traditional uses have been forgotten and, during the last 20 years, corals have been mined solely for the production of lime for the building and agricultural sectors. In addition to the illegal coral mining conducted on shallow reefs, mining is also carried out on fossil reefs located inland, which supplies most inland areas with lime for building cement. This type of coral mining is legal and is regulated through the issuance of permits.

STUDY SITE

Bandaramulla Reef is located 6 km west of Matara and supports one of the oldest artisanal fishing communities in Sri Lanka. It is a fringing reef which extends for about 500 m across Bandaramulla Bay forming a shallow reef lagoon (figure 2). The depth of the lagoon ranges up to 3 m. The lagoon is occupied mostly by large dead *Millepora* boulders and mounds of *Acropora* rubble. The eastern part of the reef has been completely mined producing considerable quantities of coral rubble and exposing the sand bed during the last four years. Until recently, the central and the western part had not been mined because of the pressure from the fishermen and some of concerned villagers. Unfortunately however, in July 2003, a group of people supported by local gangsters started mining the central part of the reef, especially the reef top (figure 3).

Resources extracted from Bandaramulla Reef lagoon include finfish e.g. jacks (Carangidae), emperors (Lethrinidae), snappers (Lutjanidae), groupers (Serranidae), spiny lobsters (*Panulirus* spp), sea cucumbers (Holothuroidea) and also variety of fish, molluscs, crustaceans for ornamental purposes. Other important fish caught within the lagoon are *Selar crumenophthalmus* (Scads) *Sardinella brachysoma* (Sardinella) and other herring species. In particular, the scad fishery is very important for fishermen as it provides high profits even though fishermen use only traditional fishing gears such as pole and line and hook and line. This fishery is seasonal and exists

Figure 2. Eastern side of the lagoon formed behind Bandaramulla Reef.

Figure 3. Western side of the lagoon formed behind Bandaramulla Reef. Recently mined patches of reef are visible in the foreground as pale areas.

only during particular months of the year. In addition, seaweed culture has been established in the reef lagoon as an experimental trial and is carried out with great enthusiasm by the villagers.

PRESENT THREATS TO THE REEF

Bandaramulla Reef lagoon is an ideal place for traditional fishermen to fish. Unfortunately however, they use large granite boulders to anchor their boats, which crush and destroy everything on the bottom. In addition, the use of gill nets and the trampling corals when casting nets cause severe damage to the reef, especially to delicate corals such as *Montipora* and other newly settled corals. Usage of moxy nets and spear guns, and breakage of corals using crowbars further worsen the situation. Therefore, the low coral cover and diversity in the lagoon is a direct result of such unsustainable destructive fishing practices.

Off site developments cause serious threats to coral reefs because of their sensitivity and the interrelated nature of these ecosystems (Spurgeon, 1992). In addition, the rate of reef recovery from a disturbance will be largely dependent on the anthropogenic impacts and the environmental conditions encountered by newly settled coral recruits. On Bandaramulla Reef, high sediment influx from a nearby part of the shoreline which has been eroded causes severe impacts on coral larval settlement. As a consequence, the recovery rate of is very low while other reefs along the southern coast show promising signs, with large numbers of new coral recruits in many places.

METHODOLOGY

Coral mining activities at Bandaramulla Reef were monitored between July and September 2004. The numbers of bags collected and the number of people involved in mining and transporting mined corals were recorded secretly. In addition, on-site personal interviews were held with coral miners and selected villagers to collect data on the number of trips transported per week, the date of transport, the transportation time, number of bags loaded on the lorry and income levels. On each visit to the reef, the contents of ten randomly selected coral bags were examined. All dead corals within the bags were identified to the highest level possible and the number of live corals in the sample were identified and counted.

The benthic community was recorded using five line intercept transects 20 m in length. Transects were laid parallel to the reef crest and the linear extent of all coral colonies bisected by the line was recorded (English *et al.*, 1994). The cover of each substrate type was calculated as a percentage cover of the total coral cover and then categorized into percent cover classes (see table 2 for details). Fish communities were surveyed along the same 20 m transects. All fish within a 2 m wide band along the transect were counted. Time taken to record each transect was approximately 15 minutes.

RESULTS

Mining Activities

The commencement of mining activities each day varied in order to avoid the attention of police and local villagers and also as a response to tidal variation. Most commonly, mining was conducted very early in the morning around 5 am, and early afternoon around 1 pm or 5 pm. Initially, miners collect robust branching and massive corals from the shallow reef top. Then they break up other larger coral boulders into manageably sized pieces using iron bars. The broken pieces were then placed into polythene bags and lifted onto air filled tyre tubes, which are used to transport the corals ashore. The coral bags are then stored in the shallow water (<1 m) in order to conceal them from villagers and police until they can be loaded for transportation to kilns.

Age Distribution of Coral Miners

Almost all miners are early school leavers within the age group from 15 to 30 years (figure 4). During the non-monsoon season (November to April), they are ornamental fish collectors, hook and line fishermen or are engaged in other shallow water fishing activities. In the Bandaramulla area, some of young fishermen switch to coral mining activities only during the monsoon period (May to October) when the sea is rough and turbid enough to restrict all other fishing activities.

In each ten bag sample examined, dead massive corals predominated, namely *Goniastrea, Porites, Leptoria, Favia, Favites*, *Pavona* and *Platygyra*. The most common live corals found in bags were *Pocillopora, Podabacia, Leptoria, Favia, Favites, Goniopora, Hydnophora, Montipora* and *Galaxea* (table 1). The average number of live colonies in each ten bag sample was 19.44 (±7.29 S.D.). However, these live colonies were relatively small and were usually attached to the large dead boulder corals.

The number of coral bags mined per day is a function of the number of people involved and the time during which mining is permitted by the tidal cycle. The average extraction rate is 55.33 bags per day and the mean weight of each bag is 40.15 kg (±28.55 S.D.) giving an estimated total weight of coral mined within the month surveyed of 66 645 kg. Assuming similar amounts of coral are mined throughout the year, this translates into an estimated annual coral extraction rate of 799 metric tons.

Lorries, trucks and sometimes bicycles are used to transport corals. Loading, unloading and all transportation activities are only done early in the morning be-

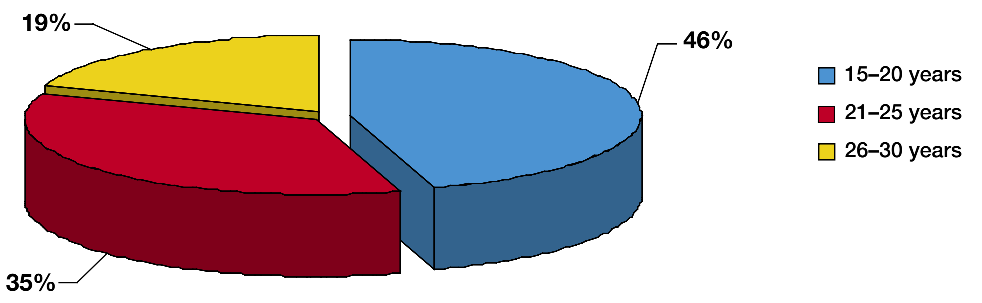

Figure 4. Age distribution of coral miners.

Table 1. Numbers of bags containing live corals transported to lime kilns per month

Date	Number of bags transported	Number of live corals counted in each 10 bag sample	The most common live corals contained in bags of mined coral
03/08/2004	170	24	*Pocillopora, Podabacia, Leptoria*
06/08/2004	155	11	*Pocillopora, Hydnophora*
10/08/2004	180	23	*Podabacia, Porites, Favites, Platygyra*
13/08/2004	140	-	
15/08/2004	140	13	*Galaxea, Montipora*
21/08/2004	190	26	*Pocillopora, Podabacia, Favia, Leptoria*
23/08/2004	160	17	*Pocillopora, Podabacia, Porites*
27/08/2004	175	8	*Goniopora, Podabacia*
01/09/2004	185	26	*Pocillopora, Pavona, Leptoria*
03/09/2004	165	27	*Leptoria, Favia*

tween 0300 and 0530. The middlemen engaged in transportation buy mined coral at the mining site for Rs. 45 per bag and then sell it to the lime kiln for Rs. 75 per bag, thus earning Rs. 30 per bag. The average number of coral bags transported per trip is 166 (±17.44 S.D.) with a value of about Rs. 12 450. The truck owner earns 40% of the total value and the remainder is shared between the miners and those involved in transportation. One single miner earns approximately Rs. 750 per day, which is only about two hours work.

The most abundant live coral species are *Pocillopora damicornis, Podabacia crustacia* and *Goniopora* spp. (table 2). Live coral abundance and cover is extremely low on Bandaramulla Reef primarily because the reef was severely affected during 1998 El Niño event and the recovery since has been very low. Large colonies of *Acropora formosa, A. hyacinthus* and *Millepora* sp. were completely bleached and died. Most remaining corals are less than 15 cm in diameter except colonies of *Goniopora, Porites, Platygyra* and *Leptoria.* Even though baseline data describing the pre-bleaching coral diversity are not available, it is clearly evident that there is a shift in the coral community composition when the existing community is compared with the composition of remaining dead coral colonies. The time needed for the 'original' species composition to be reestablished is extremely unpredictable and will depend

Table 2. Categorised percent live cover of each coral species recorded during surveys of Bandaramulla Reef

Family	Species	Percent cover
Pocilloporidae	*Pocillopora damicornis*	***
	Pocillopora verrucosa	*
Fungiidae	*Podabacia crustacia*	***
	Podabacia spp.	*
Agariciidae	*Pavona* spp.	*
Merulinidae	*Hydnophora minuta*	*
Acroporidae	Acropora hyacinthus	*
	Montipora aequituberculosa	*
	Montipora spp.	*
Poritidae	*Porites* spp.	**
	Goniopora spp.	***
	Alveopora spp.	*
Faviidae	*Favites pentagona*	*
	Favites spp.	**
	Goniastrea spp.	*
	Favia spp.	*
	Platygyra spp.	*
	Leptoria phrygia	**
Oculinidae	*Galaxea fascicularis*	**

* 1– 5%
** 5–10%
***10–15%

Figure 5. Barren substrate caused by mining activities.

on the extent of the damage and the capacity of surviving species to recover (Tamelander, 2002). In addition, unsustainable and destructive fishing practices used in the lagoon, such as moxy nets, spear fishing, and most importantly coral mining have also reduced the coral cover and diversity in the lagoon (figure 5).

The relationship between reef fish diversity and habitat is likely to be a complex phenomenon. The total number and diversity of reef fish were relatively low in shallow waters when compared with the deeper sites of the reef (table 3). The diversity of fish is relatively high along the reef slopes of mined areas compared with the reef top and bottom substrate. It is well known that there is a positive correlation between reef fish communities and live coral cover (Bell & Galzin, 1984). Reductions in coral cover on Bandaramulla Reef caused mainly by mining activities and destructive fishing methods has also caused concomitant declines in the reef's fish diversity. The absence of butterfly fish (Chaetodontidae) during surveys suggests that these fishes could be used as sensitive indicators of the health of coral reefs (Reese, 1981). Detritivorous and carnivorous fish diversity and abundance were greater at the newly mined sites whereas herbivore diversity was the highest at sites that had been subjected to intense mining activities some time ago. Herbivorous pomacentrids and acanthurids dominate the counts.

Table 3. Abundance of each fish species recorded during surveys of Bandaramulla Reef

Family	Species	Abundance
Muraenidae	*Gymnothorax javanicus*	*
	G. undulatus	*
	Echidna nebulosa	*
Serranidae	*Cephalopholus argus*	*
	Epinephelus merra	**
Scorpaenidae	*Pterois volitans*	*
Syngnathiformes	*Fistularia commersonii*	**
Balistidae	*Rhinecanthus* sp.	*
Pomacanthidae	*Pomacanthus annularis*	*
Diodontidae	*Diodon hystrix*	*
Ostraciidae	*Arothron meleagris*	**
Tetraodontidae	*Canthigaster solandri*	*
Pomacentridae	*Stegastes fasciolatus*	***
	Plectroglyphidodon dickii	***
	Plectroglyphidodon lacrymatus	****
	Abudefduf sexfasciatus	**
Pempheridae	*Pempheris* sp.	*****
Acanthuridae	*Zanclus cornutus*	*
	Acanthurus striatus	***
	Acanthurus triostegus	*
	Acanthurus lineatus	**

Number of fish:
* 1– 5
** 6–10
*** 11–15
**** 16–20
***** >20

CONSEQUENCES

While the Bandaramulla area is blessed with the rapid increase of coastal tourism in the southern region, coral mining and other destructive fishing activities hinder this development. Net economic losses in potential tourism and the coastal erosion caused by coral mining, has been extremely high over the past few years. Both ornamental fish collection and the reef food fish industry are in danger of imminent collapse. As a result, tourist visits would gradually decrease due to the reduced aesthetic value of

Figure 6. Small coral fragments resulting from mining activities and the disintegration of coral skeletons after bleaching are highly mobile and have a high potential to abrade and damage almost all bottom dwelling organisms.

the reef caused by coral destruction and ornamental fish removal. In addition, loss of coral reefs in the southern parts of Sri Lanka would drastically affect the people who directly depend on the coral reefs for their income.

Sedimentation, increased beach erosion and pollution caused by mining activities along the coast might result in an array of environmental problems. For example, coral mining has increased beach erosion along the west coast, south of Colombo and along the south coast of Sri Lanka (Wilhelmsson, 2002). The dead coral branches and rubble produced by coral mining are very mobile and their movements cause severe damage to sessile organisms such as sponges, octocorals, anemones, hard corals and all other soft bodied organisms dwelling on the bottom (figure 6).

More than 42% of the bottom surface of the lagoon was covered with sand and silt. There is a large probability that the increased mining activities will expand this sand and silt area. As a result, newly settled corals and other remaining live coral colonies may be subjected to mechanical abrasion and even smothering due to high suspended particle content and vigorous water movement across the damaged reef.

Permanent damage to the reef, the low availability of larval influx, the effect of environmental conditions such as increased current velocity, sediment level and competition with fast growing algae, caused as a result of mining activities would further impede the recovery rate of the reef. In addition, sedimentation and high water currents in the lagoon reduce the abundance of appropriate habitats for targeted fish species restricting artisanal fishing activities which have been practiced for centuries. The abundance of reef fish and all other reef dwelling organisms is dwindling threatening the livelihood of ornamental fish, lobster and sea cucumber collectors.

SOLUTIONS

There is an awareness of the extensive damage caused to the coral reefs from coral mining and other destructive activities. However, miners are poor and not in a position to stop their activities unless there is an acceptable alternative source of income. Therefore, it is a prime target of the government to provide suitable and satisfactory income sources to coral miners. Expansion of present seaweed culture, provision of alternative livelihood options in various sections of the growing tourist industry would be well-accepted solutions.

It is recommended that enforcement of the existing ban on coral mining be improved with better capacity and tools. Corrupt enforcement officers, including police, lack of arrests, delays in bringing cases to court and lack of or improper sentencing are major problems in controlling coral mining. The establishment of a task force with full potential and power to monitor and control all coastal destructive activities around the island, including coral mining, would help in controlling the situation. In addition, finding alternatives for coral lime through surveys for inland lime deposits is needed. Although inland mining activities are practiced, there are number of problems associated with it, such as the pale colour of the lime extracted, the inadequate quantities in the deposits to make the industry economically feasible and low demand. Research for finding new formulations

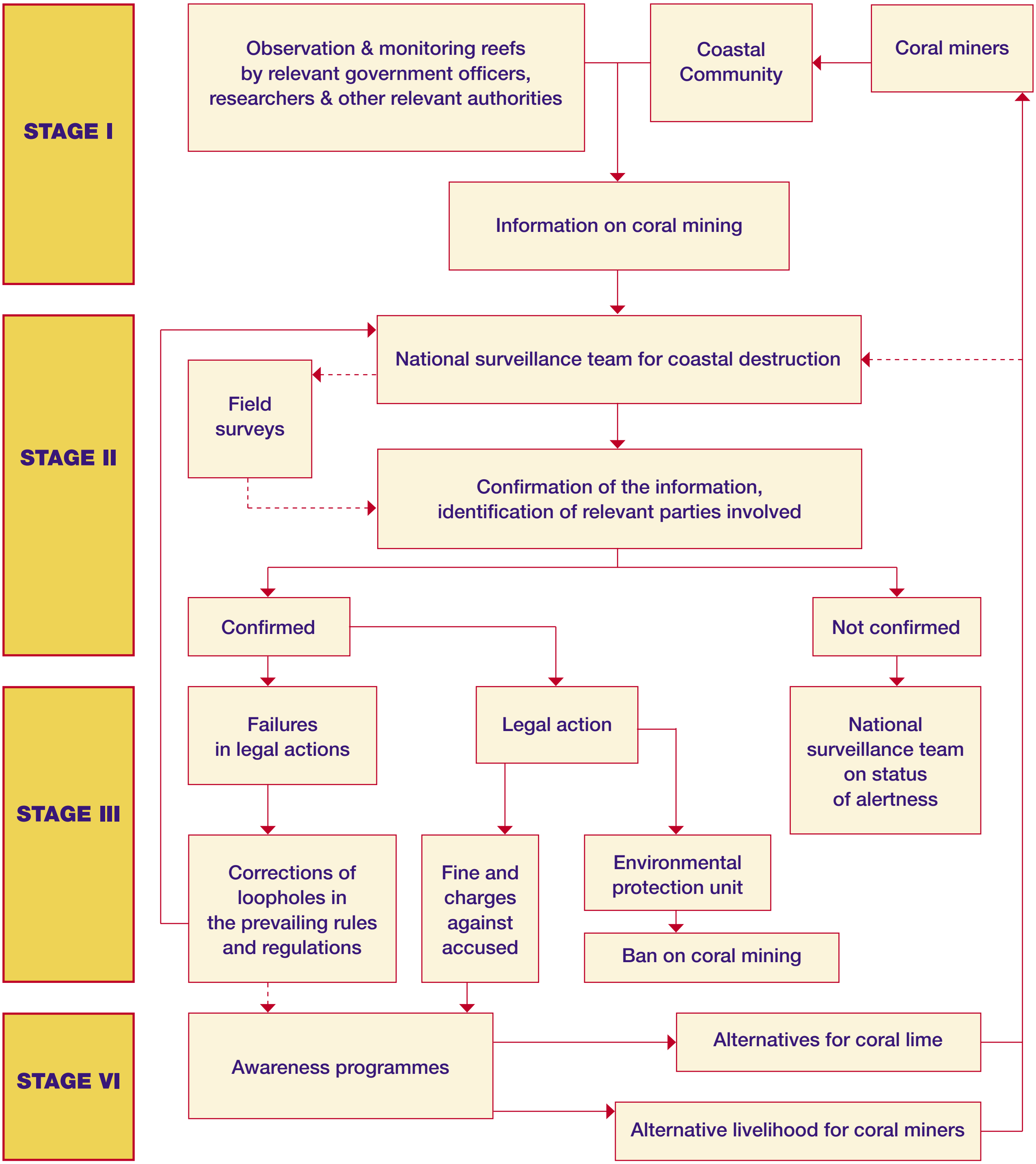

Figure 7. Action plan in the case of coral mining (Adapted from De Silva, 1998).

as a substitute for coral lime provides reasonable solutions to the problem (figure 7).

Mining activities have decreased in some places due to the increased law enforcement efforts and the vigilance of some stakeholders. However, the fines for such destructive activities are relatively low when compared to their income. On the other hand, there are a number of loopholes in existing regulations which make it difficult for law enforcing authorities to bring the accused to the court. Whatever the situation, the government is responsible for strengthening the existing legislations with higher fines, formulating sound regulations and improving enforcement. Various institutes, such as universities, governmental departments, and non-governmental organizations, coral miners, lime kiln owners, inland coral miners and community representatives, should be encouraged to participate in a multi-disciplinary, multi-stakeholder process to formulate a well constructed national policy to solve the coral mining problem.

Finally, there are a number of isolated reefs located around the country that have escaped the attention of scientists, the government, universities, non-governmental organizations or other relevant parties. The biodiversity of those reefs is very high and provide an excellent calm lagoon environment both for animals to live and human to conduct various activities. There should be a programme to identify these places of importance and manage them by legally gazetting them as a natural reserves or marine parks. Bandaramulla Reef is such an unidentified reef but it has been exposed to various threats over the last centuries.

CONCLUSION

Bandaramulla Reef supports a considerable number of fishermen and, during the last two years, has seen an expansion in the tourism industry. However, the reef itself is in great danger due to the low recovery rate after the degradation resulting from elevated sea temperatures caused by the 1998 El Niño event and anthropogenic activities, particularly vigorous coral mining activities that have started during the last couple of months. In order to control the situation, an awareness raising programme organized for the coastal communities on the importance of corals and the implications resulting from their destruction would be beneficial. In addition, alternative livelihoods such as seaweed culture; career opportunities in the tourist industry for coral miners and alternatives for coral lime are some of the possible solutions to the current situation. Strengthening and enforcing existing legislations assuring proper implementation, Sound and strict rules and regulations with high fines for all persons engaged in mining activities and other coastal destructive activities are also necessary. In order to implement the law, necessary facilities, power and acceptable wages for all coastal governing and enforcement officers are essential. Finally, formulation of a permanent national policy to terminate all destructive coastal practices is the final goal for a sustainable usage of non-recoverable natural resources including those extracted from coral reefs.

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Awareness Raising and Feasibility
of Reef Restoration through Coral Transplantation in Tuticorin, Gulf of Mannar, India

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key words: reef restoration, coral transplantation, fish houses

INTRODUCTION

The Gulf of Mannar (GOM) contains 21 islands, which form a chain of small fringing reefs on shallow shores stretching 170 nautical miles between 8º46' and 9º14' N latitude and 78º9' and 79º14' E longitude from north of Mandapam to south of Tuticorin. This area is renowned for its floral and faunal wealth. Patterson *et al.* (2004) reported 104 coral species belonging to 38 genera from the area. A large number of traditional fishermen from the mainland use the reefs as fishing grounds. In 1982, the fishery production in the area was 2 375 tons and in 1983, it was 2 150 tons (Venkataramanujam & Santhanam, 1985). Molluscs, holothurians and algae are harvested in large quantities (Patterson, 2002). Although the conservation authorities of Gulf of Mannar Marine National Park have curtailed destructive reef activities considerably, dynamite fishing and coral mining still occurs in the area.

The Tuticorin coast, which is located at the southern most part of the Gulf of Mannar Marine Biosphere Reserve (GOMMBR), consists of five islands (Tuticorin group) of which one, Villanguchalli, now lies 1 m below mean low water level, as a result of excessive coral mining and soil erosion. Five fishing villages, Pudukadarkarai, Thirespuram, Siluvaipatti, Vellapatti and Tharuvaikulam border the Tuticorin coast, and about 7 000 registered fishermen from these villages depend mainly on fishing around the islands for their livelihood.

Although the average live coral cover around the Tuticorin group of islands is about 29%, large areas of the reefs have been degraded by coral mining, destructive fishing and pollution and, as a consequence, there are no pristine reefs in Tuticorin today (Patterson *et al.*, 2004). However, degraded reefs could recover through natural dispersal and re-colonization by larvae from adult colonies elsewhere (source reefs) if favourable environmental conditions were restored and the pressure from human activities reduced. The time required for recovery would depend on the scale of the disturbance and level of stress on the reef system (Loya, 1976; Harriot & Fisk, 1988) and might be as little as 5 years, but it could also take centuries (Harriot & Fisk, 1988; Edwards & Clark, 1998).

Recovery is particularly slow following episodes causing large-scale coral mortality that results in the disintegration of the reef framework to rubble and unconsolidated sediments, which are, unsuitable for settlement, survival and growth of coral recruits and thus inhibiting natural recovery (Done, 1992). For example, reefs that had been mined in the Maldives showed no recovery after 25 years due to lack of suitable substrata for coral settlement and highly mobile sediment after the mining activities (Brown & Dunne, 1988).

The recovery of a reef area can however be stimulated through, for example, the placement of artificial hard substrata on the seabed to enhance the conditions for colonization (Clark & Edwards, 1995; Thongtham & Chansang, 1998) or by clearing or consolidating loose sediment. Transplantation of corals has been suggested as a viable methodology for expediting the recovery of damaged or degraded coral reefs (Rinkevich, 1995). However, transplantation of entire colonies from an undamaged reef area (donor site) to a damaged site is essentially redistributing the damage, since recovery of the donor site may be slow (Lindahl, 1998). Thus, simple, low-tech methods of coral transplantation that are less destructive to donor sites have been investigated for restoring coral cover to damaged low energy reefs, using unattached coral fragments to mimic and accelerate asexual fragment-driven reef recovery processes (Guzman, 1991; Bowden-Kerby, 2001).

Fragmentation is a very important mode of reproduction among many of the major reef building corals and therefore, is important for the recovery of coral communities after disturbance (Highsmith, 1982). Rehabilitation of coral reefs through transplantation of coral fragments could be seen as a way to by-pass the phases of early slow growth and high mortality rates among newly settled recruits (Harriot & Fisk, 1988) by using the corals' inherent ability to reproduce through fragmentation. In determining transplantation effort in a particular area, results from other regions may not be applicable, since both physical and biological conditions for survival and reef development after transplantation vary greatly among localities and species (Guzman, 1991; Smith & Hughes, 1999). Thus, in order to investigate the feasibility and means of enhancing the recovery of reef areas in Tuticorin through coral transplantation, this study aims to test the survival of different species and growth forms (i.e. massive and branching) at different sites in Tuticorin. Further, this project serves to raise awareness of the importance of corals for reefs and fish populations among fishermen and women from Vellapatti village who are, solely dependent on fishing in the degraded reef areas fringing the islands off the Tuticorin coast (Patterson *et al.*, this volume). All coral transplantation studies were conducted in 4 different sites along the Tuticorin Coast (figure 1).

MATERIALS AND METHODS: INVOLVEMENT OF THE LOCAL COMMUNITY

Coral transplantation was performed with extensive involvement of the local fisher community, to establish awareness and understanding of the importance of corals for reefs and fish populations, and also for cost efficiency. Initially, a survey was conducted together with the fisher folk and an ideal patch reef area outside Vann Island and the park area was selected. The substrate of the site had been denuded by illegal mining and the use of dragnets and was composed predominantly of coral rubble. Before coral transplantation and restoration commenced, several awareness-raising meetings were conducted with the villagers in Vellapatti. The benefits of conserving coral reefs, the ill effects and consequences of destroying reefs and the wise use of non-destructive types of net were highlighted. After the completion of the awareness-raising programme, the women were encouraged to participate in the community-based coral transplantation project activities. A core group of the most interested 30 people was selected to participate and were briefed on the objectives and methodology of the project. Participants were taught how to handle and attach the coral fragments (figure 2) prior to the commencement of restoration in order to promote higher survival of the fragments.

PREPARATION OF CORAL FRAGMENTS AND GENERAL TRANSPLANTATION METHODS

Colonies of branching and massive corals, representing about 3–5% of the total coral population, were collected by SCUBA divers in baskets from a donor site with high coral cover and diversity outside the harbour patch reef at 6.5 m depth. The donor site was about 4km from the 4 study sites and the corals were transported by boat in

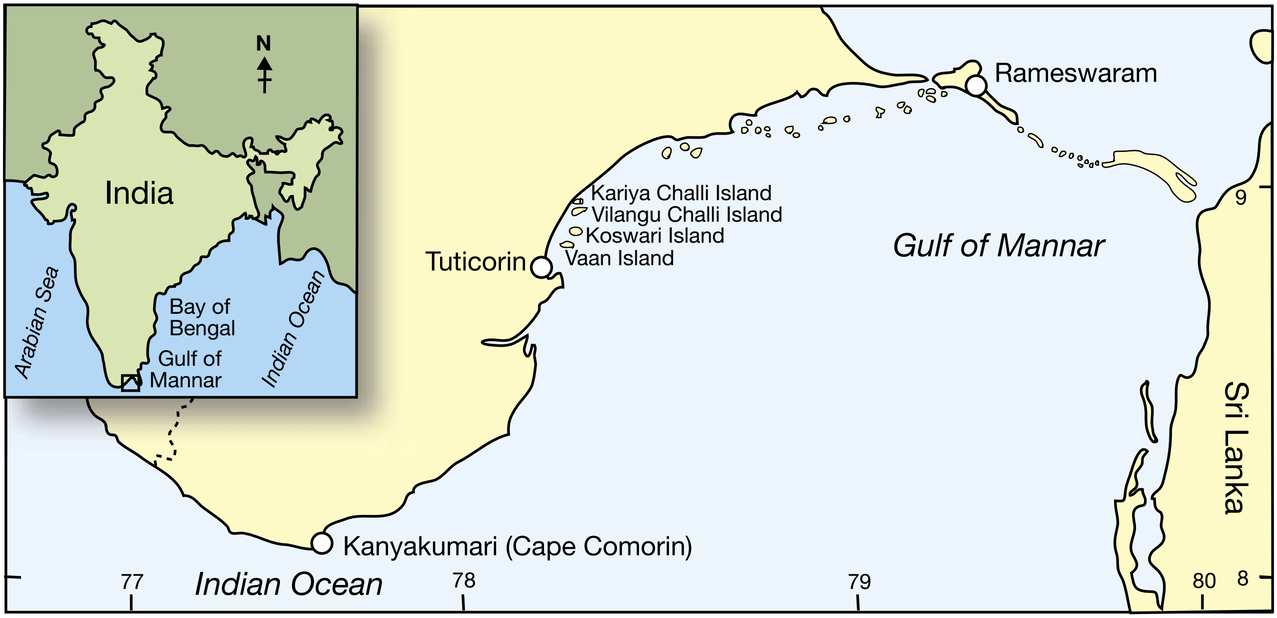

Figure 1. Map showing the study sites.

Figure 2. Training fisher women how to fix coral fragments on ferro-cement slabs.

large fibreglass tanks filled with seawater. During transportation, the fragments were protected from direct sunlight using thick, wet cloth. The water in the tank was changed when the amount of mucus secreted by the corals into the water deemed hazardous to the health of the corals. Colonies of coral with massive, columnar, encrusting, branching, foliaceous and laminar forms were divided into fragments approximately 8 cm in size using a hammer and a chisel and then kept in basins filled with seawater. Fragments were fixed to ferro-cement slabs (20 cm x 5 cm x 1.5 cm) that had been washed in seawater, using nylon ropes or galvanized wires. Initially, the wire was tied tightly around the fragments through holes in the slabs, then around the slab. For each fragment, the firmness of the attachment to the slab was then checked. Loose fragments were retightened before being transferred to the transplantation site. The initial length of each fragment was measured before SCUBA divers placed the slabs on the seabed.

STUDY SITES

Site 1. Tuticorin Port Breakwater

The Tuticorin Port study site is located at Lat. 8°45'N and Long. 78°13'E, encompasses about 1800 m^2 inside the southern breakwater and is totally free of any anthropogenic activities. The patch reef is dominated by branching corals and provides excellent substrate for healthy growth of corals. A preliminary transplantation study was conducted between April and July 2002 where 90 fragments of *Acropora nobilis,* 105 fragments of *A. intermedia,* 25 fragments of *Favia palida* and 30 fragments of *Porites lutea* were collected from donor sites and fixed tightly on different substrates like cement slabs, clay pots and stones using nylon strings and were transplanted on dead coral substrate at a depth of 1.5m.

Site 2. Vaan Island Patch Reef

Vaan Island is situated approximately 5 km from Vellapatti fishing village. Fringing reefs are seen on the south-eastern face of the island while the intertidal zone supports branching and massive corals. The branching corals include the genera *Montipora* and *Acropora* while the massive coral assemblage is comprised of *Favia, Favites*, *Hydnophora*, *Goniopora* and *Platygyra,* all thriving between 1 m and 3.2 m depth. Transplantation was conducted outside the area of Vaan Island Park in September 2002. Data describing growth and survival was subsequently collected during the period between September 2002 and August 2003. Fragments of *Acropora nobilis* (60), *A. cytherea* (55), *Montipora foliosa* (30 fragments), *M. hispida* (26) and *M. divaricata* (40) were fixed on a concrete frame and deployed at a depth of 5.6 m.

Figure 3. A 12 month old culture of *Acropora intermedia*, *A. cytherea*, *Tubinaria mesentarina* and *T. peltata* growing on concrete frames deployed at a depth of 5.5 m.

Site 3. Harbour Area Patch Reef

The third site was a patch reef 5 km in length situated approximately 1.2 km offshore near the harbour. This site is largely composed of sand with a dense cover of monospecific *Turbinaria* sp. at a depth of 5.5 m. In February 2003, 10 concrete frames, each with a surface area of 1 m^2, were deployed as platforms upon which fragments of *Acropora intermedia* (35), *A. cytherea* (21), *Tubinaria mesentarina* (25) and *T. peltata* (20) were transplanted (figure 3). The concrete frames and transplanted coral covered an area approximately 3 m long and 3 m wide. Data describing the growth and survival of fragments was collected until January 2004.

Site 4. Harbour Area Patch Reef – Fish Houses

At this site, a novel low-tech method for reef restoration termed 'Fish House' was investigated (figure 4). The fish houses were constructed using cement and limestone. This artificial structure was served a dual purpose – to enhance the fish assemblage and as substrate for coral transplantation. Each fish house consisted of 3 or 4 holes

Figure 4. Fish house, constructed using cement and limestone.

and coral fragments were fixed on the structure between the holes using nylon rope. In July 2003, 40 fish houses, supporting a total of 150 coral transplants, were deployed at a depth of 5.5 m over an area of 25 m^2. On each fish house, 3 or 4 fragments of *Acropora intermedia* and *A. cytherea* were fixed. Growth and survival data was collected between July 2003 and June 2004.

Survival and Growth Rate

Initial survival of the coral fragments was recorded 15 days after transplantation, and further subsequent measurements of survival and growth were recorded monthly. Estimates of growth were obtained by measuring the length and width of each fragment using Vernier callipers and recording them on underwater slates. The average growth of each fragment was calculated as the geometric mean diameter (Clark & Edwards, 1995). Data was collected for a period of one year and processed using 2-way ANOVA to find out the difference in growth rate between sites and coral types (branching and non-branching corals). Underwater photographs of the transplanted fragments were taken using a Canon digital camera.

Sedimentation Rates

Heavy sedimentation adversely affects coral recruitment, growth and survival, and can result in fewer coral species, lower growth rates and greater abundances of branching forms and decreased net productivity (Roger, 1990). In this study, the sedimentation rates were estimated by using sedimentation traps (English *et al.*, 1997). Five sediment traps were deployed in two coral transplantation sites (Site 2 – Vaan Island patch reef, Site 3 – Harbour area patch reef) and the contents were collected monthly. The collected samples were sieved to separate particles into different size categories using a sieve shaker and the particle size composition was analysed using Wentworth's scale (1922). Once sieved, each fraction of the sample was weighed and the average sedimentation rate was calculated and recorded.

RESULTS

The preliminary experiment was conducted at site 1 for 4 months and the overall survival of transplanted corals was 75%. Survival of branching corals, *Acropora nobilis* and *A. intermedia,* and non-branching *Favia palida* and *Porites lutea* was 80% and 70% respectively and growth rate was 2.15 cm ± 0.08 and 0.94 cm ± 0.04. respectively. In subsequent experiments conducted at sites 2, 3 and 4, overall survivorship of transplanted coral fragment after one year was 73.84% (figure 5).

Generally, branching corals had formed the second-

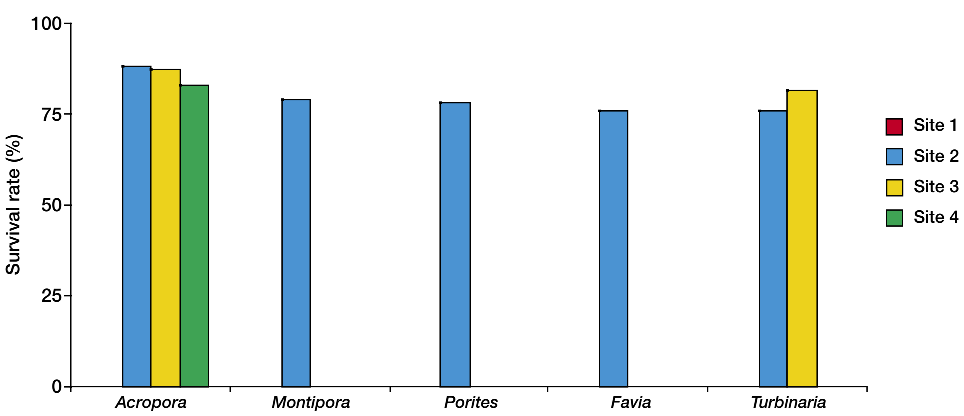

Figure 5. Survival rate of transplanted corals of each genera at each site.

Table 1. Mean annual growth rate (cm·year^{-1}, ± S.E.) of the transplanted corals at different sites

	Site 1	Site 2	Site 3	Site 4
Acropora intermedia (n=60)	–	–	11.75 ± 0.74	9.58 ± 0.31
A. cytherea (n=60)	–	8.17 ± 0.30	9.32 ± 0.80	6.80 ± 0.18
A. nobilis (n=60)	–	4.81 ± 0.18	–	–
Turbinaria mesentarina (n=60)	–	–	1.14 ± 0.09	–
T. peltata (n=60)	–	–	1.98 ± 0.17	–
Montipora foliosa (n=60)	–	2.06 ± 0.09	–	–
M. hispida (n=60)	–	2.65 ± 0.18	–	–
M. divaricata (n=60)	–	1.24 ± 0.04	–	–
Porites lutea (n=60)	–	1.85 ± 0.11		
Favia palida (n=60)	–	1.53 ± 0.08		
Branching coral (n=20)	2.15 ± 0.08	–	–	–
Non-branching coral (n=20)	0.935 ± 0.04	–	–	–

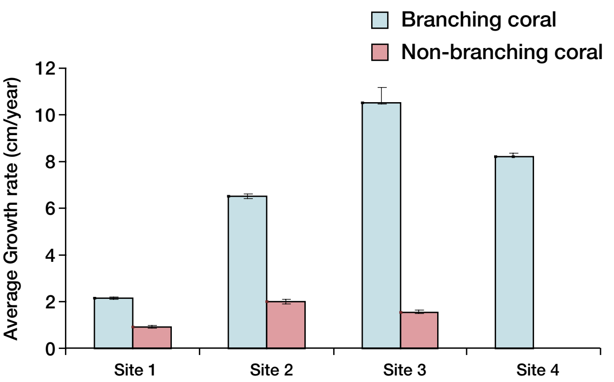

Figure 6. Average growth rate (± S.E.) of branching and non-branching corals at each site.

ary basal disc within 10 to 20 days after transplantation, while non-branching corals required between 20–30 days. All fragments were completely fused to the substrate after 3–5 weeks. A few fragments were toppled by wave action and were subsequently buried by sand killing them.

The growth and survival rate of the different species of corals at the different sites is presented in table 1. The fastest growth rate was recorded for *A. intermedia* transplanted at site 3. At all sites, branching corals showed higher growth rates than the non-branching corals (figure 6 and 7). The results of 2-way ANOVA showed that the difference in the mean growth rate of the branching

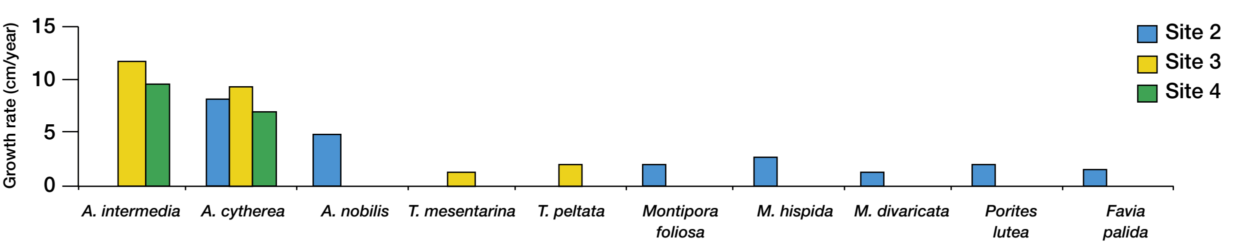

Figure 7. Average growth rate of each coral species at sites 2, 3, and 4.

Table 2. Summary of results of 2-way ANOVA investigating differences in the rates of growth of branching and non-branching corals at different sites after one year

ANOVA *Source of Variation*	*SS*	*df*	*MS*	*F*	*P-value*	*Level of Significance*
Between coral types	65.49974	1	65.49974	10.19812	0.04958	P<0.05
Between sites	20.63327	3	6.877755	1.070846	0.478225	P>0.05
Error	19.26819	3	6.422729			
Total	105.4012	7				

Branching corals (*Acropora intermedia, A. cytherea, A. nobilis*) and Non-branching corals (*Turbinaria mesentarina, T. peltata, Montipora foliosa, M.hispida, M. divaricata, Porites lutea, Favia palida*)

Table 3. Analysis of sediment collected at sites 2 and 3

Sediment size	Site 2 (Vaan Island patch reef)	Site 3 (Harbour area patch reef)
Medium sand (%)	22.17	54.34
Fine sand (%)	30.28	32.98
Very fine sand (%)	47.28	11.38
Average sedimentation rate (g/month)	212.17 ± 34.63	202.45 ± 33.0

and non-branching corals did not differ significantly between the sites (table 2) but that the growth rate of branching corals was significantly greater than non-branching corals.

Sediment Analysis

Medium sand

An average of 54.34% medium sand was found at site 3 due to the sandy bottom and high wave energy. Site 2 had 22.17% medium sand and is characterized by a sandy bottom with rubble, dead coral and algae.

Fine sand

An average of 32.98% fine sand was found at site 3, followed by site 2 with 30.28%. The higher percentage at site 3 may be due to the action of water currents.

Very fine sand

An average of 47.28% very fine sand was found at site 2, followed by site 3 (11.38%) which exhibited a greater composition of coarse particles.

Sedimentation rate

Site 2 showed an average sedimentation rate of 212.17 g·month^{-1} (± 34.63), followed by site 3 (202.45 g·month^{-1} ± 33.0). The highest (299.75 g·month^{-1}) and lowest (162 g·month^{-1}) sedimentation rates were recorded at site 2 during July (2003) and April (2003) respectively.

The composition and rate of sedimentation at sites 2 and 3 is summarised in table 3.

DISCUSSION

Large coral fragments often have higher survivorship probabilities (e.g. Hughes & Jackson, 1985; Done, 1987; Smith & Hughes, 1999), but obviously, it is a trade-off between size and numbers of fragments that can be generated from a single donor site. With the techniques used in this study, fragments of only 8 cm showed relatively high rates of survival. For example, the survival rate of transplants in this study was 73.84% after one year and was considerably greater than the 40% survival of larger transplants used in a study at Sumilon Island, Philippines after the same period (Alcala *et al.*, 1982).

Edwards and Clark (1998) argue for less focus on transplanting fast-growing branching corals, with relatively high mortality rates after transplantation and generally quite good natural recruitment rates. Instead, when transplantation is justified at all, they recommend slow growing massive corals, with high post-transplantation survival, and low natural recruitment rates. On the other hand, branching *Acropora* corals can provide structural stability binding reef elements, thus enhancing the habitat for other sessile organisms (Gilmore & Hall, 1976; Connell & Keough, 1985; Lirman & Fong, 1997). Further, post-transplantation mortality rates are highly site and species specific (Edwards and Clark, 1998), including between species of *Acropora* (Clark and Edwards, 1995), and relatively good post transplantation survival rates have been shown for example by *Acropora intermedia,* a species suggested to be relatively well adapted to fragmentation as a natural reproduction strategy (Smith & Hughes, 1999). This species showed the highest growth rate among the transplants in this study. Furthermore, this experiment generally showed a slightly higher rate of survival of fragments of *Acropora* than of other genera, which also have been shown by Alcala *et al.*, (1982). We thus suggest that when natural recruitment is inhibited, for example by unconsolidated rubble unsuitable for settling and survival of recruits, transplantation of *Acropora* corals can be appropriate, although the particular species used should be selected with care.

In the present study, the experiments were carried out based on the findings of the pilot study indicating that nylon rope may be more suitable than the galvanized wire to secure the fragments. Further, the concrete slabs were found to be the most suitable substrate on which to transplant fragments. This information can be used to enhance future restoration efforts in the area and may be useful in determining the needs for subsequent rehabilitation actions to enhance fragment survivorship. Further, Rinkevich and Loya (1985) found that contacts between fragments of *Stylophora pistillata* from different colonies resulted in reduced rates of growth and reproduction. Therefore, the described method of coral transplantation would probably work best if fragments that are attached to the same string section originate from the same colony. The faster growing genus *Acropora* accreted to the concrete substrate within 2 months while massive corals took longer to accrete. Highest growth rates occurred in fragments of *Acropora*, a genus of relatively fast growing corals.

In the transplanted fragments, the polyps and proto branches started developing from the second month onwards because early basal disc formation consumes some time before vertical growth begins. The main problem faced by transplants was competition for space on the substrate because some gastropods routinely occupy the area, minimizing the opportunity for the transplanted corals to expand horizontally. The present study indicates that the sedimentation rate is minimal, and affects the corals to a minor extent only. An exception is the colonies of *Turbinaria* spp. at site 3, where sediments accumulate inside the cup shaped structure of the colony, which may lead to the slow mortality of the coral.

Coral transplantation by the fragmentation method using cement block substrata is a relatively labour intensive method, compared to for example the 'seeding' of unconsolidated coral fragments on the seabed. However, in our view, the higher survival rates compensates for the increased labour of fixing the coral fragments to solid substrates, and also spares donor sites from repeated collection to replace dead fragments. Also, transplantation on the cement frames helps to protect the fragments from sedimentation. Thus, this method for restoring damaged coral patches may in the long term and conducted at larger scales be a viable way to rehabilitate a damaged coral reef environment and restore the marine life in specific areas along the Tuticorin Coast.

The involvement of local community in the reef restoration work created awareness among the fisher folk of the need for conserving corals and associated resources. Also, the fisher folk improved their understanding and skills in communicating issues about their environment and resources. This participatory involvement in resource management is considered vital for the protection and conservation of corals by the fisher folk themselves.

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Improving Living Conditions for Reef Dependent Fisher Families

in Tuticorin, Gulf of Mannar, Southeast coast of India

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key words: alternative livelihood, vermi-composting, crab fattening

INTRODUCTION

The Tuticorin Coast is the most environmentally stressed coastal area in the Gulf of Mannar (Patterson, 2002). Population increases, lack of other employment opportunities, and low literacy levels force local villagers to depend mainly on the marine resources that can be harvested from around the four coral reef fringed islands off the coast. As most of the fishermen do not have adequate financial support for large vessels, they are restricted to reef areas that are easily accessible with small boats. Strained by decreasing fish catches, they are often compelled to use more effective and also destructive fishing methods, which reduce the productivity of the reefs even further. Overfishing and the use of destructive fishing methods have been prevalent for many years. Coral mining has been practiced for the past several decades, and many poor fishermen are involved in this illegal practice for their daily livelihood (Patterson, 2002). The number of boats involved in mining varies with the fishing season. Although this practice is now considerably less common, it still persists. Cyanide fishing is used to catch reef fishes and the use of various types of destructive fishing nets such as beach seine nets and trawl nets are causing harm to the benthic environment in Tuticorin. Further, a small section of fishermen are also involved in dynamite fishing using gelignite sticks to kill shoaling fishes which, in turn, destroys the whole reef habitat. Lack of awareness and adequate literacy, limit the villagers understanding of the long-term value of the resources. The development of many industries along the coast, destruction of mangroves for saltpans, and disposal of domestic sewage also pose considerable impact to this ecosystem and the dependent coastal folk (Easterson, 1998; Murugan & Patterson, 2000).

Suganthi Devadason Marine Research Institute (SDMRI) has implemented series of activities to make coastal communities in five selected villages along the Tuticorin coast less dependent on the coral reef resources by providing opportunities for income diversification and alternative livelihoods. Further, efforts have been made to raise the awareness of increasing problems. In order to reduce pressure on the reefs, and make people less vulnerable to changes in the supply of food and income from these ecosystems. This report summarizes the findings and results achieved to date through the following projects:

- Assessment of the socio-economic and fishery status in the villages;
- Creating awareness on the sustainable use of the marine resources;
- Introduction of alternative and supplementary sources of food and income to fisher families.

SELECTED VILLAGES

The Tuticorin Coast in the Gulf of Mannar is the core region of the southern part of the Marine Biosphere Reserve. Five villages namely Tharuvaikulam, Vellapatti, Thalamuthu nagar/Siluvaipatti complex, Thirespuram and Inico Nagar are dependent on the adjacent reef areas for the fin and shellfishes.

Tharuvaikulam (population: 10 085) is located about 15 km from the main town of Tuticorin.

Vellapatti (population: 2 138) is located about 11 km from Tuticorin. The village is unique as the crab fishery is a major occupation. Recently, a few families have started to operate other gears for trapping of finfishes.

Thalamuthu nagar/Siluvaipatti complex (population: 13 951) includes six fishing villages namely Siluvaipatti, Thalamuthu Nagar, Sameer Vyas Nagar, East Kamaraj Nagar, Anand Nagar and Jesu Nagar. They have a common landing site at Siluvaipatti. The villages are situated close to each other and are located 5 km away from Tuticorin. The chief fishery of these villages is shrimp but it is augmented by small-scale seasonal fishing for cephalopods, emperors and siganids.

Thirespuram (population: 19 368) is located about 1 km north of Tuticorin. It is one of the oldest fishing settlements in this district and the fishermen have migrated to other places.

The total population in Inico Nagar – called Pudukadarkarai (New shore) until 2002 – is 2 189. The major fishery is sardines. On the southern side of this village, there is a small estuarine complex which is lined by stunted *Avicennia marina*. Sometimes the fisher folk also engage in collecting shrimps by hand picking in the mangrove areas.

FISHING ACTIVITIES

All these fishing villages depend mainly on fishing on the reef areas around the Tuticorin group of islands; Vaan, Koswari, Vilanguchalli and Kariyachalli. At Tharuvaikulam, boats leave the village by 3 pm and return by 8 am the following day, while at Vallams, boats leave by 4 am if the target species are finfishes and return by 8 am the same day.

A wide variety of species are landed at Tharuvaikulam, while other villages have more specific target species. In Tharuvaikulam, all 7 gears (table 1) are effective enough to bring in good catches and there are no trawling activities carried out in the village. The whole set up is very healthy and the fishing is sustainable. Good catches of emperors, groupers, jacks, skates and snappers are obtained using maya valai which, along with nets like 5 no valai, 2 no valai, and the irupuri valai, are modified gill nets. Nandu valai is a modified bottom set gill net used to catch crabs. The annual catch of crabs at this village was 104 tons, 90% of which was blue swimming crabs (*Portunus pelagicus*), 7.5% mud crabs (*Scylla serrata* and *S. tranquebarica*), 1.5% crucifix crab (*Charybdis ferriata*) and 1% three spot crab (*Portunus sanguinolentus*).

More than 31 species of gastropods were obtained as by-catch and were usually utilized for shell industries. A variety of fish species were available in the particular fishing village. The landing centers display some reef fishes

Table 1. The type of fishing gear used by fisherman in each of the selected villages along the Tuticorin Coast, Gulf of Mannar, India

Village	Gear
Tharuvaikulam	Paru valai, 5 No. valai, 2 No. valai, Maya valai, Crab nets, Hooks and lines, Irupuri valai
Vellapatti	Crab nets
Thalamuthu/Siluvaipatti	Push nets, Shore seines
Thirespuram	Maya valai, Mural valai, Nandu valai, Paru valai, 2 no valai, Disco valai, Irupuri v Chala valai, Singhi valai, Kola valai and Trawls like Thallumadi, Ola valai, Kara valai, Hooks
Inico Nagar	Chala valai

that are also landed as by-catch in many of these nets. Some species like butterfly fishes, angelfishes and trigger fishes are consumed locally as well as exported to the neighbouring Kerala state.

At Vellapatti, fishing occurs just once a day. The nets are set around 4 pm and are retrieved at 5 am the next morning. The catch is brought ashore at 9 am and all auctions take place where the catch is landed. Almost 293 tons of crabs have been landed annually, mainly blue swimming crabs, three spot crab, crucifix crab and mud crabs.

At the Thalamuthu nagar/Siluvaipatti complex, fishing is conducted only once per day. The fishermen leave during the night or early in the morning and return around 10 am. In Thalamuthu nagar complex, push nets were used to catch 60 tons of shrimps and associated by-catch of, gastropods, bivalves and crabs. Shore seines targeting emperors, siganids, crabs and cephalopods have produced 11.89 tons annually.

In Thirespuram, fishermen leave by 5 am and return before midnight with catches comprised mostly of both shell and fin fishes. At Inico nagar, the major fishing activity is focused on capturing shoaling sardines. The fishermen leave around 1 am and return by 8 am.

Different types of fishing gears are used in each selected village (table 1). In Tharuvaikulam and Thirespuram, a wide variety of gears are used, ehereas in Vellapatti and Inico nagar, fishermen practice only crab and sardine fishing respectively. In the Thalamuthu nagar complex, only push nets and shore seines are used.

Fishermen from these villages also use different types of vessel. The most common vessels used at Tharuvaikulam are both the large boats that operate gill nets and vallams, which are indigenous country crafts. At Vellapatti, on the other hand, only vallams are used for fishing related activities. Fishermen in Thalamuthu nagar and Thirespuram also have vallams but fish for reef fishes like emperors, groupers and snappers. At Inico nagar, the vallams are used only to catch sardines.

ASSESSMENT OF SOCIO-ECONOMIC STATUS

Questionnaires were used to acquire pertinent household, socio-economic and fishing related information. Interviews were then conducted with focus groups such as the village administration and fisher folk of either sex.

The majority of the coastal families in the five villages depend solely on the income generated through fishing activities for their livelihood. Many fishing families are poor and lack the basic facilities such as clean drinking water, sanitation and electricity. Health and education seem to be the immediate issue in parallel with poor sanitary conditions. The five villages have different modes of fishing with a variety of gears. Illegal coral mining is considerably less common and more efforts to raise awareness of the damage this activity causes in the area can eradicate this occupation.

Annual Income of Fishermen

Tharuvaikulam: The average annual income depends on the type of vessel used by the fisherman. Fishermen who are involved in fishing with small boats earn about Rs. 30 000–45 000 annually, while those involved in fishing with traditional vallam earn between Rs. 25 000–30 000 annually. The poorest fishermen are those that operate small 'vathai', which are generally used to transport goods and fishermen from the small boats to the shore.

Vellapatti: Fisher folk earn average annual income of between Rs. 30 000 and 45 000, although there are seasonal differences throughout the year. During peak seasons, they are able to earn Rs. 1 000 per day while during the lean season only Rs. 50–100 per day is earned.

Thalamuthu nagar: The fishermen are able to earn about Rs. 35 000 to 45 000 annually. During peak seasons, they earn around Rs. 1 000 per day while during the lean seasons they are satisfied with a meagre Rs. 75 per day.

Thirespuram: The average annual income of fishermen in Thirespuram varies according to the species targeted or the type of fishing they are engaged in. Chank divers earn up to Rs. 500 per day during the peak seasons while sometimes, they do not even earn a single rupees. Gill net operators, earn around Rs. 600–800 per day during

the peak season and only Rs. 50–100 during the lean season. Fishermen who are employed as deck hands on trawlers, work in shifts with one day on and one day off and earn around Rs. 150 per working day.
Inico nagar: The average annual income of fishermen in the sardine fishery is estimated to be around Rs. 15 000–21 000, with monthly incomes fluctuating, between Rs. 750–2 000 depending upon the season.

The Role of Self Help Groups

The Self Help Groups (SHGs) in all villages play a major role in the generation, saving and wise use of financial resources. The Government is encouraging SHGs in order create confidence among the women. In Indian culture, the women at home play an important role in maintaining the family and also it is believed that the women would be more reliable in repayment of borrowed funds and so it would be easy to sustain any programmes with their involvement. The majority of the women SHG's are under the control of the Tuticorin Multipurpose Social Service Society (TMSSS) run by the Roman Catholic Diocese. The Bishop of Tuticorn District is the president and is assisted by several members. There are 98 SHG's under the administration of the TMSSS in all the coastal villages of Tuticorin with a total of 2 019 members. The main objectives of the TMSSS are to:

- bring socio-economic changes by organizing technical programmes;
- develop skills for income generating programmes;
- improve the sense of saving;
- remove illiteracy among children below 14 years of age.

The number of SHG's in each village varies with the population of the respective village. Each SHG consists of a president, secretary, treasurer and 17 members. In each village, all the SHGs are managed by a single coordinator who meets with the groups once a month to assess and co-ordinate their activities. The SHG's play a leading role in the generation and administration of saved funds. The amount saved by each varies but ranges between Rs. 50 000 and Rs. 100 000 (US$ 1 064 and 2 128). The total savings of all 98 SHGs of Tuticorin up to March 2002 was Rs. 5 030 843 (US$ 107 039) (TMSSS Annual Report 2001–2002). Each group deposits their savings in a bank and the related original papers are lodged at the TMSSS office. Each SHG meets once in a week in order to discuss the wise use of funds, repayment of loans and the plan for the coming week.

The savings were loaned to SHGs for various purposes, so that they could avoid borrowing from moneylenders at high interest rates, which was found to be one of the reasons for the continued poor economic status of the households. In order to rectify this situation, women within the villages were encouraged to increase their savings to enable them to use the available funds for income generating activities. On behalf of each SHG, TMSSS takes a loan that is three times the amount of the total saved by each group and distributes the money to the members of respective groups based on their contribution. Each member is required to pay back the amount loaned in monthly instalments within 21 months at 9% interest. The women use these loans mainly to help their family members (husband/sons) to buy fishing materials or for family functions. In addition, women belonging to SHGs are empowered in social and economical domains and actively participate in decision making and planning processes, linking them with micro-enterprises and banking institutions (Patterson, 2003).

The livelihood of fishermen is jeopardized by declining reef resources resulting from overexploitation by growing populations and an ever-increasing number of fishing boats, which are employing increasingly destructive methods to catch fish. In addition, all fishing activities within these villages tend to be controlled by middlemen who offer loans to fishermen for boats and nets in return for a certain portion of their catch to be sold to them at a low fixed price. The inability of fishermen to sell their entire catches at fair market prices has hindered the economic development and financial security of many coastal fisher folk. For example, at Inico Nagar, all the auctions are carried out through middlemen who get a commission of 6–7%. As a result, the fishermen are forever indebted to these middlemen who grow wealthier while the fisher folk who carry out all hard work obtain only meager prices for their catches. The basic reasons behind the problems are lack of awareness and alternative livelihoods.

CREATION OF AWARENESS

In 2001, a survey to assess the awareness of fisher folk about corals determined that only 29% of men and 3.1% of women were aware of the ecological significance of corals (Patterson *et al.*, 2002). Thus, SDMRI has conducted series of awareness programmes in these villages, to promote the importance of corals, healthy fishing practices and the need to curb illegal coral quarrying and destructive fishing practices (figure 1). Mainly fisher women were targeted as they play a very important role within the family and social set up. By explaining to the women the ill effects of coral quarrying, the loss of habitat for many fin and shellfishes and loss of potential fishery zones in the near future, the message subsequently reached the ears of active male fishing representatives in their family. The awareness programmes also focused on families actively involved in removing live and dead corals from the offshore islands and, as a result they have now started to argue against destructive activities in all villages. In Vellapatti, coral quarrying has stopped totally, and the fishermen have also adopted less destructive fishing methods. The fisher women in Tharuvaikulam are strongly opposing coral mining and destructive fishing which has curbed these activities considerably. The practice of dynamite fishing using gelignite and amatol sticks has ceased completely in Thirespuram village, once famous for this type of illegal fishing. The women fisher folk have turned out to be the most effective educators of the male working members of their families. They have also informed their Self Help Groups (SHGs) that conservation should be practiced by them in order to maintain the resources for future generations. Following the completion of this series of awareness programmes, another survey of the knowledge about ecological significance of corals among male and female fisher folk determined that awareness levels had increased beyond 80% and 20% in males and females respectively. Through our awareness programmes, the basic knowledge about the need of conservation of the coral reef ecosystem was increased substantially.

Figure 1. Coral reefs awareness programme in Tharuvaikulam village in Tuticorin coast.

ALTERNATIVE LIVELIHOOD SCHEMES

In order to improve the living conditions of fisher folk and to reduce the pressure in the marine ecosystem, alternative livelihood schemes were introduced to empower the women under Self Help Group (SHG) to earn extra income on their own, to help their family to enhance their socio-economic status.

Apart from short-term training programmes on pickle preparation from marine fishes and shrimps, no viable alternative livelihood programmes have been implemented in the past. SDMRI has involved in the capacity building especially on vermi-composting, crab fattening and development of value added products from under-utilized resources such as gastropod meat with support from CORDIO and other agencies.

Vermi-Composting

Vermi-composting is a simple technique of converting biodegradable wastes into value added biofertilizer using earthworms. Earthworms breakdown degradable waste and consume it along with the soil. Further, the breakdown is taking place in the intestine of the earthworms by the microorganisms and digestive enzymes present in the intestine. The digested materials are expelled in the form of granules called *worm casts*, which are seen in the top layer of soil. The worm casts along with the urine and other secretions of the earthworms, dead adult worms and enormous quantities of beneficial microorganisms are collectively called *Vermi-compost*. The vermi-compost contains all the micronutrients, humus and organic matter, essential for soil health and plant growth.

Vermi-Compost Preparation

A pit of 2 m x 0.5 m and 1 m deep is dug in the soil and a 5 cm layer of broken bricks or pebbles is spread at the bottom. Thereafter, a thick layer of sand is spread over the pebbles to drain excess water. A layer of soil is spread on top of this, and, after being moisturized, the soil is inoculated with locally collected earthworms. Small lumps of cow dung are placed over the soil and covered with bio wastes like for example dry leaves. This process of spreading alternate layers of cow dung and bio waste is repeated until the pit is filled. Water is sprayed liberally until the entire contents of the pit are moist but not wet. The pit is then watered and monitored regularly for about 25 days, and kept covered with coconut or palmyrah leaves to prevent disturbance of the vermi-bed by birds. After 25 days, the appearance of juvenile earthworms is a healthy sign. Water management is the most important criteria in vermi-culture, as worms require moisture for their survival. Once a week the contents of the pit should be turned upside down for uniform conversion.

As the compost is getting ready and the change of refuse into a soft, spongy, sweet smelling, dark brown compost is noticeable, no additional water is added which compels the worms to move into the vermi-bed. This will facilitate the harvesting of the compost without much damage to the worms. The harvested compost is placed in the form of a cone on a solid ground in bright sunlight. This will facilitate whatever worms still present in the compost to move to the lower layer. We can recover the worms from the lower layers of the compost and transfer them in a new composting unit.

Benefits

The organic wastes generated every day, which otherwise can cause environment and health problems can be recycled. The use of vermi-compost will reduce the quantity of the chemical fertilizers. This reduces the input costs for cultivation. And there are no ill effects when using vermi-compost excessively unlike with chemical fertilizers.

The wastelands will be improved when the application of vermi-compost and the introduction of earthworms improve the soil properties. Vermi-compost will change the structure of the soil and provide oxygen to the roots of the plants. Further, an enhanced disease resistance will be developed in the soil.

Vermi-compost increases the quantity and quality of the products. It provides plant growth promoting substances and other essential nutrients to the plants. The taste and quality of the products will be improved and the keeping quality and shelf life period will be enhanced.

It prevents the soil erosion and water evaporation. It improves the soil pH. It enhances the growth of beneficial microorganisms.

Vermi-composting does not require sophisticated instruments that need to be maintained.

It creates job opportunities to rural, coastal and urban populations. The sale of vermi-compost and earthworms

Figure 2. Training programme for coastal fisher women in the preparation of vermi-composts.

provides additional or alternate sources of income to women and unemployed youths thereby improving their livelihoods.

Training of Fisher Women

SDMRI has initiated training programmes on vermi-composting through CORDIO, particularly to coastal fisherwomen belonging to the SHGs of Thirespuram, Punnakayal, Vellapatti and Tharuvaikulam (figure 2). The training programmes were organized as an awareness raising activity because the sources of organic waste available are comparatively large in these areas (seaweeds, sea grasses etc in the shores and dry leaves of shady trees). The women who attend to household work can take care of the vermi-compost pits in their leisure time.

Twenty women from Vellapatti village were trained at a commercial vermi-composting farm at Puliuthu where they obtained practical experience in large-scale vermi-composting methods (figure 3). At Vellapatti, the soil is sandy in nature and unfit for the preparation of the pits. Therefore, through CORDIO programme, 13 vermi-composting pits were constructed for trained families with brick walls to avoid sinking of the pits and SDMRI

Figure 3. Local fisher women gaining practical experience in large-scale vermi-composting methods.

Figure 4. Harvested vermi-compost ready for sale.

provided technical back up. Regular monitoring of the pits and technical advice is provided freely to the villagers. Effective composting has continued since the initiation of this vermi-composting programme. SDMRI has arranged buyers for their bio-fertilizer and every pit owner is earning about Rs. 1 500 to 2 000 per crop. The women of Thirespuram have started to prepare vermi-composts in their own in their backyards, and are now able to harvest rich yields of both compost as well as worms that can be utilized for the next filling. Once the bio-fertilizer is ready to be harvested, SDMRI arranges buyers on behalf of the women (figure 4). After the second training programme in Tharuvaikulam in 2004, women started to venture into vermi-composting in their own village. This is an economical improvement for the coastal people and also a viable alternative/additional livelihood option especially to the fisher women.

Vermi-composting has become very popular income generative activity because of its low investment, less time consuming and promising market value. This activity is fast spreading among other villages and SDMRI is keen to provide training to other villages.

Crab Fattening

All crustaceans undergo 'moulting', a process by which their exoskeleton is shed in order to grow. In recently moulted crabs, the carapace is very soft and are locally known s 'water crabs' and do not fetch attractive prices at the market. Usually, they are discarded. Culturing these crabs until the carapace hardens is called crab fattening. The mud crab (*Scylla serrata*) takes 21 to 24 days for fattening but the swimming crabs *Portunus pelagicus* and *P.sangunolentus* fatten within 7 to 9 days. The fattened crabs generate a normal market price just like other crabs.

Benefits

Crab fattening is simple process and it can be used as one of the viable alternate livelihood programmes for earning additional income by the fisherwomen. The crab fattening saves the resource and gives an additional income a SHG of between Rs. 1 000 to 1 500 per month.

Training to Fisherwomen

The daily economic loss for fishermen due to 'moulted crabs' was unavoidable until recently when the crab-fattening process was initiated. Groups of fisherwomen representing the coastal villages were trained in the process of crab fattening by SDMRI during 2002. Responding to the interest put forth by the fisher women of the crab-fishing village Vellapatti, a one-week training programme was organized by SDMRI under the CORDIO programme. The training covered all aspects of fattening from choosing the moulted crabs, fattening, feeding the molted crabs with inexpensive baby clams, *Donax faba* and the harvest of fattened crabs (figure 5). They were trained to fatten the mud crabs and blue swimming crabs.

After the training programme, a proposal was prepared for the construction of a fattening unit exclusively for the SHG women of Vellapatti fishing village. Five SHGs volunteered to take up the responsibility of the entire operation from stocking to harvesting and selling. The district administration sanctioned a grant for the

Figure 5. Fisher women feeding crabs held in cement holding tanks with baby clams.

construction of the crab-fattening shed. After the construction of the fattening shed, all the five SHGs, involving around 60 women, were successfully carrying out the fattening programme. Regular monitoring and technical back up was provided by SDMRI as a part of CORDIO programme.

The local women fisher folk of Vellapatti fishing village have taken up crab fattening process to generate income as an alternate livelihood scheme. Initially, the costly and export oriented mud crabs were preferred for fattening, as they are exported in live condition and there is a demand for them throughout the year, and crab stocking was carried out in all tanks. However, the fattening period for mud crabs was found to be as long as 3–4 weeks. Thus, instead of mud crabs, the blue swimming crabs are being fattened for a period of 7 to 9 days with higher stocking density. The moulted blue swimming crabs are purchased for 1 rupee per crab and sold for an attractive price approximately Rs 7–9 per crab. The crab fattening is a viable alternative/additional livelihood programme and could effectively be practiced in Tuticorin coast by SHG fisherwomen in the other villages.

Crab fattening has become very popular, as it is highly viable with good market value. Other funding agencies have also come forward to provide training to coastal folk in crab fattening. However, in order to provide more hands on trainings to fisher folk, a training unit in one of the coastal villages in Gulf of Mannar is essential. This training unit could also help to give proper guidance and monitoring of the fattening activity by the villagers.

Development of Value Added Products from Under Utilized Marine Resources (Gastropod Meat)

Background

Seafood, primarily in the form of fin fishes, crustaceans and molluscs, has been source of protein since time immemorial. In India, the cost of the seafood (fin fishes and crustaceans) is increasing rapidly due to the high demand in local and export markets making it unaffordable to people in poorer sectors of society. Hence, there is a need to promote an alternative and cheaper source of nutritious food to meet the needs of poor people. In the molluscan group, the cephalopods, bivalves and gastropods form important fishery resources next to crustaceans. Meat from molluscs is rich in protein and they can be an inexpensive source of nutrition. In India, gastropod meat is not popular like other seafood due to lack of awareness combined with the conventional food habit of the people. As direct consumption of gastropod meat may not be appeal to the public, the incorporation of dried meat into some value added products was thought to be more acceptable.

Benefit

The available gastropod resources can be utilized wisely without any waste. The development of value added products from the under utilized gastropod resources with low technology would help the fisher women to earn extra income during their free hours. The women can also start their own small-scale cottage unit for the preparation of value added products. It would also help to promote an alternative and cheaper source of nutritious food to meet the needs of poor people

Training to Fisherwomen

A total of 25 fisherwomen from Vellapatti village participated in the training programme. Crab fishing is the main fishing activity in Vellapatti village, however huge quantities of gastropods are also landed as by-catch. The gastropods were used only for their beautiful shells and operculum, but the meat was wasted without knowing its nutritional value. During the training, the fisherwomen were made aware of the value of the resources and were taught to prepare value added products such as pickles, soup powder, chutney powder and other common local products using gastropod meat. They were also taught how to hygienically handle the meat to enhance the quality. The follow-up survey conducted after the training programme showed that the villagers started consuming the gastropod meat. Development of value added products from these under utilized gastropods is the first of it kind and will serve as better alternative protein source in the near future. Now the nearby villagers (Tharuvaikulam) are also asking to conduct such kind of programmes. The villagers are also willing to take up small-scale cottage industry to prepare the products from gastropod meat to earn additional income.

The training on the development of value added products using under utilized gastropod meat has created awareness among the fisher folk of Vellapatti village to utilize the meat and also the neighbouring villagers to ask for such training. However, in order to market the developed products locally, the villagers need to set up small-scale unit, which they cannot afford. It would be worth providing such small units in 2 or 3 villages in Gulf of Mannar, so that additional income could be generated by the fisher women through the wise utilization of gastropod meat, which has, by enlarge, been neglected.

CONCLUSION

The people living along the Tuticorin Coast of the Gulf of Mannar mainly depend on the reef resources for their livelihoods. The lack of awareness and viable alternative livelihood programmes are major hindrances to improving their socio-economic status and also threatens the sustainable use of the reef ecosystem. This 'demonstration project' focusing on awareness and alternative livelihood programmes showed good results among the fisher folk and is now a role model to other coastal villages of the maritime states.

The creation of awareness coupled with alternative livelihood programmes in these villages has created considerable interest among the people to protect, conserve and manage the reef resources for the coming generations. Such a level of awareness and viable options for income and food generating activities should be replicated at a larger geographic scale in order to sustainably use reef resources. SDMRI already plans to initiate similar efforts in other villages in Tuticorin in the near future and throughout Gulf of Mannar in the longer term, and additional donors have showed their interest.

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Building an Integrated Coral Reef Monitoring Network

– Lessons from the GCRMN South Asia

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ABSTRACT

The Global Coral Reef Monitoring Network (GCRMN) has been operating in India, Maldives and Sri Lanka since late 1997 with the goal to establish a regional network of people and institutions to collect coral reef information for integrated and poverty-oriented reef management planning and policy-making. This paper briefly summaries the activities and experiences of the 'GCRMN South Asia' from its first five years of operation, including a capacity building framework developed to assist identify, collect and use coral reef information to inform and influence management and policies. Important messages of the paper are that effective coral reef monitoring and management structures need to consider first and foremost the needs of the people who depend on the reefs for their survival. Secondly, it is critical that information of all types (ecological, socioeconomic, cultural, political and institutional) is available in a range of formats to develop holistic policies and management solutions. Through the activities presented below, a set of lessons relating to gathering, organizing, and disseminating that critical information to end-users have emerged, which may be useful in future work within and outside the region.

INTRODUCTION

Recent studies show that coral reefs underpin the livelihoods of millions of people worldwide, especially in Asia, the Pacific, East Africa and the Caribbean (Whittingham *et al.*, 2003). In some areas, particularly small island states, the dependence is extremely high. Many of these people are very poor and regularly depend upon the reefs as a *keystone resource*. Others depend on the reefs as a *safety net* at certain times of the year to ensure they escape the worst of poverty. These people are extremely vulnerable to reef degradation and many are starting to become poorer (IMM, 2003a).

In recent decades, however, the coral reef ecosystems in South Asia have come under increasing pressure from environmental stress, unsustainable fisheries and harvesting methods, climate related coral bleaching and diseases, land-based sources of pollution, sedimentation, dredging and coral mining, and from inappropriate coastal development caused by insufficient planning, management, and policy decisions (Rajasuriya *et al.*, 2004). These negative impacts erode the livelihoods provided by healthy coral reefs to local people. The impacts vary among stakeholder groups, but in general the poorest stakeholders are finding that their livelihoods are declining more than other coastal stakeholders and they are the least able to respond to this change.

If coral reef management are to be successful on the longer-term, it has to effectively address the needs and aspirations of the poor people depending on reefs, ensuring the benefits are equitably distributed among all stakeholder groups. Almost any form of resource management will affect the way people interact with reef resources, and dramatic changes in their access to reefs are likely to influence their livelihoods. And where people's livelihoods are marginal and subjected to stress and conflict, this will likely seriously affect their ability to pursue a sustainable livelihood. To avoid this situation, informed and holistic reef management that address the concerns of local reef users is vital.

Building capacity for integrated coral reef monitoring, aiming not only to collect ecological and socioeconomic data on status and trends, but also synthesise and disseminate this information into planning and policy processes, is an important step in achieving this goal.

This paper briefly presents the activities and experiences of the GCRMN South Asia, including the project approach, which has evolved from a mainly environmental focus to a more holistic development-environment approach, and presents some experiences that may assist further coral reef monitoring and management planning.

GCRMN SOUTH ASIA PURPOSE AND PROJECT SET-UP

In 1995, the Global Coral Reef Monitoring Network (GCRMN) was formed by a range of international organisations and institutions to raise awareness on the global reef decline and provide better information on reef status and user practices to managers and policy makers.

The GCRMN South Asia (GCRMN SA) was formed in 1997 as a regional node of GCRMN by the governments of India, Maldives and Sri Lanka in response to the International Coral Reef Initiative's 'Framework for Action' (ICRI 1995) addressed at a regional ICRI workshop in Bandos Island, Maldives.

Addressing the close linkages that exist between the health of coral reef ecosystems and the welfare of poor coastal communities that rely on them, the overarching goal of GCRMN South Asia were to *'reduce poverty amongst coastal communities in South Asia'*, with the specific project purpose to *'inform and influence management planning and policies towards more sustainable and equitable exploitation of coral reefs'* (For a detailed definition of the concepts of 'equity' and 'sustainability' used by GCRMN South Asia, please refer to DFID 1999).

To achieve this purpose, the project set out to deliver the following specific *outputs*:

(i) Enhanced capacity among national and regional partners to develop integrated coral reef monitoring programmes;
(ii) Monitoring systems for the ecological and socioeconomic aspects of coral reefs operational at target sites adapted for local and national use;
(iii) Processes for more effective use of coral reef monitoring information to contribute to coral reef management planning;
(iv) Increased regional awareness and understanding of issues related to sustainable use of coral reefs.

Training in ecological and socioeconomic reef monitoring, tailored information dissemination and regional networking have been facilitated by a succession of GCRMN Regional Coordinators from a project office based in Colombo, Sri Lanka working in close collaboration with National GCRMN Coordinators appointed in India (based at the Ministry of Environment & Forestry with Zoological Survey of India, ZSI), Maldives (based at the Marine Research Centre, MRC, Ministry of Fisheries) and Sri Lanka (based at the Natural Aquatic Resources Agency, NARA, Ministry of Fisheries).

Financial support, including a regional coordinator position, has been provided by UK Department for International Development (DFID), and technical and managerial support provided by the Intergovernmental Oceanographic Commission (IOC) of UNESCO and IMM Ltd (a UK based development and policy group acting on behalf of DFID), with local administrative assistance from the IUCN Sri Lanka office. Additional guidance has been received from a range of sources, including the Global GCRMN Coordinator and DFID technical advisors.

GCRMN South Asia Capacity Building Framework

Building capacity to achieve above four outputs has been the focus of GCRMN SA over its first five years. Consultations, training, pilot monitoring, awareness raising, and formal and informal networking have contributed to the establishment of a regional network of institutions and skilled people across the region. Between late 1997 and 2003, more than 150 people from national agencies and NGOs were involved in 26 planning meetings, training workshops and field activities across the region. A capacity building framework has been developed to provide the skills to produce and use coral reef information to inform and influence management planning and decision-making (figure 1 on next page). It involves four interrelated requirements:

1. Understanding Information Needs

Government agencies, NGOs or local communities may all be responsible for particular aspects of coral reef ecosystems, and it's rarely a single entity that oversees and understands all aspects of managing the resource. All the stakeholders need information to fulfil their role in the decision-making processes, and they often need it in a different format to help them achieve their specific objectives. *Therefore*, in order to effectively inform each different stakeholder, the following must be specifically recognised: Who needs to be influenced? What information is required? What is the best information format? How is the information effectively disseminated?

2. Building Capacity to Collect and Analyse Information

Coral reef management presents decision makers with complex issues relating to the status of both the ecosystem itself, the diversity of stakeholders using it, and the institutions governing the resource. Information about each level of complexity must be collected, analysed and presented in a form that is accessible to decision makers. *Therefore*, the network partners need capacity, skills and knowledge to collect and analyse information that effectively represents both environmental, social and economic status and trends.

3. Developing Information Systems

Information management systems such as databases and websites assist reef managers in storage and exchange of monitoring data and information, but integrated reef management also needs formal and informal linkages and conduits between institutions and people to enhance information flows. *Therefore*, to effectively inform and influence management planning and policy making, the GCRMN SA network must have *both* the data systems to store, manage and analyse monitoring information, *and* the networking capacity and human and institutional relationships that enables effective dissemination of this information.

4. Informing and Influencing Reef Management

Coral reef decision makers represent different sectors; have different objectives and differing levels of understanding of coral reef ecosystems and their stakeholders. A variety of reef management information is therefore required in a range of different formats. Very often, however, it is left to the information 'producer' to decide what information to collect, its format and dissemination, without always realising the requirements of the information 'user'. As a result, much reef information informs a too narrow range of stakeholders. *Therefore*, the GCRMN SA partners need the skills and understanding to produce and disseminate a range of information to a range of different users, in tailored formats, at strategic times, if they are to effectively inform and influence management planning and decision-making.

Understanding Information Needs in Reef Management

Planning meetings, consultations and skills in monitoring and analysing local ecological, socioeconomic and cultural conditions surrounding reefs and their use, including stakeholder's different needs and aspirations, has

Poverty reduction among coastal communities in South Asia

↑

Information that effectively informs and influences resource use, management and policy making at local, national and international levels enabling equitable and sustainable coral reef use

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Building capacity to produce and use information on environmental and socio-economic conditions of coral reefs and their use

4. Develop skills to use coral reef status information to inform and influence reef management planning and policy making

- Training in informing and influencing management and policy processes
- Link information providers with end users
- Promote the use of Informing & influencing strategies

2. Develop capacity to collect coral reef information

Provide training and guidance in:
- Ecological monitoring (survey designs, dive training, taxonomy)
- Socio-economic monitoring and reef livelihood assessments
- Data analysis & interpretation

Support pilot ecological monitoring and reef livelihoods assessments at demonstration sites

3. Develop systems for information sharing

- Facilitate networking among institutions and people
- Develop coral database in consultations with all stakeholders
- Establish national Coral Reef Fora
- Communicate via website, newsletter, other media
- Distribute publications
- Education and awareness raising in local language

1. Understand information needs in effective management planning

Through workshop and consultations, build understanding of:
- Processes governing the management and use of coral reefs
- Diversity of stakeholders in these processes and their information needs
- Local and national institutions and decision structures relating to coral reefs

Figure 1. GCRMN South Asia capacity building framework.

gradually enhanced the partners understanding of the information requirement of integrated reef management and the decision-processes governing coral ecosystems.

To help understand the political and institutional aspects of coral reef planning and decision-making, GCRMN SA commissioned national studies in each country (Cattermoul et al, 2003) identifying key information needs and institutional planning and decision-processes. The studies contain information on: (i) Current policies and policy instruments for the management of reef ecosystems at the national, and community levels; (ii) A description of the institutions, and their specific roles, that are responsible for the formulation and implementation of policies, legislation, and projects; (iii) The sorts of decisions that are made by these different institutions and the type and form of information needed by those institutions to plan and implement their roles in relation to reef ecosystems management; (iv) The information systems these institutions use to generate, store, analyse, use and disseminate the information; (v) The gaps in the current systems including: information quality and quantity; information detail; its appropriateness for use; and the skills, attitudes, and knowledge to implement systems; (vi) Recommendations on how skills and systems might be improved to satisfy these needs during a future phase of GCRMN SA. It is recommended to undertake similar studies in order to design and effectively utilise monitoring efforts in a given geographic area.

Key Lessons Learned

- It is essential that information provided to decision makers is provided in a format that decision makers can utilise. Implementing a study of decision-making processes in the early stages of developing an information network will provide a valuable framework for planning other initiatives such as skills enhancement, management information systems development, and dissemination strategies.
- Decision makers are influenced by many factors beyond scientific evidence. These may include wider government policy, political gain, economics, and social welfare.
- Participatory monitoring (both ecological and socioeconomic) can be an effective way of enhancing local community's understanding of coral reef ecosystems and their use, thus enabling them to play a more active role in management, policy, and decision-making processes. Likewise, local communities and stakeholders often have valuable information that should be incorporated in the policy and management planning processes.

Building Capacity to Collect and Use Coral Reef Information

Coral reef management presents decision makers with complex issues relating to the status of both the ecosystem itself, the diversity of stakeholders using it, and the institutions governing the resource. Information about each level of complexity must be collected, analysed and presented in a form that is accessible to decision makers. The GCRMN SA delivered training workshops and guidance in both ecological monitoring and socioeconomic monitoring.

Ecological Monitoring

Training in ecological monitoring techniques, coral taxonomy, scuba diving, survey design and data analysis were provided in India, Maldives and Sri Lanka in 1998–1999, followed by pilot monitoring at demonstration sites in each country (figure 2). Emphasis was placed on using the common GCRMN survey method and data formats (English *et al.*, 1997), allowing comparison between sites. More recently, the less labour intensive ReefCheck survey method (Hodgeson *et al.*, 2004) have been introduced and are now commonly used for routine monitoring across the region, complementing detailed GCRMN monitoring surveys at selected permanent sites.

GCRMN SA assisted formulation of national Monitoring Action Plans, with strategies for supporting and

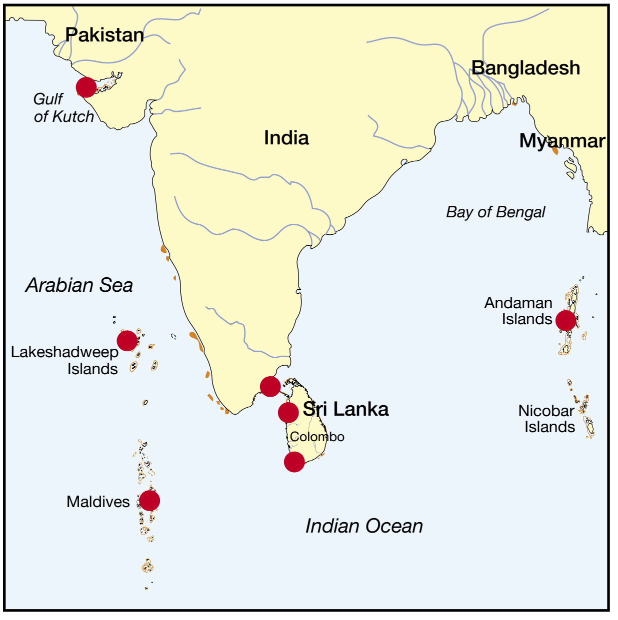

Figure 2. GCRMN South Asia training and monitoring demonstration sites indicated in red circles; *India:* South Andaman Island, Gulf of Manar, Agatti Island (Lakshadweep), Gulf of Kuchch; *Maldives:* Male Atoll, Vavuu Atoll; *Sri Lanka:* Unawatuna, Kandakulya. Training and demonstration site monitoring is an important step in raising the awareness of reef issues at both local and high levels. India, for example, where coral reef monitoring and management had previously been very limited, now has developed a national reef monitoring program (ICRMN) and scientific centres across the country. In Sri Lanka, the training helped further develop and consolidate previous efforts.

implementing reef monitoring activities, in consultation with government departments in each country. These have been implemented only partly, though, and ecological monitoring has been undertaken by government agencies at varying levels of intensity through valuable collaboration with programs such as CORDIO ('Coral Reef Degradation in the Indian Ocean' supported by SIDA-SAREC), which has supported routine monitoring in the region since 1998. The utilisation of early GCRMN training, skills and networking in other regional projects is a good example of collaboration and cost-effective sharing of competences and resources. Support for ecological monitoring to GCRMN partners has also been provided by AusAID, Asian Development Bank (ADB), and recently the Global Environmental Facility (GEF).

Socioeconomic Monitoring and Reef Livelihood Assessments

Socioeconomic reef monitoring on people's interaction with reefs represents a key requirement for implementing strategies for sustainable and equitable resource use, and has been a core focus of GCRMN SA. The common GCRMN Socioeconomic Monitoring manual (Bunce *et al.*, 2000), which was partly developed at a large regional workshop at Kadmat Island, India, September 1998, has been used as a key training resource in South Asia. Training in participatory monitoring surveys, site selection and development of protocols tailored to the local conditions where held in Gulf of Mannar and Sri Lanka, followed in 2000–2001 by training at demonstration sites in Sri Lanka, Maldives, South Andaman Island and Lakshadweep Islands, India. 12-month pilot surveys were undertaken by local groups funded by GCRMN SA at sites where ecological reef monitoring were already taking place, bringing together multidisciplinary information for use as baselines for longer-term monitoring.

Participatory monitoring was also used to raise awareness among local stakeholders and enable their participation in management decision processes. In Mahatma Ghandi Marine National Park, Wandor, South Andaman Island, for example, an important goal of the socioeconomic monitoring was to stimulate greater involvement of local communities in future conservation strategies, and a major outcome of site-specific surveys was the development of dialogues with the local communities. In Agatti Island, Lakshadweep, socioeconomic surveys recorded knowledge on traditional reef use practices from senior generations.

Findings from these surveys are reported in a series of papers and reports, of which some has been translated and distributed in local dialects (Hoon, 2002; MRC, 2003; Singh *et al.*, 2002). The information also contributed to the IMM-implemented, DFID-funded *Reef Livelihoods Assessment* project on how different local communities benefit from reef resources and how they assess those benefit flows in terms of their wider livelihoods (reported in 'Poverty & Reefs', Whittingham *et al.*, 2003).

Key Lessons Learned

- Socio-economic monitoring and ecological monitoring should be viewed as an integrated activity. But appropriate institutions to undertake for socioeconomic and ecological monitoring are not likely to be the same. It is therefore essential that dialogue and collaboration between different institutions are established at the outset of monitoring to ensure information is closely integrated. A division between socio-economic and ecological disciplines is unlikely to be perceived as meaningful by local stakeholders and could lead to confusion.
- Developing the capacity of national government institutions to provide in-house training and guidance can assist fulfil the long-term training requirements of a constantly changing workforce. Providing a readily accessible supply of training material that caters to different levels of skills and knowledge can complement national training efforts.
- Participatory monitoring requires incentives for local participants both on the shorter and longer term. In the short term, financial incentives may be used, but the impact and sustainability of such inputs must be carefully considered. In the long term, the demonstration of effective impacts of monitoring is an important aspect of participation.
- Participants should not just be seen as a source of information but as the actors determining the agenda for monitoring and analysing the results of that monitoring.
- It is rarely possible or constructive to recommend one uniform approach to socioeconomic monitoring. Social and economic conditions and the patterns of reef use will vary among locations, and an approach that suits one location may not work in another.
- Using locally-based institutions with a pre-existing role and relationship with the community will assist establishing a monitoring programme and help ensure that information feeds into the policy process or management efforts more effectively. The more precisely the monitoring meets the information requirements at the local and national levels, the more likely is it used and will receive long-term national support.

Principles for Poverty-Oriented Coral Reef Monitoring and Management

Over the evolution of GCRMN SA, the project approach evolved from an initial mainly environmental (ecological monitoring) focused to a more holistic development-environment approach, addressing the purpose of 'poverty reduction' by promoting holistic and people-centred reef monitoring and management (for further background and theory, see IMM, 2003a, b). The following principles were adopted, which are recommended always to consider in development of a poverty-oriented monitoring network:

- The probability of achieving a sustainable future for coral reef ecosystems is greatly reduced in areas where poverty persists. The network therefore *aims to be Poverty Focused*: (i) It recognises the coastal poor as a very important sub group of coral reef stakeholders; (ii) It understands linkages between poverty and coral reef exploitation; (iii) It recognises the need to include the very poor and marginalised in reef management processes.
- The network seeks the views of the local resource stakeholders in the management process and therefore *aims to be People-centred*: (i) It understands the diversity of stakeholders, their needs and aspirations; (ii) It understands the impact of policy and institutional arrangements upon resource users; (iii) It fully involves people and respects their view; (iv) It defines success not only in terms of international and nation-

al development objectives but also in terms of the priorities of vulnerable reef-dependent stakeholders; (v) It recognises the inherent potential of the poor (indigenous knowledge, skills, attitudes and relationships) and builds upon this.

- The network seeks to *promote Micro – Macro Linkages*: (i) It aims to develop linkages between macro level policy and institutions to community level organisations; (ii) It aims to ensure that high-level policy making processes involve the local communities and consider local social, cultural, economic, and environmental conditions; (iii) It aims to ensure that high-level policy is informed by lessons learnt and insights gained by donor projects, management initiatives and other interventions at the local level.
- The diversity of stakeholders that affect and are affected by the benefits from coral reefs covers a wide spectrum of sectors, ranging from fisheries and tourism to agriculture and industry. All of these sectors must be engaged in the process of change if coral reef management initiatives are to meet with success. The network therefore *aims to be Holistic*: It embraces the complexity of the issues facing coral reefs and reef dependent communities that exist across a diversity of sectors.

Figure 3. a) Socioeconomic training workshop, Andaman Islands; b) Socioeconomic survey, Andaman Islands; c) Parrot fish for sale at a local market, Chennai, India; d) Pricing the crab catch, Gulf of Mannar, India; e) Andaman Islands, India; f) Ecological reef monitoring; g) 'A Tomorrow of our Coral Reefs', IUCN exhibition, Colombo, Sri Lanka.
Photo: EMMA WHITTINGHAM, PHILIP TOWNSLEY, K. VENKATARAMAN, JOS HILL and OLE VESTERGAARD.

- The issues facing coral reef ecosystems and their stakeholders are complex and characterised by a wide diversity of stakeholders; they will not be solved with isolated interventions. The network therefore seeks to *promote Partnerships*: It recognises the need for multi-agency cooperation, including representatives from both the public and private sectors, as well as and community organisations.

Developing Systems for Information Sharing

Effective systems for sharing and using reef status information in management planning and decision-making entails not only a database and a set of information products; institutional networking and personal linkages that develops through local, national and regional level collaboration, trust and sharing are integral to an effective information system, as briefly highlighted below:

a. Local, Regional and International Networking

Formal and informal networking and sharing of expertise among network partners, government departments, NGO's, private sector and stakeholders at both local and national level is required for effectively producing and disseminating socioeconomic and ecological information into management and policy processes. The structure of GCRMN SA is designed to facilitate transfer of information for use in management planning by local and national partners, as well as to inform international coral fora (figure 4). By collaboration at training workshops, national and regional meetings, and international fora such ICRI meetings and scientific symposia, a growing level of cohesion has developed among the network partners, representing a valuable platform for developing and implementing management activities. Through serving as a common focus for coral reef-related activities, the GCRMN SA project has brought together a large group of stakeholders and created synergies with other coral reef initiatives and coastal management projects. For example, early GCRMN monitoring in Kandakulya and Unawatuna, Sri Lanka guided the ADB Coastal Resource Management Project (CRMP) in development of local management strategies. In Maldives, the ecological monitoring established with the Marine Research Centre assisted work of AusAID on marine protected areas in Addu Atoll.

Figure 4. GCRMN South Asia logo *Act locally, Inform globally*. Coral reef status information is disseminated via national status reports and the biannual global GCRMN status reports (e.g., Wilkinson 2004), CORDIO status reports, project documents and scientific papers. Networking with international coral reef research and management communities have been established by partners attending international fora such as the International Coral Reef Symposia (Bali 2000, Okinawa 2004); ITMEMS II (Philippines 2003); or ICRI general meetings and regional workshops (Cebu 2000, Maputo, 2001, Cancun 2002). Logo designed by Prasaana Weerakody, Sri Lanka.

b. Database Development in Consultation with Users and Stakeholders

GCRMN SA partners early expressed a need for a coral reef database to store and exchange reef monitoring information across the region and to serve as a repository for documents, training material, survey protocols, details on related projects and as a contact directory for regional coral reef experts, NGOs, and agencies working with coral reef issues.

The development process involved extensive and indepth participation of data providers and users from each country to determine the required content, structure and functions, aiming to develop a system tailored national requirements. The final database structure is 90% similar between the three countries, but certain features are adapted to specific national terminologies and features. The prototype version has features such as a protocol for socioeconomic survey data and geographical mapping functions. Manuals and training has been provided in all three countries and data entry of existing data (e.g. fisheries statistics) has been commissioned at government agencies. The prototype version can be downloaded from the GCRMN SA website. It is not yet fully functioning in the region and further progress requires coordination support and establishment of infrastructures for regional dataflow and technical support. One step further has been taken in India, where the database has been further adapted to national needs and is now hosted at the Ministry of Environment & Forestry in Delhi.

The fact that a regional database infrastructure has not yet been fully implemented is due partly to the extensive resources it requires, but also the time needed to build strong relationships and mutual trust between network partners at a level where they are willing to share detailed data. However, engaging several institutions in the early design process has helped build such relationships and should facilitate future database development and data exchange.

c. National Coral Reef Stakeholder Fora

In 2002, the GCRMN SA, jointly with the South Asia Cooperative Environment Programme (SACEP) and CORDIO South Asia, initiated a national Coral Reef Forum in both Sri Lanka and Maldives, serving as fora for discussions and learning among a broad spectrum of coral reef stakeholders, including resource users, NGOs, researchers, government departments, international donors and private sectors (e.g. hotel owners, dive operators and aquarium fish traders). The fora have met 1–2 times per year. At its second meeting, held in November 2002, the Sri Lanka Coral Reef Forum received official endorsement by the 1st Secretaries of the Ministry of Environment and Natural Resources and the Ministry of Fisheries and Ocean Resources, respectively, and support and strong commitment was expressed to integrate efforts between departments and sectors (see further details in 'Forum News' on the website). For these expressions of good will to develop further, the national fora can be useful instruments to generate future collaboration and activities.

d. Information Products and Publications

GCRMN SA has produced a large amount of information to inform and influence individuals and organisations about coral reefs and related management and policy issues, and has facilitated interaction with stakeholders through a range of information products, including:

(i) a *project website* serving as regional information centre with news, documents and contacts (www.gcrmn.org);

(ii) a *project library* with handbooks, scientific papers, technical guidelines, project reports and awareness material on coral reef issues and coastal management compiled in the project office, Colombo. A bibliography is available from the project website and hardcopies of documents can be forwarded upon request;

(iii) a *project Newsletter* with updates on project development and international coral reef news presented in a regional newsletter and national 'Forum News', printed and distributed to partners across the region;

(iv) *Local language reports* with findings and results of socioeconomic assessments translated into local dialects (e.g. Hoon, 2002) for dissemination to local managers, officials, school teachers, NGO's and wider public.

e. Education and Awareness Raising

Awareness raising and education materials to inform local reef users as well as schoolchildren include message boards, leaflets, exhibitions, field guides and presentations at meetings. A national mobile school exhibition – *A Tomorrow for Our Coral Reefs* – touring schools in Sri Lanka with posters and videos in local languages and a research colloquium and national art competition for school children was organised in 2001 by IUCN Sri Lanka, jointly with GCRMN SA and CORDIO SA, in association with the Ministry of Ports, Shipping and Fisheries, to raise awareness on the status of coral reef ecosystems, their value and vulnerability, and the need for equitable and sustainable management.

Key Lessons Learned

- There is a tendency for organisations and individuals to work in isolation. A motivating external, neutral entity can bring people and institutions together who would otherwise not interact naturally.
- Much information produced is not disseminated widely enough to fulfil its potential. Systems such as a database, a regional document library, and an organisation work directory can help, as well as informal networks between people and institutions.
- When developing a database, equal emphasis should be given to the systems and skills needed to collect, enter, transfer, manage, and use the information. A weakness in any part of this process is likely to halt the entire system.

- It is likely that external support will be required to assist both the development and the establishment of a database. National governments will need to recognise its value before they commit national resources to it.

Developing Skills in 'Informing and Influencing' Management and Policy Processes

Building skills in *using* reef monitoring information to 'inform and influence' coral reef management and decision processes is essential to achieve the overall purpose of better informed reef management.

In three national GCRMN SA workshops, participants explored the complexity of producing different types of information and how to respond systematically to the complexity of information requirements in terms of informing and influencing a diversity of stakeholders with different backgrounds and objectives, and developed case-specific strategies for different coral reef issues. Through parallel work of IMM Ltd on a DFID-funded 'Sustainable Coastal Livelihoods' project, an 'informing and influencing framework' was developed and subsequently tested in the national GCRMN SA workshops. The framework includes a series of stepwise considerations: (1) Are key stakeholder groups involved? (2) What is their role or stake in the management objectives? (3) Is there any action or change required by the stakeholders? (4) Is there information required to achieve this change? (5) What is the best media to address specific the information needs? (6) Does this information already exist and, if so, where?

Reports with experiences from the three workshops are available from the GCRMN SA website, with further theory and background in IMM 2003c.

Key Lessons Learned

- In many situations, a wide range of reef-related information exists, but is not used effectively. Given the high cost of collecting and analysing data, every effort should be made to maximise the use of existing knowledge before embarking on extensive monitoring efforts.
- If information generated by research is to bring about change in policies and policy implementation, it needs to be made available in many different forms tailored the diversity of different stakeholders involved.
- Informing and influencing strategies should be considered as an integral part of a research-planning process. Using a framework to cope with complexity in a structured way can greatly improve the effectiveness of the project / research outputs.

SOME CONSIDERATIONS FOR FUTURE DEVELOPMENT

After five years of operation, the national network partners conducted a comprehensive review of the impact of the GCRMN SA activities on reef monitoring in the region (see GCRMN South Asia Review, 2003). It concluded that important progress was achieved towards raising awareness and building capacity to provide information on equitable and sustainable coral reef management issues in the region. Partners concluded that coral reef issues are being more seriously considered at both local and national levels and that the network objectives appear to be more firmly anchored in national policy agenda's. Over the years, GCRMN SA has progressively evolved to address different information requirements of reef management in South Asia and is slowly becoming driven by the countries themselves.

An important learning aspect of the first years of activities is that it indeed took five years to just establish the GCRMN SA as an institution, or process, within the region. That is how long it takes to build respect and confidence among the wide range of people and institutions the project has worked with. And a key output from the activities are primarily increased dialogues between partners and formal and informal networking in the three countries, which are currently laying the foundation for new coral reef efforts. The acceptance of GCRMN SA as an institution serving national and local needs, rather than an isolated project fulfilling primarily international priorities, is fundamental to sustaining this impact. It is hoped that future coral reef initiatives in the region can build on the participation and ownership established. Continued support for collaborative efforts, for example through the national Coral Reef Fora, would be useful to further integrate reef management and policies.

Still there is scope for increasing the government support for routine ecological and socio-economic monitoring in all three countries, in particularly to address poverty issues in a natural resource management context. The project review recommended first and foremost to further evolve reef monitoring that takes fully into account the needs and aspirations of the poorest reef users. Emphasis on holistic approaches, training in socio-economic monitoring, support for reef livelihoods assessments and development of alternative livelihoods are important priorities. A people-centred approach to resource management is likely to increase the chance of management success. Resource management should be viewed as an instrument within a larger framework of coastal development with poverty reduction as the overall goal. Otherwise there is a tendency for the poor to be viewed as an obstacle, rather than as part of the solution. Developing a wider appreciation of the linkages between poverty and the status of coral reef, and how healthy coral reef ecosystems can contribute to national objectives of poverty reduction, may further commitments from governments towards reef monitoring and management.

It appears that the efforts and outputs of GCRMN SA and related projects have had some influence on the regional and international policy climate towards poverty issues within coral reef management. Along with the development of GCRMN and CORDIO, the regional intergovernmental body for environmental affairs, SACEP, has expressed increasing will to engage actively in coral reef issues, including addressing local people and livelihoods aspects. Similarly, calls for pro-poor strategies in reef management have been expressed in recent documents of ICRI partners, most notably in the ICRI statement 'Global Vision for Local Action' (ICRI CPC, Seychelles, April 2005). These are all positive developments. It is important to note, however, that the local reef users will feel little change in their situation unless the good words and intentions are followed up with action on the ground.

Guidance and training in integrating local reef users and pro-poor aspects in the planning, design and implementation of marine protected areas would be a useful step to ensure equitable and sustainable management outcomes. As part of this, future efforts could aim at refining and implementing approaches for targeted information dissemination to reef stakeholders, managers and policymakers. Further, national studies of policy and institutional aspects of coral reef planning and decision-making processes may be useful in this work, including addressing the diversity of stakeholders associated with reefs and build further awareness of the complexity of coral reef issues.

There still is a need for technical guidance and a modest regional coordination to drive these efforts. Further interaction with international coral reef efforts such ICRI, developing efforts of SACEP, as well as the global coral reef data repository ReefBase, may stimulate further commitments of the Governments of South Asia to address coral reef issues. Emphasis should be placed on *two-way* communication, ensuring new knowledge and useful tools are feed back into national and local coral reef activities.

Today, GCRMN SA activities are being continued with coordination support through CORDIO South Asia and IUCN Global Marine Program from IUCN's Asia Regional Office in Colombo, Sri Lanka. Support is provided to continue ecological monitoring at permanent sites in the region, as well as part of the previous socioeconomic assessment initiated in Lakshadweep Reef, India. With the momentum achieved through the DFID-IOC/UNESCO implemented GCRMN South Asia Project, the National Coral Reef Fora will be continued to maintain dialogues between local authorities, NGOs, researchers and the private sector, and to further the development of a regional coral reef database system.

Learn More

Documents available from the GCRMN South Asia project website at www.gcrmn.org include:

1. GCRMN SA Informing & Influencing Strategy – Guidance for Future Interventions (2003)
2. Understanding Information Needs – Country Reviews of Information Needs for Coral Reef (2003)
3. GCRMN SA Planning Framework
4. GCRMN SA Coral Reef Database overview
5. GCRMN SA Partner Review (2003)
6. Agatti Island, Lakshadweep, Socioeconomic study (Hoon, 2003)
7. Vaavu Atoll, Maldives, Socioeconomic study (MRC, 2003)
8. Wandor, South Andaman Island, Socioeconomic study (Singh *et al.*, 2002)
9. Whittingham, E., Campbell, J., & Townsley, P., (2003) *Poverty and Reefs*. DFID-IMM-IOC/UNESCO.

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Most recently, the regional monitoring expertise and network capacity has contributed to rapid assessments of the impact of the Indian Ocean tsunami on 26 December 2004. The joint coordination of the IUCN Regional Marine Programme, CORDIO and GCRMN was key in mobilizing coral reef assessment teams throughout the region, and regular reports to policy makers, scientists and the general public were issued from early January 2005. The IUCN/CORDIO/GCRMN network also contributed significant sections to the regional report prepared by UNEP and to the development of a methodology for assessment of tsunami impacts on coral reefs for ICRI and ISRS. In addition to the networking and coordination mechanism, the reef monitoring capacity built and the baseline information gathered in the region through GCRMN and CORDIO activities since the 1990s has proven invaluable after the tsunami. Many times the only information available originates in these initiatives and their collaboration with government and non-government institutions such as MRC, NARA, SDMRI and RWMC. This reemphasizes the need for continued strengthening of monitoring capacity and programmes, and importantly also provides an impetus to further develop GCRMN as an inclusive and efficient network of institutions and individuals in the region.

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