Contents

Section 2. Thematic Reports

Appendix

Executive Summary

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 environ-

mentally 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

DAVID OBURA

CORDIO East Africa, Mombasa, Kenya

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).

SELECTED REFERENCES

Alidina, H., (2004) *Prospects for Improving Artisanal Fisheries Management in Diani-Chale, Southern Kenya*. Dalhousie University, Halifax, Nova Scotia MSc Thesis.

Alidina, H., (this volumn) "Local Level Coral-Reef Fisheries Management in Diani-Chale, Southern Kenya: Current Status and Future Directions".

Horrill, J. C., Kalombo, H., & Makoloweka, S., (2001) *Collaborative Reef and Reef Fisheries Management in Tanga, Tanzania*. IUCN East Africa Programme. Tanga Coastal Zone Conservation and Development Programme.

ICRI/ISRS (2005) *Tsunami Damage to Coral Reefs. Guidelines for Rapid Assessment and Monitoring*. Victoria, Seychelles. International Coral Reef Initiative/International Society for Reef Studies (30).

IUCN (2004) *Managing Marine Protected Areas: A Toolkit for the Western Indian Ocean*. IUCN Eastern African Regional Programme, Nairobi, Kenya. xii + 172 pp. www.wiomsa.org\mpatoolkit.htm

Malleret-King, D., (2004) *A Socio-Economic Baseline Assessment of the Mnazi Bay and Ruvuma Estuary Marine Park*. IUCN/UNDP-GEF/Mnazi Bay Ruvuma Estuary Marine Park Project, Nairobi.

Malleret-King, D., & King, A., (2002) *Socio-Economic Monitoring Pilot Project (SEMPP) for Coastal Eastern Africa. Review Document*. CORDIO East Africa. CORDIO East Africa, Mombasa, Kenya.

Malleret-King, D., King, A., Mangubhai, S., Tunje, J., Muturi, J., Mueni, E., & Onganda, H., (2003) *Livelihood appraisal: Understanding Fisheries associated livelihoods and the Constraints to their Development in Kenya and Tanzania*. (FMSP project R8196)

McClanahan, T., Sheppard C., & Obura, D., (2000) *Coral Reefs of the Indian Ocean: Their Ecology and Conservation*. Oxford University Press.

Mohammed, S., Muhando, C., Machano, H., Daniels, C., Tyler, E., Jiddawi, N., & Yahya, S., (2005). *Status of Coral Reefs in Tanzania*. Proceedings of the 10th International Coral Reef Symposium, 27 June–1 July 2004, Okinawa, Japan.

Mohammed, S., Muhando, C., Machano, H., Daniels, C., Tyler, E., Jiddawi, N., & Yahya, S., (2005) "Tanzania".Motta, H., & Costa, A., (this volume) "Mozambique".

Mwaura, J., Obura, D., & Nyaga, W., (2003) *Participatory Reef Monitoring; its Implications for sustainable resource use, Diani-Chale, Kenya*. 3rd WIOMSA Scientific Symposium.

Obura, D., (2002) "Status of Coral Reefs in East Africa". In: Lindén O, Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status report 2002*. CORDIO, Kalmar. pp 108.

Obura, D., (2004) "Status of Coral reefs in Eastern Africa: Kenya, Tanzania, Mozambique and South Africa". In: Wilkinson, C., (ed.) *Status of Coral Reefs of the World, 2004*. Global Coral Reef Monitoring Network (GCRMN). Australian Institute of Marine Science, Townsville, Australia.

Obura, D., (this volume) "Kenya".

Obura, D., (2005b) "Resilience and climate change – lessons from coral reefs and bleaching in the Western Indian Ocean". *Estuarine Coastal and Shelf Science*.

Obura, D, & Abdulla, A., (2005) *Assessment of Tsunami Impacts on the Marine Environment of the Seychelles*. IUCN/UNEP, Gland/Nairobi.

Obura, D., Causey, B., & Church, J., (in review) "Management response to a bleaching event". In: Phinney, P., Hoegh-Guldberg, O., Kleypas, J., Skirving, W., & Strong, A., (eds.) *Corals and Climate Change*. American Geophysical Union, Washington, DC.

Obura, D., (in review) *Impacts of the 26th December 2004 tsunami in East Africa*. Ocean & Coastal Management.

Pereira, M., (2003) *Recreational Scuba Diving and Reef Conservation in Southern Mozambique*. University of Natal, Durban MSc Thesis.

Pereira, M., (this volume) "Demography, Participation and Attitudes of Recreational Scuba Divers and an Assessment of the Diving Intensity in Southern Mozambique".

Schleyer, M., & Celliers, L., (2005) "Resilience and climate change – lessons from coral reefs and bleaching in the Western Indian Ocean". *Estuarine Coastal and Shelf Science* 603: 373–390.

Sheppard, C., Spalding, M., Bradshaw, C., & Wilson, S., (2002) "Erosion vs. recovery of coral reefs after 1998 El Niño: Chagos reefs, Indian Ocean". *Ambio* 31: 40–48.

TDFMN (2005) "Tanga Dynamite Fishing Monitoring Network". Unpublished communications and monitoring sheet report. dobura@cordio.info

Visram, S., (2004) *The Diversity and Bleaching Responses of Zooxanthellae in Kenyan Corals*. University of York, York.

Visram, S., (this volume) "Resilience of zooxanthellae to bleaching stressors: An experimental study".

Wanyonyi, I., Malleret-King, D., & Obura, D., (2003) *Linking Socio-Economic Monitoring to Managements Needs in East Africa; a Diani-Chale Pilot Study*. 3rd WIOMSA Scientific Symposium.

Wilkinson, C., (2004) *Status of Coral Reefs of the World: 2004*. Australian Institute of Marine Science, Townsville, Australia.

Assessing the Status and Improving Management of Coral Reef Resources:

Experiences and Achievements in South Asia

DAN WILHELMSSON[1], J. K. PATTERSON EDWARD[2], ARJAN RAJASURIYA[3], JERKER TAMELANDER[4] & NISHANTHI PERERA[5]

[1]CORDIO South Asia1999-2004, Colombo, Sri Lanka; [2]Suganthi Devadason Marine Research Institute, Tuticorin, Tamil Nadu, India; [3]National Aquatic Research and resources Agency, Colombo, Sri Lanka; [4]CORDIO/IUCN Regional Marine Program; [5]South Asia Cooperative Environment Programme, Colombo, Sri Lanka

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

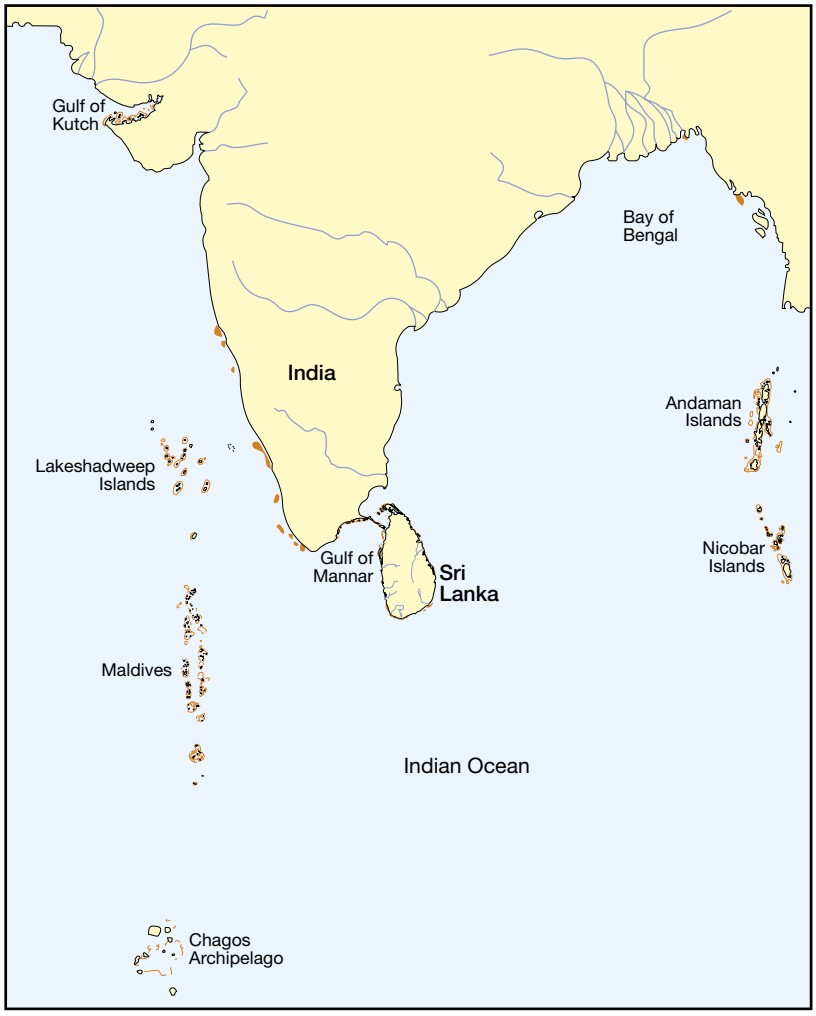
INTRODUCTION

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 dam-

age 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 respon-

sible 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 mar-

keting 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 tour-

ism, which can build on the experiences from this pilot project (TCP, 2004). Unfortunately, the tsunami on December 26, 2004, caused many casualties as well as damage to the infrastructure at Rekawa. This tragic event will have long-lasting and serious consequences for the development of the area, including the tourism sector.

DISCUSSION AND FUTURE PERSPECTIVES

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

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

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

Enhanced Co-Ordination of Efforts among Donors and Implementing Agencies

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

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

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

Reconstruction after the Tsunami

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

Empower Governmental Agencies for More Efficient Surveillance and Law Enforcement

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

access to alternative income sources (e.g. Dharmarethnam & Kirupairajah, 2001), increased law enforcement needs to be accompanied by extensive development programmes providing other livelihood opportunities.

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

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

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

ACKNOWLEDGEMENTS

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

REFERENCES

Amaralal, K. H. M. L., Vidanage, S. P., & Wimalasena, H. D., 2002) *Impacts of coral bleaching on tourism in Sri Lanka*. Socio-economic and Market Research Division. NARA, Colombo 15, Sri Lanka. (*unpublished*) Report submitted to the CORDIO South Asia Program.

Arthur, R., (2000) "Coral bleaching and mortality in three Indian reef regions during an El Nino southern oscillation event". *Current Science* 79(12): 1723–1729.

Auberson, B., (1982) "Coral transplantation: an approach to the re-establishment of damaged reefs". *Philipp. J. Biol.* 11(1): 158–172.

Bakus, G., Arthur, R., Ekaratne, S., & Jinendradasa, S. S., (2000) "India and Sri Lanka". In: McClanahan, T. R., Sheppard, C. R. C., & Obura, D. O., (eds.) *Coral Reefs of the Indian Ocean; their ecology and conservation*. 295-324.

Bavinck, M., (2003) "The spatially splintered state: Myths and realities in the regulation of marine fisheries in Tamil Nadu, India". *Development and Change* 34(4): 633–656.

Bellwood, D. R., Hughes, T. P., Folke, C., & Nyström, M., (2004) "Confronting the coral reef crisis". *Nature* 429: 827–833.

Berg, H., Öhman, M. C., Troeng S., & Lindén, O., (1998) "Environmental economics of coral reef destruction in Sri Lanka". *Ambio* 27: 627–634.

Bhattacharya, A., & Sarkar, K. S., (2003) "Impact of overexploitation of shellfish: northeastern coast of India". *Ambio* 32(1): 70–75.

Brown, B. E., & Dunne, R. P., (1988) "The environmental impacts of coral mining on coral reefs in the Maldives". *Environmental Conservation* 15(2): 159–166.

Cesar, H., Saleem, M., Waheed, A., & Wilhelmsson, D., (2000) *Assessing the impacts of the 1998 coral bleaching on tourism in the Maldives and Sri Lanka* (unpublished). Report prepared for the CORDIO Program, Stockholm, Sweden.

Chandramohan, P., Anand, N. M., & Nayak, B. U., (1993) "Shoreline dynamics of the Lakshadweep Islands". *Indian Journal of Marine Sciences* 22: 198–204.

Connell, J. H., (1997) "Disturbance and recovery of coral assemblages". *Coral Reefs* 16:101-113.

Dawson-Shepherd, A. R., Warwick, R. M., Clarke, K. R., & Brown, B. E., (1992) "An analysis of fish community responses to coral mining in the Maldives". *Environmental Biology of Fishes* 33: 367–380.

Deepak Samuel, V., Patterson, J., & Patterson Edwards, J. K., (2002) "Destructive fishing in reef and mangrove areas of Tuticorin coastal waters". *Proceedings of the National Seminar on Marine and Coastal Ecosystems: Coral and Mangrove. Problems and Management Strategies*. SDRMI Researh Publication No. 2: 98–103.

Devaraj, M., & Vivekanandan, E., (1999) "Marine capture fisheries of India: Challenges and opportunities". *Current Science* 76(3): 314–332.

Dharmaretnam, M., & Kirupairajah, R., (2002) *Coral destruction in the east coast of Sri Lanka*. (Unpublished) Report submitted to CORDIO South Asia.

Flewwelling, P., (2001) *Fisheries management and MSC in South Asia: Comparative analysis*. Field Report C-6 (En). FAO/ Norway Government Co-operative Programme.

Guzman, H. M., (1991) "Restoration of coral reefs in Pacific Costal Rica". *Conservation Biology* 5(2): 189–195.

Hinrichsen, D., (1998) *Coastal Waters of the World*. Island Press. ISBN: 1-5596-382-4. 275 p.

Hoegh-Guldberg, O., (1999) "Climate change, coral bleaching and the future of the world's coral reefs". *Marine and Freshwater Research* 50 (8): 839–866.

Hoon, V., (2003) "A case study from Lakshadweep". In: Whittingham, E., Campbell, J., & Townsley, P., (eds.) *Poverty and Reefs: Volume 2 Case Studies*. For DFID, IMM and IOC-UNESCO by UNESCO, Paris: 187-226.

Hughes, T. P, Baird, A. H., Bellwood, D. R., Card, M., Connolly, S. R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J. B. C., Kleypas, J., Lough, J. M., Marshall, P., Nyström, M., Palumbi, S. R., Pandolfi, J. M., Rosen, B., & Roughgarden, J., (2003) "Climate change, human impacts and the resilience of coral reefs". *Science* 310: 929–933.

IPCC, Inter-Governmental Panel on Climate Change (2001) *Climate Change 2001*. Synthesis Report, www.ipcc.ch/pub/syreng.htm

IUCN (2001) *A tomorrow for our coral reefs*. Project completion report submitted to CORDIO.

IUCN (2004) *A tomorrow for our reefs, Phase 2*. Project completion report submitted to CORDIO. The World Conservation Union (IUCN), Sri Lanka Office.

James, P. S. B. R., (1994) "Endangered, vulnerable and rare marine fishes and animals. Threatened fishes of India". *Proceedings of the National Seminar on Endangered Fishes of India, 26 April, 1992*, Nature Conservators, Muzaffarnagar: 45–53.

Jayashree, B., & Arunachalam, S., (2000) "Mapping fish research in India". *Current Science* 79(5): 613–620.

Kannan, R., Kumaraguru, A. K., Sundaramahalingam, A., Ramakrishnan, M., & Rajee M., (2001) "Socio-economic status of coral reef resource users of Pamban region, Gulf of Mannar, South India". *Man in India* 81(1–2): 103–121.

Kulkarni, S., & Saxena, A., (2002) "The conservation status of coral reefs of Andaman and Nicobar Islands". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 103–113.

Kumaraguru, A. K., Jayakumar, K., & Ramakritinan, C. M., 2003. "Coral bleaching 2002 in the Palk Bay, southeast coast of India". *Current Science* 85(12): 1787–1793.

Le Tissier, M. D. A., Hills, J. M., McGregor, J. A., & Ireland, M., (2004) "A training framework for understanding conflict in the coastal zone". *Coastal Management* 32: 77–88.

Loya, Y., (1990) "Changes in a Red Sea coral community structure. A long term case history study". In: Woodwell, G. M., (ed.) *The Earth in transition: Patterns and processes of biotic impoverishment*. Cambridge: 369–384.

Ludwig, D., Hilborn, R., & Walters, C., (1993) "Uncertainty, resource exploitation, and conservation: Lessons from history". *Science* 260: 17–36.

McClanahan, T. R., (2000) "Bleaching damage and recovery potential of Maldivian coral reefs". *Marine Pollution Bulletin* 40(7): 587–597.

Meenakumari, B., (2002) "Problems and prospects of Indian fisheries". *Proceeding of the national seminar on marine and coastal ecosystems: Coral and mangrove. Problems and management strategies.* SDRMI Research Publication No. 2.

MRC (2003) *Socio-economic assessment and monitoring of coral reef resources at Vaavu atoll, Maldives*. Prepared by Marine Research Centre, Ministry of Fisheries, Agriculture and Marine Resources for Global Coral Reef Monitoring Network- South Asia Region.

Muley, E. V., Venkataraman, K., Alfred, J. R. B., & Wafar, M. V. M., (2002) "Status of coral reefs of India". *Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia, 2000*: 847–859.

Naseer, A., (1997) "Profile and status of coral reefs in Maldives and approaches to its management". In: Hoon, V., (1997) *Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs*. Proceedings No.22, CRSARD, Madras.

Nyström, M., & Folke, C., (2001) "Spatial resilience of coral reefs". *Ecosystems* 4(5): 406–417.

Obura, D. O., (2001) "Can differential bleaching and mortality among coral species offer useful indicators for assessment and management of reefs under stress?". *Bulletin of Marine Science* 69(2): 421–442.

Öhman, M. C., Rajasuriya, A., & Lindén, O. (1993) "Human disturbances on coral reefs in Sri Lanka". *Ambio* 22: 474–480.

Olsen, S., & Christie, P., (2000) "What are we learning from tropical coastal management experiences?". *Coastal Management* 28: 5–18.

Patterson, J. K. E., (2002) "The coral reefs of the Tuticorin Coast of the Gulf of Mannar, South-East India". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) (2002) *Coral Reef Degradation in the Indian Ocean. Status Report, 2002*: 114–118.

Patterson, J. K., Patterson, J., Venkatesh, M., Mathews, G., Chellaram, C., & Wilhelmsson, D., (2004) *A field guide to stony corals (Scleractina) of Tuticorin in Gulf of Mannar*. SDMRI Special Research Publication No. 4.

Peninsi, E., (2005) "South Asia Tsunami: Powerful tsunami's impact on coral reefs was hit and miss". *Science* 307(5710): 657

Perera, C., Wilhelmsson, D., & Rajasuriya, A., (2002) "Reef fisheries and coral reef degradation in Sri Lanka". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 149–157.

Perera, N., (ed.) (2004) *Alternative livelihoods through income diversification: An option for sustainable coral reef and associated ecosystem management in Sri Lanka*. South Asia Co-operative Environment Programme (SACEP) and Coral Reef Degradation in the Indian Ocean (CORDIO). 99 p.

Pet-Soede, L., Wafar, M. V. M., Venkataraman, K., Rajan, P. T., & Wilhelmsson, D., (2000) "The Status of the coral reefs of India following the bleaching event of 1998". In: Souter, D., Obura, D., & Lindén, O. (eds.) 2000. *CORDIO Status Report 2000*: 69–74.

Pillai, C. S. G., (1996) "Coral reefs of India, their conservation and management". In: Menon, N. G., & Pillai, C. S. G., (eds.) *Marine Biodiversity, Conservation and Management*. Central Marine Fisheries Research Institute, Cochin: 16–31.

Pramanik, S.K. & Nandi, N.C. 2002. An appraisal of alternative livelihood to capture fishery affecting Sundarban mangrove ecosystems, West Bengal. *Proceedings of the National Seminar on Marine and Coastal Ecosystems: Coral and Mangrove. Problems and Management Strategies*. SDRMI Research Publication No. 2.

Premeratne, A., (2003) "Case study on evaluation of management strategies used for coastal resources management with particular reference to experiences in controlling coral mining in Sri Lanka". *Proceedings of the 2nd International Tropical Marine Ecosystems Management Symposium, Manila, 2003*, in prep.

Qazim, S. Z., (1999) "Coastal erosion and its protection". *Journal of Indian Ocean Studies* 7(1): 63–73.

Rajasuriya, A., De Silva, M. W. R. N., & Öhman, M. C., (1995) "Coral Reefs of Sri Lanka: Human Disturbance and Management Issues". *Ambio* 24: 428–437.

Rajasuriya, A., Maniku., M. H., Subramanian, B. R., & Rubens, J., (1998) "A review of the progress in implementation of management actions for the conservation and sustainable development of coral reef ecosystems in South Asia". *Proceedings of International Tropical Marine Ecosystems Management Symposium (ITMEMS)*, Townsville, November, 1998.

Rajasuriya, A., Maniku, H., Subramanian, B. R., & Rubens, J., (1999) "Coral Reef Systems in South Asia". In: Lindén, O., & Sporrong, N., (eds.) (1999) *CORDIO Status Report 1999* 11–24.

Rajasuriya, A., & Karunarathna, C., (2000) "Post bleaching status of the coral reefs of Sri Lanka". In: Souter, D., Obura, D., & Lindén, O., (eds.) (2000) *CORDIO Status Report 2000*: 54–63.

Rajasuriya, A., (2002) "Status report on the condition of reef habitats in Sri Lanka, 2002". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) (2002) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*.139–148.

Rajasuriya, A., Zahir, H., Venkataraman, K., Islam, Z., & Tamelander, J., (2004) "Status of coral reefs in South Asia: Bangladesh, Chagos, India, Maldives and Sri Lanka". In: Wilkinson, C., (ed.) *Status of Coral Reefs of the World: 2004*. Australian Institute of Marine Science. Vol. 1: 213–231.

Ramachandran, U., (2002) "Traditional food formulation and its future: Examples from South Asia". *Asia Pacific Journal of Clinical Nutrition* 11(6): 137–148.

Ramanujam, N., & Sudarsan, R., (2003) "A study of coastal transformation at Tuticorin as a result of emerged and submerged natural breakwaters of Van Island, Gulf of Mannar". *Environment Geology* 43 (5): 521–525.

Reaser, J. K., Pomerance, R., & Thomas, P. O., (2000) "Coral bleaching and global climate change: Scientific findings and policy recommendations". *Conservation Biology* 14(5): 1500–1511.

Risk, M. J., & Sluka, R., (2000) "The Maldives: A nation of Atolls". In: McClanahan, T. R., Sheppard, C. R. C., & Obura, D. O., (eds.) *Coral Reefs of the Indian Ocean; their ecology and conservation*: 325-351.

Rowan, R., (2004) "Coral bleaching: Thermal adaptation in reef coral symbionts". *Nature* 430: 742.

Samarakoon, J., (2004) "Issues of livelihood, sustainable development, and governance: Bay of Bengal". *Ambio* 33(1–2): 34–44.

Sakthivel, M., (1999) "Strategy to increase export of fish and fishery products from India". *Current Science* 76(3): 405–412.

Sen, G., (1995) "Creating common ground between environmentalists and women: Thinking locally, acting globally?". *Ambio* 24 (1): 64–65.

Shakeel, H., & Ahmed, H., (1997) "Exploitation of reef resources: Grouper and other food fishes". In: Hoon, V., (1997) *Proceedings of the Regional Workshop on the Conservation and Sustainable Management of Coral Reefs*. Proceedings No.22, CRSARD, Madras.

Shanthini, C. F, Patterson, J., & Patterson Edward, J. K., (2002) "A case study from Vellapatti fishing village of Gulf of Mannar, Southeast coast of India – Reef fisheries and socio-economics". *Proceedings of the National Seminar on Marine and Coastal Ecosystems: Coral and Mangrove. Problems and Management Strategies*. SDRMI Researh Publication No. 2.

Singh, A., & Andrews, H. V., (2003) "A case study from South Andaman Island". In: Whittingham, E., Campbell, J., & Townsley, P., (eds.) *Poverty and Reefs: Volume 2 Case Studies*. DFID, IMM and IOC-UNESCO: 147–186.

Smith, J., & Hughes, T., (1999) "An experimental assessment of survival, reattachment and fecundity of coral fragments". *J. Exp. Mar. Biol. Ecol.* 235: 147–164.

Spurgeon, J. P. G., (1992) "The economic valuation of coral reefs". *Marine Pollution Bulletin* 24 (11): 529–536.

Stone, L., Huppert, A., Rajagopalan, B., Bhasin, H., & Loya, Y., (1999) "Mass coral reef bleaching: A recent outcome of increased El Niño activity?". *Ecology Letters* 2: 325–330.

Sundarmoorthy, T., Badrinath, P. S., & Kumar, L. P., (2004) "Conservation strategy for Andaman and Nicobar Islands ecosystems". *Proceedings of the National Seminar on New Frontiers in Marine Bioscience Research, National Institute of Ocean Technology, Chennai, 22–23 Jan., 2004*.

TCP, Turtle Conservation Project (2004) *Project completion report on CORDIO funded TCP Programs in Rekawa, Southern Sri Lanka*. Report prepared for the CORDIO Program, September 2004.

Torell, E., (2000) "Adaptation and learning in coastal management: The experience of five East African initiatives". *Coastal Management* 28: 353–363.

Turner, J. R., Vousden. D., Klaus, R., Satyanarayana, C., Fenner, D., Venkataraman, K., Rajan, P. T., & Subba Rao, N. V., (2001) *Report of Phase 1: Remote Sensing and Rapid Site Assessment Survey, April 2001. Coral reef systems of the Andaman Islands*. Government of India and United Nations Development Programme, Global Environment Facility. 76 p.

UNEP (2005) *After the Tsunami*. United Nations Environment Programme. ISBN: 92-807-2565-3. 140 p.

UNICEF (2001) *The state of the world's children 2001*. United Nations Children Fund, UNICEF House, 3 UN Plaza, New York, 10017 USA. 117 p.

Wafar, M. V. M., (1986) "Corals and coral reefs of India". *Proc. Indian Acad. Sci. (Anim. Sci/Plant Sci.)* Suppl.: 19–43.

Wafar, M. V. M., (1999) "Status report India". In: Lindén, O., & Sporrong, N., (eds.) *CORDIO Status Report 1999*: 25–26.

Weerakody, P., (2004) "Blast fishing on Rumassala Coral Reef: An overview of the problem focusing on trends and practices". In: Perera, N., (ed.) (2004) *Alternative livelihoods through income diversification: An option for sustainable coral reef and associated ecosystem management in Sri Lanka*. South Asia Co-operative Environment Programme (SACEP) and Coral Reef Degradation in the Indian Ocean (CORDIO). 99 p.

Venkataraman, K., (2002) "Status survey of the Gulf of Mannar coral reefs following the 1998 bleaching event, with implications for reserve management". *Proceedings of the 9th International Coral Reef Symposium, Bali, Indonesia, 2000*: 855–859.

Venkataraman, K., (2004) "Conservation and management of coral reef ecosystems of Andaman and Nicobar and Lakshadweep Islands". *Proceedings of the National Seminar on New Frontiers in Marine Bioscience Research, National Institute of Ocean Technology, Chennai, 22–23 Jan 2004*.

West, J. M., & Salm, R. V., (2003) "Resistance and resilience to coral bleaching: Implications for coral reef conservation and management". *Conservation Biology* 17(4): 956–967.

Westmacott, S., Cesar, H., & Pet-Soede, L., (2000) "Assessment of the Socio-economic impacts of the 1998 coral reef bleaching in the Indian Ocean: A summary". In: Souter, D., Obura, D., & Lindén, O., (eds.) (2000) *CORDIO Status Report 2000*: 143–159.

Westmacott, S., & Rijsberman, F., (2000) "Cost-effectiveness analysis of coral reef management and protection: A case study of the Republic of Maldives". In: Huber, R. M., (ed.) *Integrated Coastal Zone Management of Coral Reefs: Decision support modelling*. Herndon, VA, USA: World Bank. The Office of the Publisher.

White, A. T, Vogh, H. P., & Arin, T., (2000) "Philippine coral reefs under threat: The economic losses caused by reef destruction". *Marine Pollution Bulletin* 40(7): 598–605.

Whittingham, E., Campbell, J., & Townsley, P., (eds.) *Poverty and Reefs*. DFID, IMM and IOC-UNESCO. 232 p.

Wilhelmsson, D., Haputhantri, S. S. K., Rajasuriya, A., & Vidanage, S., (2002) "Monitoring the trends of marine ornamental fish collection in Sri Lanka". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 158–166.

Wilhelmsson, D., (2002) "Coral reef degradation in South Asia". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 93–103.

Wilkinson, C., Lindén, O., Cesar, H., Hodgson, G., Rubens, J., & Strong A. E., (1999) "Ecological and socioeconomic impacts of 1998 coral mortality in the Indian Ocean: An ENSO impact and a warning of future change?". *Ambio* 28: 188–196.

Zahir, H., (2000) "Status of the coral reefs of Maldives after the bleaching event in 1998". In: Souter, D., Obura, D., & Lindén, O., (eds.) (2000) *CORDIO Status Report 2000*: 64–68.

Zahir, H., (2002a) "Status of the coral reef of Maldives". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 119–124.

Zahir, H., (2002b) "Assessing bioerosion and its effects on reef structure following a bleaching event in the Maldives". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 135–138.

Zahir, H., Clark, S., Ajla, R., & Saleem, M., (2002) "Spatial and temporal patterns of coral recruitment following a severe bleaching event in the Maldives". In: Lindén, O., Souter, D., Wilhelmsson, D., & Obura, D., (eds.) *Coral Reef Degradation in the Indian Ocean. Status Report 2002*: 125–134.

Indian Ocean Island – Summary

ROLPH PAYET

Ministry of Environment and Natural Resources, Victoria, Mahé, Seychelles;
and Seychelles centre for Marine Research and Technology – Marine Parks Authority, Victoria, Mahé, Seychelles

key words: Indian Ocean Islands, coral reefs, coral bleaching, tsunami, climate change

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 km^2, coral reefs cover only about 3 500 km^2, 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 km^2 of ocean.

Table 1. Estimated coral cover in the Indian Ocean Islands

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

taken. 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.

REFERENCES

Ahamada, S., (2005) *Bilan du suivi de l'état de santé des Récifs coralliens aux Comores 1998–2005.* Réseau Régional de Suivi des Récifs coralliens dans les îles du sud Ouest de l'Océan Indien Projet Récif COI/FEM. Unpublished Report. 34 pp.

Ahamada, S., Bijoux, J., Bigot, L., Cauvin, B., Koonjul, M., Maharavo, J., Meunier, S., Moyne-Picard, M., Quod, J. P., & Pierre-Louis, R., (2004) "Status of the Coral Reefs in the South West Indian Ocean Island States Node". In: Wilkinson, C. R., (ed.) *Status of coral reefs of the world: 2004*. Vol. 1. GCRMN Report, Australian Institute of Marine Science, Townsville. Chapter 7, pp. 189–211.

Francis, J., Nilsson, A., & Waruinge, D., (2002) "Marine Protected Areas in the Eastern African Region: How Successful Are They?". *Ambio* Vol. 31 No. 7–8, pp. 503–511.

McClanahan, T. R., Sheppard, C. R. C., & Obura, D. O., (eds.) (2000) *Coral Reefs of the Indian Ocean.* Oxford University Press. UK.

Obura, D., & Abdullah, A., (2005) *Assessment of Tsunami Impacts on the Marine Environment of the Seychelles*. IUCN/UNEP Unpublished Report. 17pp.

Payet, R. A., (2004) "Coral Reefs in Small island States: Status, Monitoring Capacity and Management Priorities". *International Journal of Island Affairs*, Special Issue: Island Biodiversity-sustaining life in vulnerable ecosystems (February 2004), pp. 57–65

Salm, R., (1976) "The structure and successional status of three coral reefs at Mauritius". *Proceedings of the Royal Society of Arts and Sciences of Mauritius*, 3: 227–240.

Scetauroute (1999) *Comores: Infrastructure, Eau, Environnement – Etude d'impact sur l'Environnement, Document E-388*. World Bank Publication, USA.

Spalding, M. D., Ravilious, C., & Green, E. P., (2001) *World Atlas of Coral Reefs*. Prepared at the UNEP World Conservation Monitoring Centre. University of California Press, Berkeley, USA.