Coastal Oceans Research and Development in the Indian Ocean

Status Report 2008

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Foreword

Coral reefs and tropical Small Island States are among the most vulnerable of the planet's ecosystems and societies to climate change. Since the coral bleaching event in 1998 the Indian Ocean has had repeated reminders of the specter of climate change and other planetary-scale events – cyclones and floods in Mozambique and South Asia, repeated droughts in East Africa, the tsunami of 2004 affecting Asian and island states. Further, human population growth and its impact places further stress on these fragile ecosystems. With this uncertain future facing us, it is essential to build up local and regional initiatives to understand and respond to change.

The CORDIO programme which started in 1999 as a pragmatic response to the impacts of global warming on coral reefs has over the years improved our knowledge and management of coral reefs in the region. For example data collection in the Curieuse Marine Park in Seychelles, was instrumental in guiding government policy over the management of marine protected areas, especially those that have resilient coral ecosystems. Without such important and vital information politicians, parliamentarians, local governments and MPA managers will not be able to take decisions which take into consideration coral reef recovery and conservation issues. In fact this particular report has sought to bring together research and monitoring on environmental and socio-economic aspects and their relevance to management and policy approaches to education and community-based activities.

The Seychelles is acutely aware of the vulnerability of its coastline, marine and terrestrial habitats and population to climate change. With limited land area and high dependence on coastal resources we are indeed at the forefront of efforts to combat the complex and interacting problems of overexploitation, pollution, environmental degradation and climate change. In meeting this challenge we must continue to research and harness all the resources so that we can improve coastal management, reduce human pressures and adapt to climate change.

In September 2007, I launched the Sea Level Rise Foundation, a global platform of excellence on adaptation in small island states. With the continued bleaching of coral reefs, the role of reefs in coastal stability has been significantly weakened and I am confident that with the continuation of CORDIO in its work on coral reefs and as a partner of the Sea Level Rise Foundation we will be able to bring about further attention to the issues faced by small islands and low-lying coastal areas of east Africa and the world.

President James Alix Michel
Republic of Seychelles

Contents

CORDIO Status Report 2008

Part 1 – Regional Summaries

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching – facing the consequences of climate change in the Indian Ocean. CORDIO Status Report 2008. CORDIO (Coastal Oceans Research and Development in the Indian Ocean)/Sida-SAREC. Mombasa. http//:www.cordioea.org

Ten Years After Bleaching - Moving into the Next Decade

DAVID OBURA, JERKER TAMELANDER, ROLPH PAYET, CARL GUSTAV LUNDIN & OLOF LINDEN

This status report marks a decade of CORDIO in the Indian Ocean. Started in 1999 in response to the mass mortality of corals associated with the severe El Niño of early 1998, CORDIO now works in a broad range of disciplines exemplified by the contributions in this report, focusing on long term monitoring and research to improve environmental and resource management and policy development. Research areas extend across diverse fields in biological and social sciences, and support education programmes and capacity building. Reflecting the priorities faced by the majority of Indian Ocean coastal peoples, encompassing marine and coastal management and livelihood and economic security, in 2007 CORDIO changed its name to Coastal Oceans Research and Development in the Indian Ocean, from Coral Reef Degradation in the Indian Ocean. Under this new title, CORDIO is evolving into a broader network of collaborators, anchored in key institutions in the region, working from local to global scales, and continuing to focus on capacity building of partners and institutions in the Indian Ocean. Coral reefs remain central to CORDIO, and have provided a learning ground for translating our approaches to other marine and coastal systems.

Key features of the CORDIO programme heading into its second decade include the following:

A *sustainable livelihood approach* to resource use and conservation, focusing on the interactions between people and marine ecosystems.

Following the distinction between basic and applied science, we focus on *bridging the gap between management needs and science*, turning basic research on issues such as coral bleaching to applied problem solving to provide answers to management questions.

From a direct focus on supporting monitoring activities, building these up to be able to enable *vulnerability analyses*. This approach emphasizes interpretation of monitoring information with respect to current and future threats, assessing vulnerability to growing human populations and climate change.

A continued focus on *capacity building and training* at all levels, from fishers through protected area rangers to undergraduate and graduate university students to Principal Investigators, building regional capacity to resolve regional issues.

Partnerships organized along thematic lines, such as on coral bleaching, genetic connectivity, biodiversity, resilience-based management or socio-economics, building

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the critical mass of expertise in our areas of work.

A *strategic collaboration* with the International Union for the Conservation of Nature's (IUCN) Global Marine Programme, providing complementary benefits in technical capacity and access to governance processes from national to regional levels.

In the coming decade, perhaps the major question that CORDIO and other research and management-focused organizations are asking is "how bad might it get?" Predictions of the Intergovernmental Panel on Climate Change (IPCC) are for worsening climate impacts globally. With increasing population pressure in all countries of the region, additive and synergistic effects of multiple threats are likely to worsen conditions for coral reefs. While many reef scientists are cautious, and even optimistic, about the adaptive potential of corals and zooxanthellae to climate change, all driving factors are heading in the wrong direction for corals – sea surface temperature, ocean pH, local fishing pressure, distant markets for marine products, pollution, invasive species, and the list goes on. Investments made in reef resilience and research and management capacity will be essential to minimize negative trends and to preserve any capacity for improvements, let alone attempt to reverse the trends and succeed with improving environmental health and livelihoods.

The broader context of science funding shapes the ability and potential for institutions such as CORDIO to grow and implement programmes. Globalization, including the funding for science and conservation, tends towards larger more uniform structures at the expense of local more diversified projects. To some extent this goes against CORDIO's past practice of focusing on priorities identified locally and nationally, and tailoring our engagement at these levels. While larger sources of funding may become available through climate change and adaptation mechanisms, they may force greater uniformity of action across scales, and increase the challenge of designing projects and activities to suit local settings.

Looking back at where we started – with a meeting of 25 initial collaborators in January 1999 in Sri Lanka that resulted in the first status report of 15 papers and 108 pages – to where we are now – organization and participation in multiple workshops, conferences and partnerships each year, and this fifth status report that comprises 45 papers and 450 pages – is a grand endorsement of the vision that initiated CORDIO. We are grateful to Sida/SAREC, the World Bank and the Government of Finland for making the major investments that enabled CORDIO to grow from its first seed, and also to the many other substantial donors that have and continue to support our programmes. The core of CORDIO's work, however, has been the great number of researchers, managers and other professionals all committed to achieving our common goals, and with whom we have been lucky to work with over the years.

A summary of projects and current reef status in CORDIO regions – South Asia, the Andaman Sea, the Indian Ocean islands and the East African mainland coast – are contained in the following chapters. Further information on reef status is contained in the Global Coral Reef Monitoring Network's 2008 report, released concurrently with this report.

South Asia - Summary

JERKER TAMELANDER

ABSTRACT

Recovery of coral reefs in South Asia over the decade since the mass bleaching in 1998 has been patchy. In many areas coral cover has been increasing at a rather slow pace, but there are also examples of notable coral recovery, such as on the Bar Reef in Sri Lanka and some parts of the western Atoll chain in the Maldives. The Indian Ocean tsunami in 2004, although devastating in coastal areas in parts of the region, had little significant long-term impact on coral reefs, with the exception of areas where tectonic activity has left reefs exposed or where sediment deposition was very severe. However, direct anthropogenic stress continues to degrade reef areas and in combination with climate change poses an unprecedented threat both to coral reefs and the people that depend on them. To mitigate ecological, social and economic impacts on a large scale much more effort is required to improve management effectiveness, reduce direct stress and promote adaptation on reefs. This should include the application of resilience principles in addressing coral reefs and associated ecosystems as well as natural resource dependent and coastal communities, e.g. by promoting sustainable livelihoods enhancement and diversification.

INTRODUCTION

The South Asia region includes five coastal countries: Bangladesh, India, Maldives, Pakistan and Sri Lanka. Of these only India and Maldives, and to a lesser extent Sri Lanka, have major coral reef areas. These three countries have been the focus of CORDIO activities since 1999, and for the purposes of this paper the term South Asia is used mostly referring to them.

Loss of coastal biodiversity, habitat degradation and the modification of coral reefs, mangroves and other key ecosystems, with subsequent degradation of marine and coastal services and products, is a major concern to South Asian nations. The primary driver of this change is poverty and economic development pressures. All South Asian countries are grappling with significant national development challenges. India's population is 1.13 billion people, and still growing at a rate of 1.4% (UNDP 2007). In the Maldives limited land area and large distances between islands and atolls cause transport and communication problems as well as congestion - close to a third of the population of the Maldives now lives in the capital, Male. The internal conflict in Sri Lanka has been going on for a quarter of a century. Over 50,000 people have been killed, and the mobility and development opportunities for coastal dwellers in the north and east have been reduced. The direct costs of military activity and losses as a result of reduced business opportunities and tourism have been significant.

Sri Lanka, India and the Maldives all are medium human development countries, with a human development index (HDI) above the overall regional index of 0.611 (both Pakistan and Bangladesh have lower HDIs, but only sub-saharan Africa has a lower

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overall regional HDI). Poverty is widespread. In India over a third of the population lives on less than USD 1 per day, and over a quarter of the population lives under the national poverty line in both India and Sri Lanka (UNDP 2007). The coastal population is also predominantly poor and natural resource dependent (see also e.g. Whittingham et al 2003, Wilhelmsson et al 2005).

The need to promote national development has many times led to unsustainable practices, where short-term economic gains are made at the expense of the integrity of coastal and marine ecosystems and resources, and while this has led to economic growth it has not always successfully addressed local poverty. Globalization and external market forces in some cases further exacerbate the problem. This undermines both the future of human societies dependent on natural resources and services as well as the economic growth of the countries.

An equally severe threat is posed by climate change. The global temperature increase from the end of the 19th century to the beginning of the 21st century is 0.76°C, and the rate of warming has doubled over the past 100 years. Eleven of the last twelve years (1995-2006) rank among the twelve warmest years since the mid 1800s. The sea surface temperature is also increasing, and the average temperature of the global ocean has increased to depths of at least 3000 m. Sea level rise, caused by thermal expansion and melting ice, is progressing at increasing rates, and the total sea level rise during the 20th century was estimated to have been 0.17m. Increasing carbon dioxide concentrations lead to acidification of the ocean, and IPCC projects reductions in average global surface ocean pH of between 0.14 and 0.35 units over the 21st century, adding to the present decrease of 0.1 units since pre-industrial times (IPCC 2007c). While the exact effects of ocean acidification are not detailed in IPCC's fourth assessment, it has been estimated that calcification has decreased by 10% from pre-industrial times (Lindeboom 2002), and that biogenic aragonite precipitation in the tropics could drop by 14-30% by the middle of the 21st century (Kleypas et al 1999). Further, future tropical cyclones are likely to become more intense, with larger peak wind speeds and more heavy precipitation (IPCC 2007d).

Coral Reef Status, Trends and Threats

Coral bleaching

Coral reefs in South Asia suffered significant large-scale bleaching in 1998, with a significant reduction in coral cover. The impact was very variable, ranging from almost 100% mortality in some areas, such as in the Laskahdweep islands, India, and many parts of the Maldives and the Bar Reef area in Sri Lanka. Other areas exhibited much lower bleaching related mortality, such as e.g. on the Indian coast of the Gulf of Mannar, and the Andaman and Nicobar Islands. In many areas the exact impact of the 1998 bleaching event is unknown due to the lack of baseline data on both benthic and reef fish communities (e.g. Linden and Sporrong 1999, Souter and Linden 2000, Linden et al 2002, Souter et al 2005, Rajasuriya et al 2004).

Now, ten years after the 1998 bleaching event, some of the intermediate and longer term implications are becoming evident. It is clear that the recovery process is highly variable in the region. In the Chagos archipelago, where human interference and anthropogenic stress is very low, reef recovery has been remarkably fast, with a return to pre-bleaching coral cover on many reefs, and healthy recruitment rates and normalizing population structure (Harris and Sheppard 2008). Near-shore patch reefs on the severely bleached Bar Reef in Sri Lanka have also regained coral cover through abundant growth of *Acropora* spp. (Rajasuriya 2004, 2008). In the extensive Maldives archipelago several atolls show very limited recovery, as has been found through the national monitoring programme, while there are many reports of areas where recovery is higher, notably reefs in the western atoll chain (Zahir 2005, Zahir pers. comm.) Similarly, in the Lakshadweep archipelago, coral cover is increasing at most reef sites and algal turf and macroalgae have considerably reduced from earlier studies. However, the rate of coral growth remains patchy (Arthur 2008).

Although bleaching has been observed almost on an annual basis in the region since 1998 this has been mostly on a local scale and during the warm and calm period in April-May. Bleaching in the Lakshadweep in April 2007 was higher than normal summer bleaching, and some reports confirm that this pattern of bleaching is on the increase, with the possibility of some amount of bleaching-related mortality (Arthur 2008). Reports from the Indian coast of the Gulf of Mannar, which suffered little impact of the event in 1998, annually exhibits bleaching around May but usually with full recovery within weeks-months (Patterson et al 2008, Patterson pers. comm.).

Indian Ocean earthquake and tsunami 2004

The devastation from the Indian Ocean tsunami in 2004 has been documented in some detail in a number of reports (e.g. UNEP 2005, Wilkinson et al. 2006, and see reports this volume). Damage to human life, society and infrastructure was very high in many parts of South Asia, and tens of thousands of human lives lost. The reefs of the Andaman and Nicobar Islands were, due to their proximity to the epicentre of the earthquake, among the hardest-hit. In the northern group of the Andaman Islands large areas were uplifted, causing permanent damage to shallow reefs. Up to 15 meter-high waves were observed in parts of the Nicobar Islands, causing significant reef damage, and silt deposition was high. In total over 300km^2 of reefs were destroyed (Kulkarni 2008).

On a regional level, though, with the exception of areas affected by tectonic activity, the damage to coral reefs was mostly moderate or not significant, and recovery predictions are good. (Rajasuriya et al 2005, Patterson et al 2005, Zahir et al 2005, Wilkinson et al. 2005). Impacts on the reef fish community appear similarly limited, although more detailed conclusions with respect to reef associated biota can not be made for most parts of the region due to low data availability and resolution (spatial, temporal and taxonomic).

It is clear that the tsunami had a much lower impact on coral reefs than the bleaching in 1998, and indeed much lower than the chronic stress from a range of human activities. However, a significant threat lies in the synergistic effects of these stresses. Some indications of higher destruction on already degraded reefs has been reported, e.g. where mass mortality in 1998 was high, coral growth remains low and the reef structure has been weakened by bioeroderes (e.g. Rajasuriya et al 2005), and it may prevent successful recovery.

Anthropogenic stress

While large-scale disturbances such as bleaching, tsunamis and cyclonic storms may damage coral reefs over large areas, it is clear that, on a local level, much of the reef damage observed in South Asia is caused by direct anthropogenic stress. For example, over 32 km^2 of coral reef has already been degraded around the 21 islands of the Gulf of Mannar largely as a result of human activities, including the loss of an entire island to coral mining (Rajasuriya et al 2005, Patterson et al 2005). Many of the livelihood options available to a large number of poor coastal dwellers have a direct negative impact on coral reefs (Kumara 2008), and overfishing and fishing using destructive methods is a perennial problem in many parts of the region.

Surveys of reef areas where human impact and use of reef resources has been limited often find reefs in better health, such as in Chagos. In northern Sri Lanka around the Jaffna Peninsula, where reef use has been limited due to internal conflict, reefs are relatively undamaged, whereas elsewhere in the country they are heavily impacted by human activities due to poor management (Rajasuriya 2008).

Direct anthropogenic threat and poor management of coral reef areas is considerable cause for concern. The IPCC predicts that the resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change associated disturbances, including ocean warming and acidification, in combination with other stresses, such as pollution and overexploitation of resources. Direct anthropogenic stress increases vulnerability to climate change by reducing resilience and adaptive capacity because of resource deployment to competing needs (IPCC 2007a). Thus coral reefs affected by over fishing, destructive fishing, land runoff, nutrient and other pollution will be more vulnerable to increases in water temperature and ocean acidification.

Climate change

The impacts of higher temperatures, more variable precipitation, more extreme weather events, and sea level rise are already felt in South Asia and will continue to intensify. Particularly vulnerable are coral reefs, mangroves and salt marshes. Increases in sea surface temperature of one to three degrees Celsius are projected to result in more frequent coral bleaching events and widespread mortality, unless there is thermal adaptation or acclimatization by corals. However, corals are considered to have a low adaptive capacity, and species extinction and reef damage is projected with higher confidence than has been done previously (e.g. in the IPCC third assessment report) as warming proceeds. Bleaching and coastal erosion will affect fisheries resources negatively, and reduce tourism value of coastal areas (IPCC 2007 d). Some change has already been observed (e.g. Rajasuriya et al 2005), and reduced distribution of coral reefs is inevitable should present trends continue.

On small islands, such as along the Maldive ridge and the Andaman and Nicobar Islands, sea-level rise is expected to exacerbate inundation, storm surges, erosion and other coastal hazards, threatening human populations, infrastructure and livelihoods. The occurrence of unusually strong tidal waves in the Maldives in May 2007, with an unprecedented degree of flooding and significant implications for populations both in the immediate and long-term, may be a warning of things to come (Government of the Maldives, UN and IFRC 2007).

Socioeconomics and livelihoods

Socioeconomic status and trends among reef dependent communities in South Asia have been synthesized e.g. by Wilhelmsson et al (2005) and Whittingham et al (2003) including through case studies on the Gulf of Mannar (Rengasamy et al 2003), the Lakshadweep Archipelago (Hoon 2003) and South Andaman (Singh and Andrews 2003).

There are large differences in the socioeconomic status of people in the three countries, with the greatest poverty in India and the dependence of people on the marine environment strongest in Maldives - 100% of the population in the Maldives lives in the coastal zone, compared with 81% in Sri Lanka, and 26% in India (expressed as population within 100 km of the coast) (WRI 2000). However, throughout South Asia coastal and marine ecosystems and resources provide large benefits to the countries through key industries such as fisheries and tourism. In 2000 the number of people directly employed in fishing and aquaculture in India was c. 6 million, in Sri Lanka close to 150,000 and in the Maldives c. 20,000. Further, millions of people rely heavily on coastal and marine resources for economic sustenance and protein. For example, in the Maldives fish protein constitutes 60% of total protein supply on a national level, compared with 10% in Asia overall and 6% in the world (WRI 2000). On Agatti island in the Indian Union Territory Lakshadweep, 20% of the households report reef fishery and gleaning as their main occupation, but as much as 90% of the protein intake in poor households comes from reef fishing and gleaning (Hoon 2003).

A report by Kumara et al (2008) clearly shows that direct anthropogenic stress is causing significant reef damage in South Asia, with many local livelihoods threatening to undermine the ecosystems that support them. However, it is also clear that viable livelihood options are not always available to coastal dwellers, or they are not in a position to diversify income generation due to both external factors as well as intrinsic factors within the community (Cattermoul et al 2008).

The threat of climate change will further compound the already difficult social and economic situation faced by South Asian countries and their coastal communities. According to the IPCC (2007a), regions facing multiple stresses that affect their exposure and sensitivity as well as their capacity to adapt, such as South Asia, are particularly vulnerable to climate change, due to poverty and unequal access to resources, food insecurity, trends in economic globalisation, conflict, and incidence of disease. Climate change effects are already impacting the economic performance of the countries in the region, including, for example, increased damages and deaths caused by extreme weather events, and adverse impacts on natural resource dependent livelihoods, such as fisheries. Particularly the poorest people are most at risk, and climate change will impinge on the sustainable development of most developing countries of Asia as it compounds the existing pressures on natural resources and the environment (IPCC 2007a). Further predicted effects include e.g. coastal water temperature increases exacerbating the abundance and/or toxicity of cholera, crop yields decreasing by up to 30% by the mid-21st century, coastal areas increasingly at risk from flooding from the sea and, in heavily-populated mega-delta regions, from flooding from rivers (IPCC 2007a).

RESPONSES

South Asia stands to suffer significant consequences from climate change, but it is responsible for only 13.1% of global greenhouse gas emissions and, with almost half of the worlds' population, has the lowest regional per capita green house gas (GHG) emission. However, its carbon efficiency (in terms of output generated measured in GDP at purchasing power parity per unit GHG emission) is still lower than the industrialised west, although higher than in other developing regions (IPPC 2007b). It is clear that the answer to slowing and turning the global climate change trends lie in drastic mitigation actions mainly outside, but also within South Asia, especially in India. However, in view of present trends it is absolutely essential that environmental management on a local, national and regional level sufficiently address climate change threats by increasing the resilience and adaptation capacity of ecosystems and human societies, and reducing vulnerability.

To this end, CORDIO and IUCN, in association with other partners, have initiated a regional programme on resilience research and capacity building. To date this has included a range of training courses, ecological and socioeconomic studies and pilot projects.

A South Asia Reef Resilience Workshop was held in Bentota, Sri Lanka, 15-18 January 2007, bringing together coral reef scientists, managers and policy makers from five countries in South Asia and around the Bay of Bengal: Indonesia, India, Maldives, Sri Lanka and Thailand. The workshop provided insight into the state of coral reef resilience research and management adaptations internationally (see e.g. Grimsditch and Salm 2006), identified and discussed regional needs and priorities, and promoted learning and exchange of information. Resources recently developed through major international collaborations were highlighted and distributed to participants, including R2 Resilience Toolkit (R2 2004) developed by the Resilience Partnership[1] and the Manual for the Study and Conservation of Reef Fish Spawning Aggregations published by the Society for Conservation of Reef Fish Aggregations (Colin et al 2003). The workshop was followed by a regional Coral Reef Experts Group Meeting, with the objectives to facilitate peer-to-peer exchange on applying resilience principles in management among key coral reef experts in the region; as well as to develop, define and prioritize regional and national/local resilience projects for implementation. The sessions produced a number of recommendations on research and management direction and policy, and defined pilot projects (IUCN 2007a,b).

Building on these activities a regional Coral Reef Resilience Field Training for South Asia and the Andaman Sea will be organized in the Maldives in January 2008. The Field Training will build capacity

[1]Resilience Partnership: The Nature Conservancy, IUCN – The World Conservation Union, Great Barrier Reef Marine Park Authority, NOAA, World Wildlife Fund, and Wildlife Conservation Society

among marine scientists in the region in assessing and monitoring resilience and adaptation of coral reefs, and will serve as a field trial for a regional methodology on resilience monitoring under development by IUCN, CORDIO and other partners. It will also set up a South Asia regional network as part of the global Resilience Assessment project of IUCN s Working Group on Climate Change and Coral Reefs (IUCN 2006). Targeted research will attempt to identify areas naturally resilient or resistant to bleaching, and whether bleaching patterns observed are and indication of adaptation to climate change. It should, however, be noted that in terms of degree heating weeks most parts of the region have not been subjected to the same temperature stress as in 1998, and patterns observed may be normal seasonal fluctuations.

A regional research project on reef fish spawning aggregations (FSA) has also been initiated. Interview surveys were conducted among fishing communities in selected areas of India, Indonesia, Maldives, Sri Lanka and Thailand in order to determine the level of awareness of FSAs among fishers; which reef fish species form FSAs; sites of aggregation formation; seasonal patterns; and to assess fishing pressure on and status of FSAs. Results show that only a minority of fishers possess reliable knowledge of spawning aggregation sites, species and times, but possible FSAs were reported from all areas studied. As has been found in many other parts of the world, FSAs in the region are targeted by fishers. The results from this study will be used to increase awareness among communities as well as managers and policy makers of the ecological significance and vulnerability of reef fish spawning aggregations in order to design and implement suitable management responses (Tamelander et al 2008).

In order to address the plight of the many coastal natural resource dependent poor and address their resilience and vulnerability in the face of environmental change, CORDIO has entered into a partnership with a number of regional and local partners, the Coral Reef and Livelihoods Initiative (CORALI[2]). Building on knowledge on the complex relationships between people and reefs, the relationships between coastal policies and poor people's livelihoods and e.g. the impacts of change in the post-harvest fisheries sector on poor people, the initiative seeks to understand the factors that help or inhibit livelihood change, and conducts research and development focused on constructing a basic approach for supporting Sustainable Livelihood Enhancement and Diversification (Whittingham et al 2003, Cattermoul et al 2008, and the references therein). Approaches are tested through pilot initiatives at six field sites around the region. This is complemented by a range of education and awareness initiatives implemented by CORDIO and other CORALI partners.

Research is also carried out to study resource use and responses to environmental, social or political change. For example, a fish catch monitoring programme in the Lakshadweep (Tamelander and Hoon 2008) has generated information much more detailed than was previously available, and through this also identified a number of features of the fishery that are vital when developing management responses. Similar fish catch monitoring has also been initiated in the Gulf of Mannar, along with bycatch assessment in the mechanized local fishery (Patterson et al unpubl).

The data, information and knowledge generated through CORDIO activities can support and underpin management and policy responses, and over the past years CORDIO South Asia has increasingly sought to strengthen the way it communicates management and policy implications of its findings. A review commissioned in 2006 to identify past successes and shortcomings in this respect and to provide further guidance, found the scientific base to CORDIO's South Asia Programme very strong, with coral reef monitoring of high quality. The status

[2]CORALI is a collaborative initiative between IUCN – The World Conservation Union, Coastal Ocean Research and Development in the Indian Ocean (CORDIO), United Nations Environment Programme (UNEP) South Asia Cooperative Environment Programme (SACEP), International Coral Reef Action Network (ICRAN) and IMM Ltd., as well as national and local organizations in South Asia and the Andaman Sea.

reports were identified as a crucial and great achievement, and it was noted that the awareness and education, and alternative livelihoods components have made great progress on a local level, particularly in India. The review suggested that to fully realize the objective of supporting policy formulation and uptake, new partnership arrangements with relevant agencies is needed, as well as increased focus on informing policy makers in-country through project implementation partners (Samoilys 2006). A number of tools and products targeted at managers and policy makers are being developed, in part through CORALI, including a regional MPA Managers Toolkit, GCRMN reports, as well as policy influencing materials and policy fora. This will be complemented by education and awareness materials targeting a broad range of stakeholders, in particular school children and teachers.

CONCLUSIONS AND RECOMMENDATIONS

The compounded threats from direct anthropogenic stress and climate change, together with unequally distributed wealth and, for the majority of the regions people, low socioeconomic status, demands concerted and comprehensive effort from all stakeholders and at all levels. The activities presented herein, along with numerous other government, IGO, NGO, CBO and private sector initiatives, have taken significant steps to addressing this. However, it is clear that, in view of the scale of the problems the region faces, and the rate at which environmental change is occurring, the current response will not be sufficient for sustainable development and meeting Millennium Development Goals, and a large section of the region may face increasing hardship.

Marine and coastal governance needs to be strengthened on both national and regional level, including underpinning decision making with best available science findings and concerted action that is integrated across sectors. Improved flow of information and knowledge between research institutes, line agencies and ministries is needed. The recently established South Asia Coral Reef Task Force has an important mandate in this regard (SACEP 2007), as does regional bodies such as South Asia Cooperative Environment Programme (SACEP), the Land Ocean Interaction in the Coastal Zone (LOICZ) Regional Node for South Asia, and the South Asian Association for Regional Cooperation (SAARC). The evaluation analysing the efficacy of CORDIO's approach to dispensing policy advice in South Asia provides useful recommendations, and identifies opportunities for increased support to policy formulation (Samoilys 2006).

Resilience principles should be applied in the creation, zoning and management of Marine Protected Areas (MPAs), as well as in the establishment of networks of MPAs. Many of the regions MPAs remain de facto paper parks and there is a need to assess and strengthen management effectiveness across the board. The World Commission on Protected Areas and its Marine Plan of Action (Laffoley (ed) 2006) may provide useful guidance. MPAs should also increasingly go beyond biodiversity conservation, and can be applied e.g. as tools for resource and integrated coastal management. However, fair and equitable sharing of benefits must be ensured in the development of MPAs and MPA networks, to a much larger extent than has been done in the past.

South Asia's fishery resources are under strain and in many cases overexploited, and initiatives focusing on the small-scale artisanal fishery are particularly urgent, as is addressing frequent and blatant breaches of existing legislation with respect to destructive resource use. Importantly, a proactive approach should be taken with respect to management of those parts of the region where reef fish populations still are comparatively healthy, such as many parts of the Maldives and the Lakshadweep islands, to ensure resource use does not become unsustainable and to ensure benefits arising from the fishery accrue to local populations. This includes e.g. a very cautious approach to developing export fisheries for grouper and other high value reef fish. Where present, overcapacity in the mechanized and industrial fishing fleets needs to be decommissioned.

Addressing the issues outlined above and strengthening economic development in coastal and marine areas must go hand in hand with livelihoods enhancement and reducing the vulnerability and natural resource reliance among coastal dwellers. This must include efforts to engage, involve and empower local communities to address their plight. It should also be recognized that low awareness and educational levels remains an obstacle to sustainable development (e.g. Patterson et al 2008), and must be addressed through the national educational systems as well as dedicated and specific activities, such as is required e.g. to support other activities as outlined here.

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Andaman Sea - Summary

HANSA CHANSANG & UKKRIT SATAPOOMIN

INTRODUCTION

The Andaman Sea coast is one of the two main coral reef areas of Thailand (the Gulf of Thailand being the other), with a total area of 78 km^2 of primarily fringing reefs ranging from near shore to offshore areas (Chansang, et al 1999). These reefs are an important resource for tourism in Thailand. However, rapid coastal development on the Thai Andaman Sea coast over the past three decades has led to degradation of coastal resources. Although development has increased economic growth of the country as well as income of the population, it has also affected both the physical environment and socio-economic condition of coastal communities. Changes in resource uses patterns have led to increasing natural resource exploitation and degradation.

Coral reefs clearly exemplify this trend, with a change from a traditional and sustainable fishery for domestic and local consumption to increasing exploitation of reef areas for tourism and recreational uses. Concern regarding the degradation of reef habitats and depletion of reef resources this has caused has led to a number of management measures by government. However, in spite of this there are still knowledge gaps and room for improving effective management.

The devastation caused by the Indian Ocean tsunami in 2004 emphasized many of these gaps, in response to which CORDIO expanded activities to the Andaman Sea, with a view to supporting sustainable coastal development and wise utilization of living coastal resources.

Activities

Coordinated by Phuket Marine Biological Center (PMBC), CORDIO activities in the Andaman Sea were implemented in collaboration with academic institutions, government agencies and NGOs in Thailand as well as Aceh, Indonesia, covering 6 focal areas:

- Strengthening capacity for coral reef monitoring and assessment
- Monitoring of coral reefs
- Research on coral reef fishery and the fishermen
- Alternative or supplemental livelihoods
- Strengthening community participation in reef management
- Public education and awareness building.

Strengthening Capacity for Coral Reef Monitoring and Assessment in the Andaman Sea

While there is considerable coral reef monitoring capacity within the Andaman Sea region – for example, in Thailand reef monitoring has been carried out for the past three decades – monitoring capacity and effort have not been evenly distributed. In order to address this and to promote use of standard and compatible methodologies as well as strengthen networking of researchers and managers and to

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promote sharing of data, knowledge and experience, a training workshop was held in Phuket, Thailand in April 2006. Eighteen participants from Thailand and Indonesia, representing government agencies, universities and NGOs participated in the workshop.

Besides standard techniques, including benthic line intercept transect, manta tow as well as fish visual census, the course also covered training in measuring other key environmental parameters such as turbidity, salinity and temperature, as well as exercises in using data sheets, data entry and basic analysis (Dartnell and Jones, 1986; English *et al*, 1994).

The activities under this programme have successfully expanded the ongoing coral reef monitoring by increasing the numbers of monitoring teams in Thai waters - the training led to the establishment of monitoring sites on Adang Rawi Islands, Thailand, by Prince Songkhla University, and local NGOs have used the reef assessments to manage reefs for ecotourism activities in the area. Further, the training increased capacity for reef monitoring in Indonesia, and participants from Syiah Kuala University carried out reef surveys on Weh and Aceh Islands in Sumatra in collaboration with Wildlife Conservation Society (Campbell et al. 2008., Rudi et al 2008.).

It is recommended that additional parameters should be considered as indicators of reef health in monitoring reef health, besides coral cover.

Monitoring of Coral Reefs in the Andaman Sea

The reefs in Thai waters have been monitored under the long term monitoring programme (Phongsuwan and Chansang, 1993; Phongsuwan et al, 2008). As part of CORDIO support, reef monitoring in 2006 was carried out at Surin Islands National Park and Similan Islands by PMBC (Phongsuwan et al. 2008); and Adang Rawi Islands of Tarutao National Park by Prince Songkhla University (unpubl.). Results indicate that reefs in the Andaman Sea are resilient to natural stress and damage (CORDIO Andaman Sea 2007; Phongsuwan et al. 2008). The reefs did not suffer extensive damage from the bleaching event in 1998 in comparison to reefs in e.g. Maldives (Zahir *et al*, 2005) and Sri Lanka (Rajasuriya, 2002). Based on permanent transects, only 18.3% of reefs were affected by the tsunami and are predicted to show recovery within the next 3-10 years if conditions remain favorable to reef growth. However reefs close to tourist development areas show signs of degradation (Phongsuwan et al, 2008).

Baseline quantitative data of reefs in northern Sumatra, Indonesia is comparatively limited, both before and after the Indian Ocean tsunami. In the aftermath of the tsunami long term reef monitoring was recognized as a priority, and monitoring was carried out on Weh and Aceh Islands by a team from Syiah Kuala University and Wildlife Conservation Society, Aceh. The main objectives of this monitoring were to provide reliable data and information on benthic hard coral and reef fish abundance of the area. Surveys conducted at 21 sites on Weh Island and Aceh Islands in February 2007 shows that coral reef condition and reef fish abundance varies significantly between the islands, that fish population abundance is related to coral cover, and importantly that management status of the area impacts on fish communities. Natural coral recruitment was observed to take place two years after the tsunami, especially on rocky substrates in shallow waters. However, rubble substrates in deeper waters prevent recruitment due to post settlement mortality of the recruits (Campbell et al. 2008, Rudi et al. 2008).

Research on Coral Reef Fisheries

While coral reef fishing is a common occupation among local fishing communities in Thailand, in particular among indigenous people, very little is actually known about the fishery, its impact on reefs and its role for the well being of fishing communities. Increasing development and expansion of reef exploitation by a mechanized coastal fishery as well as the tourism industry, has greatly affected the lives of reef fishers by reducing access to fishing grounds and diminishing resources. A CORDIO supported study

(Narumon 2008.) has compiled socioeconomic information on reef fishing communities; the magnitude of indigenous fishing in reef areas both outside and inside marine parks; and conflicts in relation to other resource uses, in particular tourism, focusing on ethnic Thai and sea gypsy fishing communities in the southern part of Phuket (Satapoomin and Chawanon, 2008); and in Tarutao National Park and Mu Ko Phetra National Park in southern part of the Andaman Sea (Plathong et al, unpubl).

A study by Plathong et al. (unpubl) has shown that fishing in marine parks has grown from a seemingly sustainable fishery for local consumption to a commercial, illegal but profitable fishery. The combination of increasing demand of seafood for park visitors and for regular markets on the mainland makes law enforcement a challenging task. Sea gypsies have also had to adapt their lifestyles to support the growing tourism industry. This urgently requires further study to create appropriate planning and management strategies and action dealing with issues of fishing rights of traditional fishermen in and around marine parks.

The study by Satapoomin and Chawanon (2008) is the first study of its kind focusing on the reef fishery in Thai waters. Results indicate a trend of changing from traditional fishing to accommodate more modern fishing methods as well as new occupations in particular in the marine tourism sector (see also Narumon 2008). However, while the study provides a lot of information previously not available, the comparatively short time span places limitations on conclusions pertaining to the crucial questions of whether present reef fishery is sustainable or not. Continuation and geographic expansion is recommended.

Alternative or Supplemental Livelihoods

The indigenous fishing communities, locally known as sea gypsies, are traditional stakeholders of reef resources in the Andaman Sea. With changing patterns of reef uses and increasing number of other stakeholders, their livelihoods have been threatened through competition and declining resources. As yet there is only a scattering knowledge about their livelihood and socioeconomic condition. Options for providing alternative or supplemental livelihoods have been considered by government as well as NGOs. This study has reviewed previous studies and focused on extracting "lessons learned" from past livelihood projects in three indigenous communities in Phuket Province, Thailand. Research methods included literature review, interviews and consultations with organizations, local government and other stakeholders, case studies, and stakeholder meeting.

The finding shows that there were numerous projects and activities to provide alternative or supplemental livelihood but most of them did not respond to the real need of the communities. This is due to several factors: short-term activities; project not feasible economically; lacking knowledge of project personnel on strengths and weaknesses of the communities; and a deeply-root bias against the communities. Lack of coordination and collaboration among different agencies or organizations working is a major problem.

The recommendations for future action emphasize improvement on government and other agencies in working with the communities on various aspects: increasing effort in understanding and appreciating special characteristics of the communities: better coordinating and integrating work among different agencies and organizations; providing small-scale long-term alternative occupational activities while promoting market for communities' products; and creating innovative methods in working with the communities. It is hoped that information obtained will be useful to initiate some solution assisting the communities in adapting to present development.

Strengthening Community Participation in Reef Management

In Thailand, the government has recognized the importance of community involvement in resource management after decades of absolute government control. To strengthen community involvement, it is necessary to increase awareness and sense of ownership of resources by coastal communities as well as continuing planning and action by the government. The activity in this project was on strengthening the community network of long tail boat operators throughout west coast of Phuket Island. They are part of marine and coastal resources conservation volunteer network established under government support. Their main income derives from day tours to reefs. The activities by the network are assisting in reef surveillance, installation and maintenance of mooring buoys, and, reef and beach clean up. Under CORDIO support a meeting to strengthening network on coral reef conservation was held. The stakeholder workshop served the purpose of reviewing status of community involvement, introducing new groups of stakeholders into the network as well as serving as a forum for discussing about conflict among groups. The workshop has succeeded in agreement on reef uses zoning and self-regulation in order to avoid conflict of reef fishery and tourism along the west coast of Phuket Island. It is the first attempt by reef users in resolving the conflict among themselves and imposing their own regulations of reef uses. It is a starting point toward community action in reef management.

Public Education and Awareness Building

This project was initiated with the reasoning that the lack of awareness and knowledge of sustainable use by coastal communities was an underlying cause of degradation of marine resources. Therefore the strategy was to provide knowledge on resource conservation to coastal communities of the Andaman Sea by using existing facilities and expertise. The project was separated into 2 subprojects based on target groups i.e. youth and teachers.

-Training for school and college students in Phuket and Phangnga Provinces on marine resources conservation (Suksuwan et al 2007)

Phuket Aquarium was responsible for educating students in Phuket and Phangnga Provinces on marine resources and the need for wise utilization of the resources. The objectives were providing knowledge and creating awareness on living coastal resources, the importance of living coastal resources, and need for sustainable uses.

One-day training activities were carried out for 1520 high school students and college students during June to December 2006. Each session contained 30-40 students and included lectures and outdoor activities. The project was well received by education institutions in Phuket and Phangnga Provinces. It is recommended that this type of activity should be continued annually so that more students from various locations and levels can participate. In addition possible local funding should also be sought to continue the project.

-Teacher training for education on marine resources conservation (Sakoolthap et al, 2008)

This project targeted enhancing capacity of local school teachers in educating younger generations and possibly communities on sustainable use of marine resources. The Phuket Rajabhat University had developed teaching manuals and conducted two training workshops on coastal resources and management for primary school teachers (Grade 4-6) and secondary school teachers (Grade 7-9) of local school of Phuket and Phangnga Provinces to provide knowledge on resources as well as teaching local teachers to use the manuals.

The project has been well received and participants were satisfied with the manuals and trainings. It is recommended that with more input and feedback from teachers, improvement and expansion of teaching manuals should be carried out to cover all subjects on coastal and marine areas including the problems related to global warming effect and natural hazards such as tsunami. It is also aimed to acquire local government support for the activity whenever possible. The outcome of continuous activities will strengthen community awareness and involvement in managing resources in the future. The training workshops should also be continued with local funding and extend to include teachers in other provinces along the coast of the Andaman Sea.

CONCLUSION AND RECOMMENDATIONS

The CORDIO Andaman Sea project was a small project both in term of activities and duration. The project included activities to assist present management scheme as well as for long term results. For present management, the activities were: reef monitoring and capacity building in reef monitoring within Thailand and Indonesia; and activities to fill in missing gaps in reef research and management. The project has successfully initiated some actions which will lead to sustainable resource management in the long term. It requires continuous effort so that the activities will be taken up by communities. The future plan should aim at empowering stakeholders to actively participating in management by education and stimulating private sectors support. This will take time especially projects on sociological aspects such as community participation in resource management, education to create environmental awareness and adaptation of traditional users in accessing their own resources or to receive fair treatment such as for the sea gypsies.

The project has had limited success in creating reef monitoring network in the Andaman Sea. The monitoring network has been set up by research institutions volunteers, and NGOs in Thailand. The project has succeeded in establishing linkage between Thailand and Indonesia within this short duration. Some countries in the region need outside financial support to continue reef monitoring activities. Thus assistance from international organizations is needed both for organizing activities as well as for financial support in establishing the Andaman Sea network. The network should include other activities besides reef monitoring and it should be a part of the Indian Ocean network.

In conclusion it is felt that there are enough expertise and readiness of certain groups of stakeholders to carry on activities in the Andaman Sea especially in Thailand. The main obstacles are lack of coordination among various activities directed toward a common goal and lack of financial support for some activities. Besides providing extra financial support, the outside assistance can stimulate further progress by providing information exchange and lessons learned within the network. Lessons learned from Thailand can also be shared to other countries within the region which are facing similar threats regarding resource use. It is hoped that the effort in conducting work such as CORDIO can continue in the future.

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East Africa and Islands - Summary

DAVID OBURA & ROLPH PAYET

INTRODUCTION

The Eastern Africa region comprises both the islands in the western Indian Ocean and the East African mainland coast, comprising nine countries – Comoros, Kenya, Madagascar, Mauritius, Mozambique, Reunion (France), Seychelles, South Africa and Tanzania – crossing a broad range of development levels, from among the highest in Africa (Mauritius, South Africa) to among the poorest (Comoros, Madagascar). With mainland countries and islands from large to small, and a wide mix of people and cultures, the countries of the region face a diverse range of environmental and resource pressures related to the sea, and to coral reefs in particular.

As in the South Asia region (see previous summary), eastern Africa faces a wide range of linked socio-economic and environmental problems, including over-exploitation of fisheries and other living resources, destructive activities such as dynamite fishing, unplanned growth and development of villages, towns and cities and their attendant impacts on the coast and nearby coastal waters, increased tourism development, and on top of this all, climate change.

While pressures in the region tend to be lower than in Asia as population densities are lower and historical pressure has been much less, eastern African countries tend to have weaker governance structures and lower technical capability to manage impacts to the environment. And apart from the small island states, marine and coastal issues tend to have a low priority for central governments and for society as a whole, so problems tend to persist and worsen before attempts at resolution are made.

Coral Reef Status, Trends and Threats

Coral bleaching

Since the major bleaching event in 1998 marine researchers and managers have been on the alert for repeat bleaching events. 2005 saw the most extensive hotspot develop in the western Indian Ocean since 1998, and though 2007 was initially predicted to be as warm or warmer than 1998, it turned out not to be a bleaching year, with both the El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole in negative phases. During this season an early warning system was put in place that incorporated monitoring of internet-based datasets on global temperature, the ENSO and IOD indices, NOAA temperature anomaly charts and observations from the field. Monthly updates were sent out by email, and this is repeated annually during the bleaching season of January-May.

As in South Asia, sites show very variable levels of recovery from the 1998 bleaching event, with most sites still at intermediate levels of recovery. A small

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

number of reef areas that were either lightly impacted in 1998 or have showed rapid recovery since then have been noted, including sites such as the Chagos archipelago (Harris and Sheppard, this volume), Vamizi island in Mozambique (Garnier, this volume) and the Songo Songo reef system in Tanzania. These sites are the focus of increasing research to understand what characteristics enhance their resistance or tolerance to bleaching, and/or high capacity for recovery and resilience.

While CORDIO has supported monitoring programmes that initially focused on bleaching impacts and recovery, many of these are increasingly being targeted at local management needs and priorities, which from the majority of reports in this volume can be seen to be focused on community fisheries and MPA management. This entails customization of methods to suit local personnel and language (e.g. Muhando et al., this volume) and embedding monitoring programmes, both biological and socio-economic in local conservation partnerships. Complementary to this development is a focus on raising standards and improving techniques in monitoring programmes by adding indicators that relate to coral population structure, recruitment and indicators of ecosystem resilience (Obura and Grimsditch, this volume)

Basic research is increasingly being applied in the region and integrating with monitoring programmes supported by CORDIO. Recruitment studies are now widespread, in the Seychelles, Tanzania and Kenya (e.g. Furaha, this volume), and through a new global collaboration, CORDIO is building up research on coral-zooxanthellae dynamics and bleaching dynamics (Grimsdith et al., this volume). The first study on hard coral reproduction at equatorial latitudes is reported here (Mangubhai, this volume), confirming that unlike at higher latitudes where spawning is more synchronized, coral spawning in Kenya is spread over a broad season during the warmest months of the year.

Fish and fisheries

Fishing continues to be a key sector for poor communities in the region, as an activity of last resort and for economic development, but unmanaged fisheries are a key factor driving reef degradation. A number of key factors contribute to this. First is the importance of local governance in managing small-scale fisheries, touched on by many reports in this volume. Most countries in the region are attempting to build the capacity for co-management of local fisheries, whereby the past approach to centralized fisheries management is giving way to sharing responsibilities with local fisher associations. At the other end of the scale, regional processes are maturing with increased collaboration on fishery policy and instruments, with the South West Indian Ocean Fisheries Commision (SWIOFC), South West Indian Ocean Fisheries Programme (SWIOFP), and fisheries partnership agreements all increasingly active in addressing inshore and offshore fishery issues.

Increased work on artisanal fisheries is highlighted by a series of papers on the Diani-Chale fishery in Kenya (Maina et al., this volume, Tuda et al., this volume, Munywoki et al., this volume and Oluoch et al., this volume), showing how co-management of fisheries can be supported and built up in stages by progressively building up fishers' capacity to undertake management functions, such as monitoring. Extensive datasets that focus on local dynamics can result, providing estimates of daily catch rates at the local scale, and scalable up to national levels (Tuda et al., this volume). To make monitoring accessible to fishers the units and methods were adapted to the local context, and this can also be essential in resolving key conflict issues, such as on the impacts and use of illegal gears. Finally, while co-management of resources by users should be encouraged throughout the region, along with the development of local area management plans to maximise ownership and stewardship of resources, communities and their leaders need significant assistance in capacity building, to enhance their skills to exercise these responsibilities (Oluoch et al., this volume).

The roles of governance and capacity are highlighted in Tanzania. Dynamite fishing has been on the resurgence from 2005-2007, with multiple blasts daily reported in the Tanga and Dar es Salaam regions. Initially stopped in 1996 through involvement of the Tanzania Navy, political will has eroded in recent years, allowing its resurgence. Conflicting approaches to resolution of the issue between stakeholder groups and local government structures, particularly in Tanga, have led to increasing polarization of different camps with a role in ending the practise. Nevertheless, high-level meetings in late 2007 between all the ministries responsible and supported by stakeholder groups have taken place, indicating growing political will to resolve the issue. The issue is particularly poignant in Tanga, where over 12 years of investment in district level co-management, in the Tanga Coastal Zone Conservation and Development Programme, involving the Tanzania government, IUCN and Irish Aid have probably left the most highly capacitized set of district officials and village communities, yet even so dynamite fishing was able to resume.

Fish spawning aggregations (FSA) were previously unknown to science and management in East Africa. New research initiated in the Seychelles and now spreading to Kenya and Tanzania (Robinson et al. this volume) show that FSAs have indeed been common in the region, though now somewhat depleted by fishing. Indeed, fishers were well aware of their presence, targeting them for a high catch. Knowledge on FSAs will provide an additional tool for fisheries management that is highly valuable, and can complement other management options.

Poverty, livelihoods and education

The Socio-economic Monitoring programme of the Western Indian Ocean (SocMon WIO) has been increasingly active in 2005-2007, growing to include 12 sites spread across all countries in the region (e.g. Wanyonyi et al., this volume, Hardman et al., this volume and Andriamalala and Harris, this volume). Partners include scientists, national MPA agencies, community-based projects and conservation NGOs, all needing information on livelihoods and attitudes to improve the targeting of their interventions to improve the welfare of local peoples and at the same time conserve reef resources. Parallel socio-economic studies are also being conducted within countries of the region (e.g. Cinner and Fuentes, this volume), linking the social condition of communities to environmental and resource condition.

With great sensitivity among fishers to the restrictions on fishing imposed by protected areas, attitudes surveys of MPA-affected communities are increasingly being done (Hauzer et al., this volume). These also serve as valuable education tools, raising awareness of the broader issues addressed by MPAs and longer term benefits of their presence. Education programmes are increasingly being implemented, with a focus on bringing marine environmental education into the classroom through training of teachers (Ater, this volume) linked with activity programmes getting children onto the reef, participating in art competitions and annual events such as the Marine Environment Day.

RESPONSES

With increasing challenges to conserving and sustaining marine ecosystems, CORDIO has identified the following responses to increase the impacts and outcomes of its activities:

Improving and extending standard *monitoring programmes* to include higher and broader levels of data collection and sampling effort, for example:

Through IUCN's Climate Change and Coral Reefs working group, expand the scope of reef monitoring to include key indicators for coral resistance to bleaching and reef resilience to change, to better understand long term prospects for reefs under increasing local pressures and climate change.

Through the SocMon WIO programme, expand the commitment to using social science in marine ecosystem management and of monitoring key indicators for dependence on marine resources, and adaptive capacity for change.

Linking local and national coral reef monitoring with other components of coastal and ocean observation systems (e.g. seagrasses, mangroves, fisheries) of importance to governments and international institutions.

Building up *regional research* and collaboration programmes.

Genetic connectivity is a critical issue to understand where environmental quality is declining on regional scales, and a new network, the WIO Marine Genetics Network (WIOMagnet) was initiated in 2007 with funding from the WIOMSA MASMA programme. Building up capacity in Mauritius, Tanzania and Kenya, we are hoping that it will grow and join with other genetics initiatives in other countries of the region to address regional connectivity issues.

The biogeography and diversity levels of the region have never been dealt with comprehensively, and following the lead of the 'Coral Triangle' region in the Asia-Pacific, a new research agenda is being established in this volume to determine if there is a core biodiversity region in the WIO, and if so, what its relevance to the whole region may be under climate change. This work will build on work started in the East Africa and Western Indian Ocean Islands Marine Ecoregion programmes initiated by WWF (EAME and WIOMER).

Improving the *livelihood sustainability* of marine-dependent communities:

Trialing innovative individual livelihood options through the development of local opportunities and transfer from other regions in the Indian Ocean or beyond, such as with mariculture, worm composting and others.

Investing more in education, to enhance peoples' desire and ability to broaden and improve their choices. This will involve moving from our focus to date on marine and environmental education, to also including adult education and more classical education, to assist poor communities in accessing more opportunities in society.

With increased globalization and the information society, access to Information Communication Technologies (ICT) can greatly influence opportunities available to poor communities. A partnership with the Swedish institution SPIDER in providing access to mobile telephony and the internet will help identify opportunities for improving livelihood options for coastal communities.

Finally, within the context of national and international commitments and agreements in the WIO, CORDIO will increasingly focus on *policy* responses needed to achieve project and overall goals. This will require focusing attention on specific opportunities for engaging with policy makers in individual projects and countries, focusing on developing necessary and enabling conditions to support the implementation of recommendations made by projects.

Status of Coral Reefs in the Surin and Similan Archipelagos, Thailand

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INTRODUCTION

The Surin and Similan Islands are located about 60 km off the Thai Andaman Sea coast, between latitudes 9o 28' 50.7" N to 8o 28' 22.4" N, and longitudes 97o 37' 53.1" E to 97o 54' 17.9" E. Since the area is close to the continental shelf edge there is no influence from sediment or polluted water from the mainland. As a result the region contains the largest area of fringing coral reefs in Thailand, covering approximately 12 km2 (about 15% of the total area of Thai reefs in the Andaman Sea).

Surin and Similan Islands, designated marine national parks in 1981 and 1982 (Lee and Chou, 1998) are of the same chain of granitic outcrops, with a total area (including marine area) of 135 and 140 km^2 respectively. They are the most popular diving destination in Thailand. The parks face significant internal and external management challenges. According to Worachananant (2007) the parks face internal and external challenges. Internally, staff are not sufficiently skilled to manage maritime environments, and externally illegal fishing, degradation of reefs from mass coral bleaching and human activities, such as overcrowding during peak seasons, are the focus of management.

Phuket Marine Biological Center, under the ASEAN-Australia Cooperative Programme, surveyed the reefs in this area between 1988 and 1989 using the manta tow technique, to explore the status of the reefs (Chansang, et. al. 1989). Manta-tow surveys were repeated in these areas during a second period 1995-1998 (Chansang, et. al. 1999) and a third period in 2002 (Phongsuwan unpublished).

The status of the reefs has changed over time due to natural as well as human disturbances. Illegal fishing in the no-take zone is still occurring especially in the monsoon season when patrols by park staff are insufficient. The increase of intensive diving tourism causes negative impacts to the reefs (Phongsuwan, 2006, Worachananant 2007). Impacts from frequent mass coral bleaching since the early 1990s has also been reported (Phongsuwan and Chansang, 2000). Reef damage from sporadic infestations of crown-of-thorns starfish has been reported since the mid 1980s (Chansang et. al. 1986) to the present.. Lastly, in late 2004 the reefs were damaged by tsunami waves (Phongsuwan et. al. 2006, Satapoomin et. al. 2006, Phongsuwan and Brown 2007). In view of these multiple processes Phuket Marine Biological Center has updated its evaluation of reef status by repeating reef surveys in 2006, the results of which are contained in this report.

METHODOLOGY

The manta tow technique (English et. al. 1986) was used for surveying reef characteristics, by estimating percentage cover of live coral, dead coral, and other sessile fauna (e.g. corallimorpharians, sea anemones,

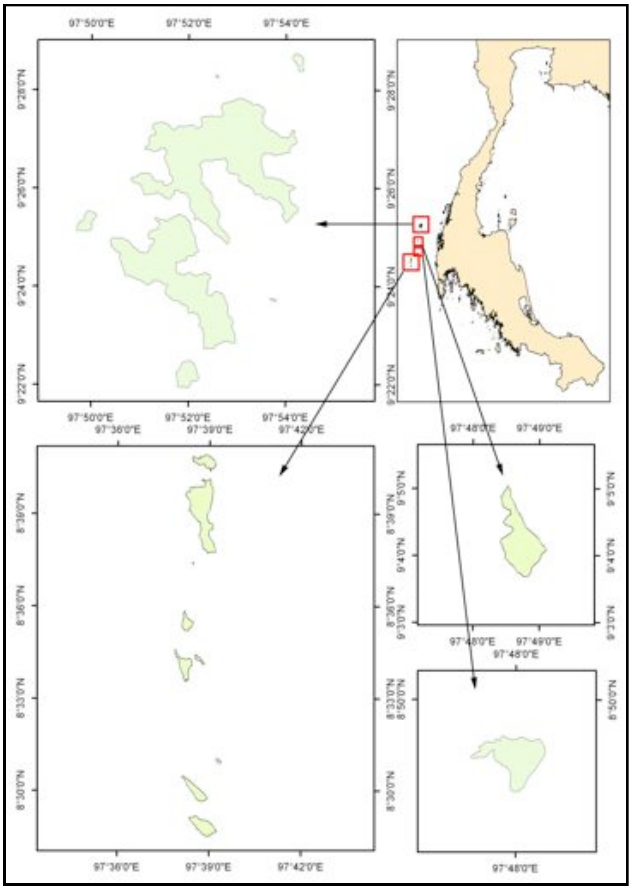

Figure 1. Study sites in Surin and Similan Marine National Parks.

soft corals, sponges), sand and rocky substrate. Coral species encountered were also recorded.

Surveys were carried out at 4 islands in the Surin and 10 islands in the Similan islands (Table 1, Fig. 1). The reefs generally extend down to 15 m, except at some specific sites such as those on the large bays on the east of Surin Island and Similan Island, where fully developed reefs continue down to 30 m depth. Two-minute manta tows were recorded on the interface between the reef edge and upper reef slope where depths ranged from 3-15 m. The number of replicate tows ranged from 4 to 190 depending on size of the island. The location of every tow was recorded by GPS.

A total of 419 two-minute-tows were made on reef

Table 1. Study sites, locations (GPS location approximately at the center of the islands) and total size of the reefs on the islands (from Chansang et al. 1999).

Island	GPS coordinates	Reef area (km^2)
Surin Mar. Nat. Pk.		
Stok	9 ° 28.512'N; 97 ° 54.436'E	0.079
Surin	9 ° 28.037'N; 97 ° 53.463'E	7.174
Pachumba	9 ° 25.205'N; 97 ° 50.062'E	0.111
Torinla	9 ° 22.112'N; 97 ° 52.156'E	0.172
Similan Mar. Nat. Pk.		
Tachai	9 ° 17.905'N; 98 ° 19.672'E	0.853
Bon	8 ° 43.362'N; 98 ° 06.714'E	0.130
Ba-ngu	8 ° 40.250'N; 97 ° 38.397'E	0.294
Similan	8 ° 38.633'N; 97 ° 38.249'E	1.941
Payu	8 ° 35.416'N; 97 ° 37.931'E	0.198
Miang	8 ° 33.789'N; 97 ° 37.770'E	0.367
Ha	8 ° 33.998'N; 97 ° 38.290'E	0.212
Payan	8 ° 31.022'N; 97 ° 38.978'E	0.014
Payang	8 ° 30.276'N; 97 ° 38.094'E	0.147
Huyong	8 ° 28.800'N; 97 ° 38.443'E	0.376

areas where the sum of live and dead coral was equal to or greater than 25% of the total benthic cover. It was estimated that each two-minute-tow covered a distance of about 120 m and therefore the whole survey covered a distance of 50 km over the reefs. Areas with sparse coral communities on rocky substrate, generally exposed to strong southwest monsoon waves, were not included in this study.

A status ranking of each reef was assigned

Table 2. Health status categories based on ratio of live coral cover (LC) to dead coral cover (DC). Decimal ratios are rounded to the nearest integer.

LC:DC	Health status
≥3 : 1	Very healthy reef
2 : 1	Healthy reef
1 : 1	Fair reef
1 : 2	Poor reef
1 : ≥3	Very poor reef

according to the ratio of live coral cover (LC) to dead coral cover (DC, Table 2). The average live coral cover surrounding the islands collected from surveys in period 1 (during 1988-1989), period 2 (during 1995-1998), period 3 (2002) and period 4 (2006) was compared.

RESULTS

The most abundant species were the main reef builders *Porites lutea, P. (Synaraea) rus* and *Acropora* spp. Table 3 shows distribution of dominant coral species at the study sites. *Acropora kosurini* named

Table 3 Dominant coral species found in the Surin – Similan Islands.

Dominant species	Stok	Surin	Pachumba	Torinla	Tachai	Bon	Ba-ngu	Similan	Payu	Miang	Ha	Payan	Payang	Huyong
Porites lutea	x	x		x	x	x	x	x		x	x			x
P. rus		x			x			x		x				
P. nigrescens		x					x		x	x			x	
P. cylindrica					x									
Acropora formosa		x					x	x				x		
A. nobilis	x	x	x	x		x								
A. clathrata		x				x	x	x						x
A. vaughani		x												
A. austera		x												
A. subulata		x												
A. humilis		x												
A. grandis		x												
A. microphthalma		x												
A. echinata-group		x												
A. florida													x	x
A. palifera							x	x						
Montipora aequituberculata		x				x								
Diploastrea heliopora		x			x	x								
Millepora platyphylla		x				x				x	x			
M. tenella		x			x		x			x	x			
Goniastrea retiformis								x						
Pachyseris speciosa		x												
Pocillopora verrucosa		x												
Turbinarea reniformis		x												
Hydnophora rigida							x	x	x	x	x	x	x	x
Echinopora lamellosa								x	x					
Heliopora coerulea	x	x			x	x	x	x	x					

Table 4. Reef health in 2006 and trends from 1995 to 2006. Total number of tows per island and the percentage of tows categorizing the reef status in each of five categories is shown. An "overall average rating" is provided for each island based on health in 2006. The long term trend in coral cover (Fig. 3) is shown: Inc – increasing, Dec – decreasing and Flu – fluctuating for statistically significant changes from one period to the next (1, 2, 3 and 4).

Island	# tows	% of tows					Overall rating		Trends
		very healthy	healthy	fair	poor	very poor			
Surin Mar. Nat. Pk.									
Stok	9	0	11.1	44.4	22.2	22.2	poor	(1 : 1.5)	
Surin	181	42.5	21	24.9	5	6.6	healthy	(1.8 : 1)	Flu: 1>2, 2<3
Pachumba	15	33.3	26.7	26.7	13.3	0	fair	(1.2 : 1)	
Torinla	13	38.5	30.8	7.7	7.7	15.4	fair	(1.2 : 1)	Inc: 1<2
Total	**218**	**39.9**	**21.6**	**24.8**	**6.4**	**7.3**	**healthy**	**(1.7 : 1)**	
Similan Mar. Nat. Pk.									
Tachai	30	46.7	20	30	3.3	0	healthy	(2 : 1)	Inc: 1<2<3<4
Bon	14	0	14.3	14.3	28.6	42.9	Poor	(1 : 2.2)	
Ba-ngu	18	5.3	21	73.7	0	0	fair	(1.2 : 1)	
Similan	46	6.5	23.9	30.4	21.7	17.4	fair	(1 : 1.3)	Flu: 1<2, 3>4
Payu	20	15	20	45	20	0	fair	(1.1 : 1)	Flu: 1>2, 2<3
Miang	13	0	7.1	78.6	14.3	0	fair	(1 : 1)	Inc: 2<3
Ha	14	0	64.3	35.7	0	0	healthy	(1.5 : 1)	Inc: 2<3
Payan	6	0	0	0	28.6	71.4	very poor	(1 : 3.2)	
Payang	22	27.3	4.5	45.5	18.2	4.5	fair	(1.2 : 1)	Dec: 1>2
Huyong	18	27.8	44.4	27.8	0	0	healthy	(2 : 1)	Dec: 1>2
Total	**201**	**15.8**	**22.7**	**38.9**	**13.3**	**9.4**	**fair**	**(1:1.1)**	
Overall	**419**	**28.3**	**22.1**	**31.6**	**9.7**	**8.3**	**fair**	**(1.4 : 1)**	

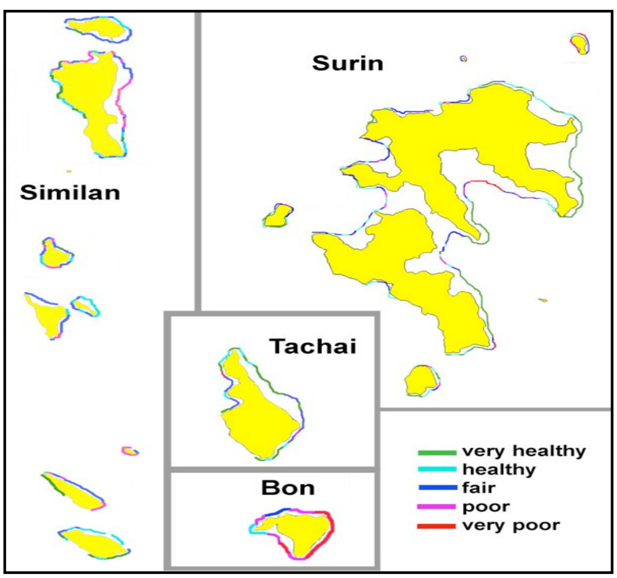

Figure 2. Manta tow results around the Similan islands for 2006.

after Surin Island and endemic to the region down to western Sumatra and the northwest of Australia (Wallace, 1999; Veron, 2000) was recorded as rare.

The condition of most of the reefs in Surin Marine National Park ranged from healthy to very healthy while those at Similan were assessed as being mostly in fair condition (Table 4). Overall, the reefs of the Surin islands are assessed to be in healthy condition, those of Similan fair. Overall results for the two island groups was an average total live cover and dead cover are 41.5% and 29.2% respectively, i.e. ratio of 1.4, i.e. fair condition. Fig. 2 shows Surin and Similan Archipelagos with the distribution of coral reefs and their health status.

DISCUSSION

A comparison of coral cover between the four study periods does not show a fixed pattern of change in live coral cover over time (Fig. 3). Two main factors have been identified as having extensively disturbed the reefs in this region. Firstly, mass coral bleaching occurred in 1991 and 1995 and a minor bleaching event was recorded in 1998 (Phongsuwan and Chansang, 2000). The negative impact of coral bleaching was remarkable especially in sheltered bays and areas with dominant *Acropora* on shallow reef flats and down to the mid-slope at approximately 15 m depth. This includes e.g. the big bays on the east and north coasts of Surin Island and on the east coast of Similan Island (Phongsuwan and Chansang, 2000). Secondly, an outbreak of crown-of-thorns starfish caused reef destruction at some sites during the mid 1980s (Chansang et.al. 1986). A survey in 1985 observed crown-of-thorns starfish densely distributed or even aggregated on the rocky coasts exposed to wave action, with a higher density on small islands than on larger islands in the vicinity. The tsunami in late 2004 had a patchy effect on certain reefs (Phongsuwan et.al. 2006).

When live coral cover is compared between the first and second periods, 1988-89 to 1995-98, it is noteworthy that reefs deteriorated significantly only at Surin, Payu, Payan, Payang and Huyong. In contrast, live coral cover increased significantly on reefs at Torinla, Tachai, and Similan. When compared between the second and third periods, 1995-98 to 2002, live coral cover increased significantly at Surin, Tachai, Payu, Miang, and Ha. No sites showed any significant declines in coral cover over this time span. It is noteworthy that in spite of significant coral bleaching at Surin Island in 1995 the impact was very site specific and did not lead to an overall decrease in live coral cover. Between the third and fourth period, 2002 to 2006, coral cover increased significantly at Tachai, while at Similan coral cover showed a significant decrease. Live coral cover at this latter location, especially on the northeast part of Similan, declined by approximately 16% due to the impact of the tsunami in late 2004.

Considering the status of the Surin and Similan reefs over the long term the system as a whole appears resilient, however with the exception of Payan, a small

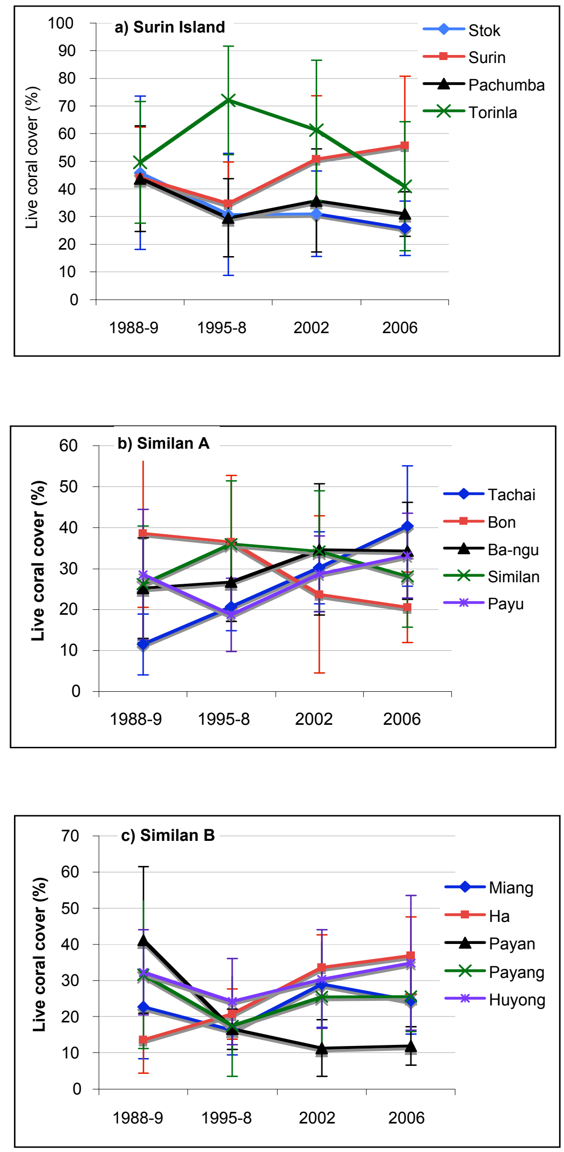

Figure. 3 Average live coral cover at study sites in a) Surin Islands National Park, and b,c) Similan Islands National Park, in the 4 survey periods. Error bars indicate standard deviation. Significant differences in coral cover from one period to the next, based on t-test of two independent samples, are summarized in Table 3.

island where an outbreak of crown-of-thorns starfish was recorded during a survey in 1995. The latest survey in 2006 revealed that the reef had still not recovered. Payang, which is adjacent to Payan, showed a significant decrease of live coral cover over the same period. There is no clear evidence for the cause of reef destruction at this site. During a visit in 2001 to Payang considerable amounts of dead coral fragments were scattered on the steep sand slope along the northeast coast, and the survey in 2006 did not record any signs of recovery. The loosened coral fragments do not provide a stable substrate for coral settlement and recruitment, a factor which has been shown to be important in delaying recovery of reefs dominated by branching corals (Brown and Suharsono 1990). Another area that has shown poor response to stress is a reef located in the northwest bay at Similan Island. Anchor damage seems to be a major factor responsible for reef deterioration here. At present there is no sign of reef recovery although a mooring system has been introduced in the bay. Loosened coral fragments were abundant at this reef site and there were very few coral recruits on large dead massive corals. Waste-water discharged from live-aboard diving boats could be considered a possible factor that might prevent successful coral recruitment or re-growth.

In contrast, a nearby site at the southern cove of Ba-ngu Island appears very resilient. This reef was damaged by crown-of-thorns starfish in the mid 1980s, but recovery was rapid due to successful recruitment of fast growing species of *Acropora* of many growth forms, including arborescent, caespitose, digitate, submassive and tabulate. Other similar sites are found at the northern coast of Surin Island, and the eastern part of Torinla and Pachumba Islands. The eastern part of Torinla was highly damaged by tsunami waves in 2004. However, the living fragments of *Acropora nobilis* could regenerate rapidly (Phongsuwan and Brown, 2007). The negative impact from diving/snorkeling tourism was remarkable at some specific sites, especially on the east of Torinla and Pachumba where the reefs are shallow and made up of fragile species (Worachananant, 2007). Interestingly, the reefs at Tachai Island, having showed signs of bleaching in 1995, showed an increase in average live coral cover throughout the 4 study periods. Dead stands of *Porites cylindrica* were still common during the survey in 1997 (Chansang et. al. 1999). However this fast growing species together with another dominant species, *P. (Synaraea) rus*, contributed to reef recovery.

ACKNOWLEDGEMENTS

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Status of Coral Reefs in Northern, Western and Southern Coastal Waters of Sri Lanka

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ABSTRACT

Selected coral reefs were monitored in the northern, western and southern coastal waters of Sri Lanka to assess their current status and to understand the recovery processes after the 1998 coral bleaching event and the 2004 tsunami. The highest rate of recovery was observed at the Bar Reef Marine Sanctuary where rapid growth of *Acropora cytherea* and *Pocillopora damicornis* has contributed to reef recovery. *Pocillopora damicornis* has shown a high level of recruitment and growth on most reef habitats including reefs in the south. An increase in the growth of the calcareous alga *Halimeda* and high levels of sedimentation has negatively affected some fringing reefs especially in the south. Reef surveys carried out for the first time in the northern coastal waters around the Jaffna Peninsula indicated that massive corals dominate the reef habitats and that human threats are relatively low at present. Reefs are relatively undamaged in the north, while elsewhere they are heavily impacted by human activities due to poor management.

INTRODUCTION

The most common types of coral reefs in Sri Lanka are fringing and patch reefs (Swan, 1983; Rajasuriya *et al.*, 1995; Rajasuriya & White, 1995). Fringing coral reef areas occur in a narrow band along the coast except in the southeast and northeast of the island where sand movement inhibits their formation. The shallow continental shelf of Gulf of Mannar contains extensive coral patch reefs from the Bar Reef to Mannar Island (Rajasuriya, 1991; Rajasuriya, *et al.* 1998a; Rajasuriya & Premaratne, 2000). In addition to these coral reefs, which are limited to a depth of about 10m, there are offshore coral patches in the west and east of the island at varying distances (15 -20 km) from the coastline at an average depth of 20m (Rajasuriya, 2005). Sandstone and limestone reefs occur as discontinuous bands parallel to the shore from inshore areas to the edge of the continental shelf (Swan, 1983; Rajasuriya *et al.*, 1995). Granite or other types of rock reef habitats are also common especially where headlands and rocks are found along the coast (Rajasuriya *et al.*, 1995; Rajasuriya *et al.*, 1998b).

Rajasuriya (2005) reported on the status of coral reefs after the mass coral bleaching in 1998 and the 2004 tsunami, the highest impacts of which were seen on shallow coral habitats. The greatest impacts of the tsunami on coral reefs were observed on the east coast whilst the northwestern coastal reefs were undamaged (Rajasuriya, 2005).

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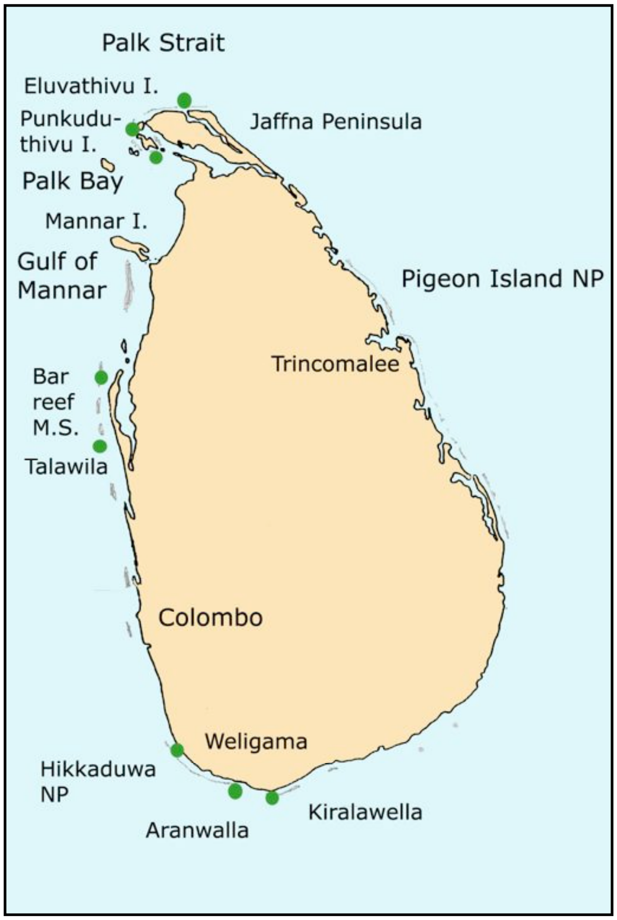

Figure 1. Map of Sri Lanka.

Reef surveys have been carried out from the Bar Reef in the northwest to Kiralawella in the south. In addition, coral reefs that were not previously surveyed by the monitoring programme were examined briefly along the coast of the Jaffna Peninsula and adjacent islands in October and November 2005 to gather preliminary data on their condition and biodiversity based on a recommendation by the Sri Lanka Advisory Group on Sethusamudram Ship Channel Project which is being constructed between India and Sri Lanka (SSCP, 2007). Reef surveys could not be carried out in the eastern coastal waters in 2006 and 2007 due to the ongoing internal conflict.

STUDY SITES AND METHODS

Study sites were located in the northern, western and southern coastal waters (Fig. 1). Permanent monitoring sites at the Bar Reef Marine Sanctuary, the Hikkaduwa National Park and Kapparatota - Weligama reef were surveyed to assess their status. In addition, reef surveys were conducted at Talawila in the northwest, and Aranwala and Kiralawella in the south (Fig. 1). Fringing reef sites at Aranwala, Kiralawella, and sites along the shores of the Jaffna Peninsula and islands were surveyed for the first time.

All reef sites except the northern reefs around Jaffna Peninsula and islands were surveyed using the 50m Line Intercept Transect (LIT) method for benthic cover (English *et al.* 1997). Eight to ten 50m LIT were used for larger reef areas such as Bar Reef, whilst a minimum of four 50m LIT were carried out on reefs with a linear extent of about 1km such as in Aranwala and Kiralawella. Five 50m LIT were used at Hikkaduwa National Park and at Kapparatota, Weligama. Point Intercept Transects (PIT) and Manta Tows (Hill and Wilkinson, 2004) were used for rapid reef surveys in northern coastal waters off Jaffna peninsula. Benthic categories recorded were live hard coral (HC), soft coral (SC), dead coral (DC), sponges (SP), coral rubble (CR), all types of algae (ALG), limestone or sandstone reef substrate (SUB), sand (SA), silt (SI) and other (OT, including e.g. tunicates and corallimorpharians). Hard corals and reef fish diversity around the Point Intercept Transects were assessed using the roving diver technique whereby a diver records species of hard corals and reef fishes in the vicinity of the transect during a 30 minute period.

RESULTS

Status of Corals

Bar Reef Marine Sanctuary

The Bar Reef Marine Sanctuary has an extensive area of patch reefs. The level of recovery has been variable among these patch reefs as they are subject to different oceanographic conditions. The results reported here

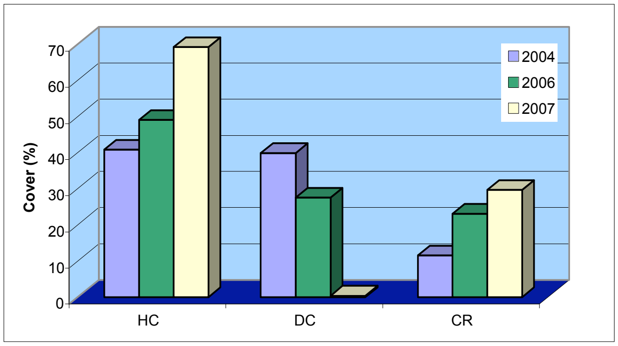

Figure 2. Comparison of cover of the most abundant substrate types in 2004, 2006 and 2007 in the Bar Reef Marine Sanctuary.

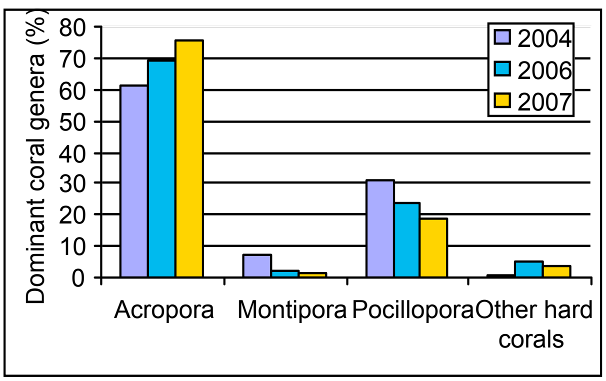

Figure 3. Comparison of the composition of live hard coral cover in 2004, 2006 and 2007 using the most abundant coral genera on the shallow reef flats in Bar Reef Marine Sanctuary.

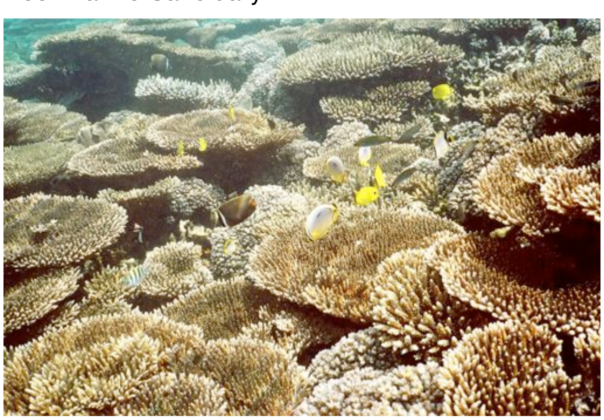

Figure 4. Coral recovery at the Bar Reef Marine Sanctuary by *Acropora cytherea* which now makes up 75% of the coral community.

are from the same group of coral patches that were monitored for recovery since 1998. They are located on the leeward side of a larger group of patch reefs.

Live hard coral (HC) cover has increased from 40% in 2004 to about 70% in early 2007 (Fig. 2). This increase can be attributed to the rapid growth of *Acropora cytherea* which constituted 75% of live hard corals in 2007 (Figs. 3, 4). Other common hard coral genera were *Pocillopora, Montipora, Echinopora, Favia, Favites, Platygyra* and *Podabacia*. Dead coral (DC) cover was less than 1% in 2007 indicating that there are few natural threats to the reef. However coral rubble (CR) had increased from 11% in 2004 to 29% in 2007 (Fig. 2).

Hikkaduwa National Park

The fringing coral reef at Hikkaduwa National Park is about 1km in length and has a reef crest parallel to the shore at a distance of about 75m. The seaward slope extends about 100m from the reef crest and has only a few encrusting coral colonies due to wave action and rapid movement of sand. The main hard coral area is located within the reef lagoon, which was dominated by branching *Acropora* species prior to 1998.

The live hard coral cover at the Hikkaduwa National Park had increased from 12% in 2005 to 26% in 2007 (Fig. 5) mainly due to the rapid settlement and growth of *Pocillopora damicornis* which had risen from 6% of the total live hard coral cover in 2004 to 35% in 2007 (Fig. 6). However, the

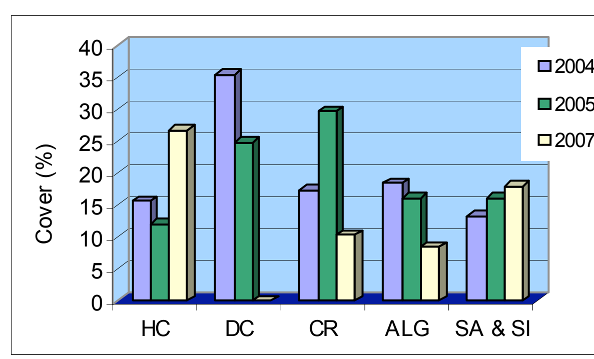

Figure 5. Comparison of cover of the most abundant substrate types in 2004, 2006 and 2007 in the Hikkaduwa National Park.

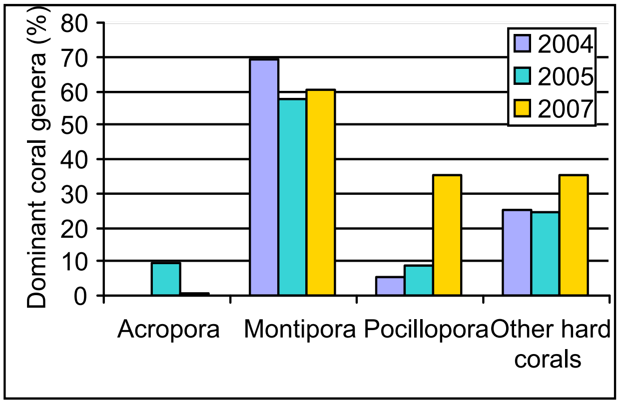

Figure 6. Comparison of the composition of live hard coral cover in 2004, 2005 and 2007 using the most abundant coral genera in the Hikkaduwa National Park.

dominant species at this site was *Montipora aequituberculata,* which had colonized most of the dead branching coral areas (Fig. 6). Other hard coral genera were *Acropora*, *Favia, Platygyra, Goniastrea, Leptoria, Goniopora, Porites, Pseudosiderastrea,* and *Psammocora*. The percent cover of *Acropora* was negligible (0.6%) as natural recruitment and growth of *Acropora* species have been adversely affected by high levels of sedimentation. The percent cover of dead corals, coral rubble and algae has been reduced while an increase was detected in sand and silt accumulation within the national park (Fig. 5).

Kapparatota, Weligama

The fringing coral reef at Kapparatota, Weligama lies on the eastern side of a headland and its reef lagoon is protected from strong wave action. The main coral area lies within its reef lagoon which is about 1 km in length and about 150m wide. The reef was dominated by branching *Acropora* species, *Montipora aequituberculata* and *Pocillopora damicornis* prior to 1998. Reef recovery has been affected by shifting coral rubble after the 1998 bleaching event by the 2004 tsunami and due to human actions such as use of destructive ornamental fish collecting methods.

There was an overall decline in the live coral cover from 52% in 2004 to 22% in 2006 at Kapparatota, Weligama (Fig. 7). Percentage of coral rubble had decreased while algae had increased from 10% in 2005 to 60% in 2006 primarily due to an increase in the growth of *Halimeda* spp (Fig. 7). Only three hard coral genera (*Acropora, Montipora* and *Pocillopora*) were common at this site where branching *Acropora* was the most abundant (Fig. 8).

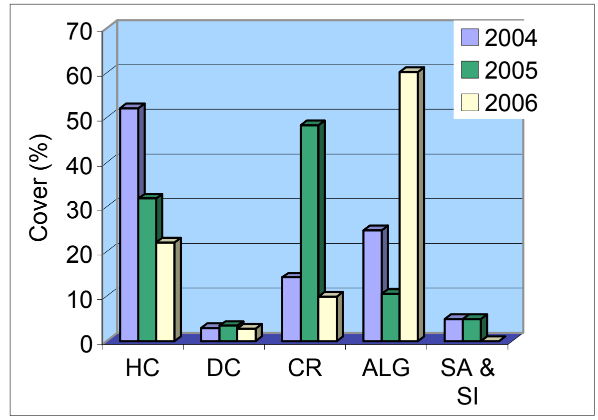

Figure 7. Comparison of cover of the most abundant substrate types in 2004, 2005 and 2006 in Kapparatota, Weligama.

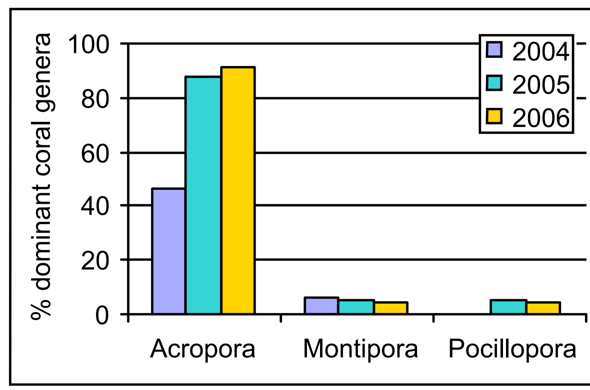

Figure 8. Comparison of the composition of live hard coral cover in 2004, 2005 and 2007 using the most abundant coral genera in Kapparatota, Weligama.

Talawila

The coral reef at Talawila is located about 500m offshore and is parallel to the shoreline. The length of this shallow reef is about 1km and it has no reef lagoon. Most of the living corals are on the reef crest and on the seaward reef slope.

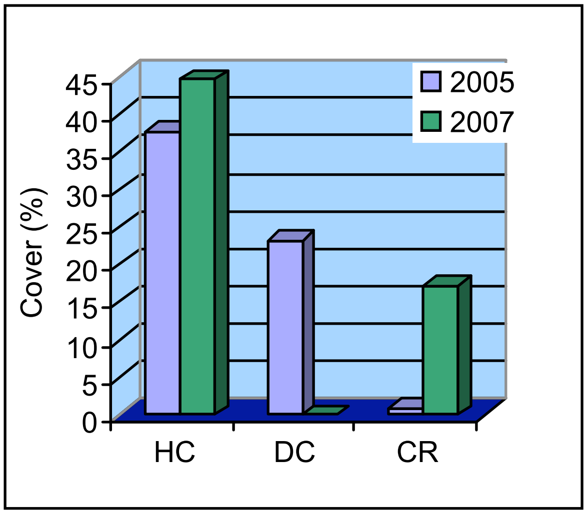

Figure 9. Comparison of cover of the most abundant substrate types in 2005 and 2007 in the Talawila coral reef .

The live hard coral cover has increased from 37% in 2005 to 44% in 2007 (Fig. 9). Coral rubble had increased from a low level of 0.8% in 2005 to 17% in 2007. The Talawila coral reef was dominated by massive corals. The most abundant genera were *Favia, Favites, Galaxea, Porites, Goniastrea, Leptoria, Platygyra* and foliose *Echinopora lamellosa*. Other live hard coral genera present were *Acropora, Hydnophora, Acanthastrea, Montastrea, Oulophyllia, Symphyllia, Turbinaria, Podabacia, Pachyseris* and *Pavona*.

Aranwala

The fringing reef at Aranwala is located within a relatively narrow and shallow coastal indentation which is about 20m wide with a sand bottom in the center. The coral areas are located on either side of this coastal indentation. The depth of the reef crest on both sides is about 1m and the reef is subject to strong wave action especially during the southwest monsoon as the wave energy is channeled into the center of the coastal indentation due to the reef structures on either side. The depth of the reef varies from 1m at the shallow shoreward edge to about 7m on the seaward

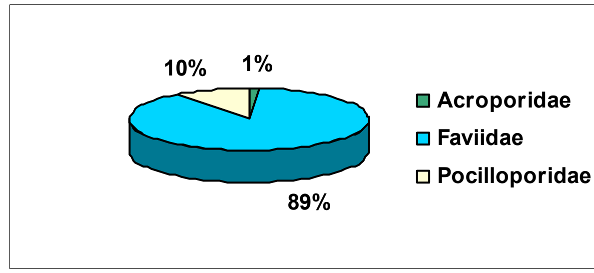

Figure 10. Percent composition of hard coral families at Aranwala, 2007.

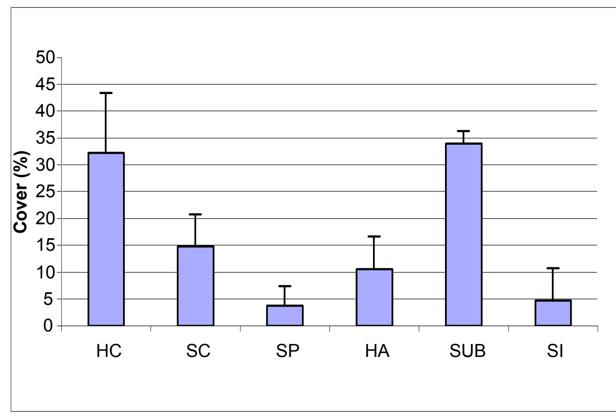

Figure 11. Comparison of the most abundant substrate types in the coral reef at Aranwala, 2007.

margin. The total length of the area surveyed was about 150m which includes reef sections on both sides of the coastal indentation.

Most of the living corals were found on the reef crest and on the seaward reef slope. Due to strong wave action massive corals of the family Faviidae (89%), comprising *Favia, Favites* and *Platygyra,* dominate the hard coral cover (Fig. 10). Live hard coral cover in 2007 was 32%, the limestone substrate amounted to 34% and the soft coral cover was 15% consisting of *Sarcophyton* and *Sinularia* species (Fig. 11).

Kiralawella

The fringing reef at Kiralawella is located in a small bay on the eastern side of the Dondra Headland which is the southernmost point in Sri Lanka. The shoreward

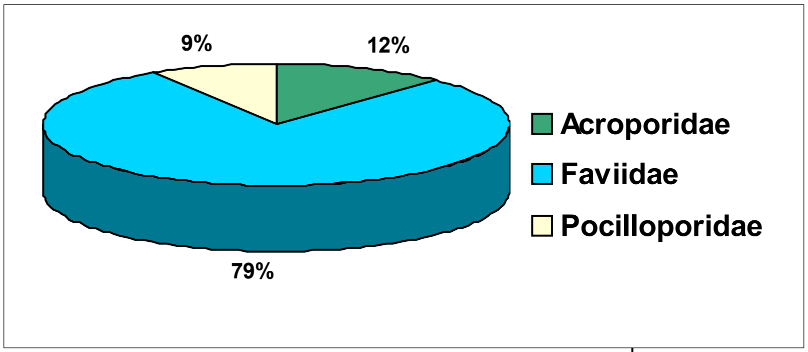

Figure 12. Percent composition of hard coral families at Kiralawella.

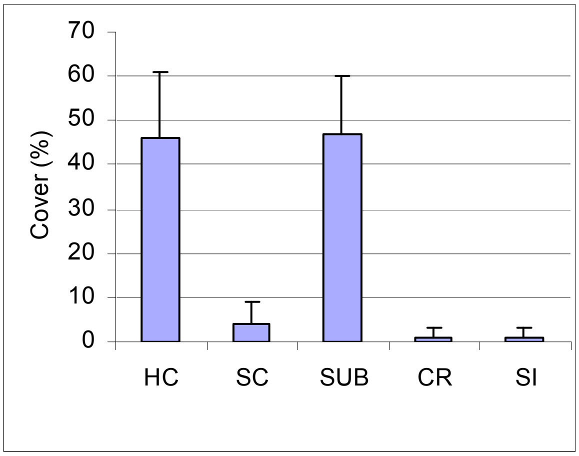

Figure 13. Comparison of the most abundant substrate types in the coral reef at Kiralawella, 2007.

edge of the reef is against the rocky shore and the seaward margin lies about 50m offshore at a depth of about 10m. The reef is about 200m in length and is subject to strong wave action during the northeast monsoon.

The most abundant live corals belonged to the family Faviidae (79%) comprising *Echinopora*, *Favia, Favites, Platygyra, Goniastrea* and *Leptoria* (Fig. 12). Extensive patches of *Echinopora lamellosa* and several large *Porites* domes were present on the lower reef slope at a depth of 6m. Overall live hard coral cover was 46%, with 47% bare limestone substrate (Fig. 13).

Coral Reefs of the Jaffna Peninsula

Fringing coral reefs are located along the northern coast of the Jaffna Peninsula and along the western shore of the islands (Swan, 1983; Rajasuriya & White, 1995). They could not be surveyed during the past two decades due to lack of access to the area as a result of the internal conflict in the country. Most fringing reefs were narrow belts without a reef lagoon with a reef crest of about 15m in width and a reef slope of about 75m. Punkuduthivu and Mandathivu Islands in the southwest corner of the peninsula had relatively larger reefs that extended about 1km into the Palk Bay. Punkuduthivu Island had a relatively narrow reef lagoon of about 30m (SSCP, 2007). The shoreward margin of most fringing reefs was against the limestone shoreline whilst the seaward edge was at a depth of about 6m.

Substrate cover was determined at four reef sites. Two sites were located in the Palk Strait along the northern coast of the peninsula, whilst the other two sites were located to the west of Eluvathivu Island and on the southern side of Punkuduthivu Island respectively (Fig. 1).

Due to similarity of the reefs surveyed and limited sampling effort (four 50m PIT at each location) the data from all four reef sites was pooled. The combined

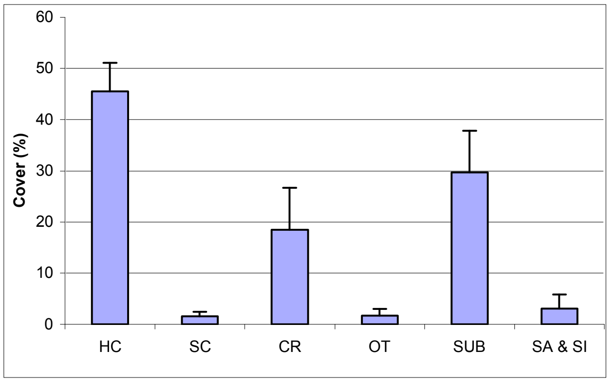

Figure 14. Percent cover of substrate types on coral reefs of Jaffna Peninsula in 2005.

Figure 15. Coral communities of the Jaffna Peninsula study sites.

live hard coral cover for all four reef sites was 45%, with 29% limestone substrate (Fig. 14).

All reef sites were characterized by abundant massive corals of the families Faviidae (*Goniastrea, Platygyra, Leptoria, Favia and Favites*) and Poritidae (*Porites lutea* and *Porites lobata*) (Fig. 15). There were extensive banks of dead branching *Acropora* at Punkudithivu Island and large living *Porites* domes of about 7m in diameter near the seaward margin of the reef. Forty species of hard corals were recorded from the reef sites (Appendix 1). Soft coral (*Sarcophyton*) was common on the lower reef slope of the northern coast of the peninsula. Seventy four species of reef fish were recorded during the survey (Appendix 2), with most records from Punkuduthivu Island. Large schools of *Scarus ghobban* and *S. rubroviolaceous* and Siganids were also present at this site. The most common species of butterflyfish was *Chaetodon octofasciatus* which is restricted to the Gulf of Mannar, Palk Bay and Palk Strait in Sri Lanka (SSCP, 2007).

Coral Bleaching

Extensive damage to reefs due to coral bleaching was not observed in Sri Lanka in 2007. Bleaching of a few colonies of *Leptoria*, *Platygyra*, *Favia*, *Favites* and *Acropora* spp was recorded from the Hikkaduwa National Park. Seasonal paling of a few colonies of branching *Acropora* were observed in the Bar Reef Marine Sanctuary in 2007 but all colonies returned to normal after one month. Paling of some massive corals (Faviidae and Poritidae) was reported in August 2007 from Pigeon Island in Trincomalee (N. Perera. pers comm.). Branching *Acropora* spp at a depth of less than 2m had been killed in Dutch Bay in Trincomalee and was overgrown with filamentous algae in late September 2007. However branching *Acropora* in slightly deeper areas (> 3m) was healthy.

DISCUSSION

Results from the monitoring indicate long-term impacts on reef structures due to the 1998 bleaching event. For several years after 1998 the dead but mostly intact coral branches maintained the reef structure, providing habitat and allowing new corals to settle and grow. Due to variability in recovery (Rajasuriya, 2005), almost every reef area has sections that exhibit good recovery and sections with poor recovery. At present, reef sections where recovery has been poor have begun to disintegrate, leading to an increase in the percent cover of coral rubble, e.g. at Talawila and some parts of the Bar Reef Marine Sanctuary. However, both areas also exhibit good coral growth, although the dominant types of hard corals have changed since 1998. In the Bar Reef Marine Sanctuary the dominant hard corals are tabulate *Acropora* (mainly *Acropora cytherea*) and *Pocillopora damicornis* whilst at Talawila massive corals dominate. The dominance of *Acropora cytherea* and its contribution to live hard coral cover at Bar Reef indicate that the opportunities for rapid colonization of coral species that were dominant species prior to bleaching, such as a number of branching Acropora species and *Echinopora lamellosa*, is low. At Kapparatota, Weligama the live hard coral cover has been reduced by half due to a combination of overgrowth of *Halimeda*, movement of coral rubble, damage caused to the reef by anchoring of fishing boats and the use of destructive ornamental fish collecting methods. Although the calcareous algae stabilize the coral rubble it prevents recruitment of corals and thus it is a barrier to the growth of the reef. Moreover it traps sand and sediment and has thus contributed to reduction of the depth of the reef lagoon. The destruction of vegetation on a nearby headland for the construction of a hotel may exacerbate the problem by increasing sedimentation and nutrient loads within the reef lagoon.

The increase of live hard coral cover in Hikkaduwa National Park is mainly due to the increase of recently recruited *Pocillopora damicornis,* which is now growing relatively rapidly on the dead coral stands. However, due to many other stresses, primarily sedimentation (Rajasuriya, 2005), there is little growth of species other than *Pocillopora damicornis* and *Montipora aequituberculata,* which survived the bleaching in 1998 and have since taken over areas formerly dominated by *Acropora muricata* and *A. hyacinthus*.

Coral species found on the northern reefs around the Jaffna Peninsula are similar to inshore reefs in the southern coast, and are tolerant of relatively high sedimentation (SSCP, 2007). Two species of reef fish (*Liza cascasia* and *Abudefduf bengalensis*) not found elsewhere in Sri Lanka were recorded in the Palk Strait and Palk Bay. The extensive dead *Acropora* stands of Punkuduthivu Island in Palk Bay indicate that they may have been killed during the 1998 bleaching event. There was no indication of recent large-scale coral mortality among other genera. Although most reefs are located along the coast human impact was negligible on the coral reefs of the Jaffna Peninsula and islands. This is primarily due to low fishing pressure and lack of development along the coast.

As reported in the past (De Silva, 1985; 1997; Rajasuriya, et al. 1995; 2004, 2005), reefs in the south and on the west coast continue to be adversely affected by uncontrolled resource exploitation, use of destructive fishing methods, coastal development, land-based pollution, sedimentation and overall poor management of the marine and coastal environment (Kumara et al. this volume). The status of Marine Protected Areas also remains unchanged, with little active management by the responsible authorities. Over-harvesting of reef fish and semi-pelagic species in the Bar Reef Marine Sanctuary using a modified form of purse seine continues unabated, leading to severe overexploitation of Carangids, Lutjanids, Lethrinids, Sphyraenids and Scarids. Most of the periodic aggregations of *Caranx sem* and *Sphyraena jello* that used to be relatively common in the northern section of the Bar Reef Marine Sanctuary have now become rare. Recently this fishing method has begun to utilize scuba diving equipment, with divers scaring the fish and driving them into the nets. Unlimited numbers of licenses are also issued to collectors of sea cucumber and chanks (a gastropod, *Turbinella pyrum*) by the authorities, and there is not sufficient capability to monitor the activities of the license holders. This has led to over harvesting sea cucumber and chanks resources in the Bar Reef Marine Sanctuary. As a result human pressures are likely to continue to increase in the future, and the ability of reefs to resist and recover from natural perturbations will diminish further.

ACKNOWLEDGEMENTS

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Appendix 1. Hard coral species recorded during reef surveys in Jaffna Peninsula, 2005.

Family	Species
Acroporidae	*Acropora cytherea*
	Acropora hyacinthus
	Acropora muricata
	Montipora aequituberculata
	Montipora foliosa
	Astreopora sp.
Dendrophyllidae	*Turbinaria mesenterina*
	Turbinaria peltata
	Turbinaria sp.
Faviidae	*Favia pallida*
	Favia speciosa
	Favia rotundata
	Favites abdita
	Favites chinensis
	Favites complanata
	Favites flexuosa
	Favites pentagona
	Montastrea valenciennesi
	Goniastrea retiformis
	Platygyra lamellina
	Platygyra sinensis
	Platygyra daedalea
	Platygyra pini
	Leptoria phrygia
	Leptastrea purpurea
	Echinopora lamellosa
Merulinidae	*Merulina ampliata*
	Hydnophora exesa
Mussidae	*Symphyllia agaricia*
	Symphyllia radians
	Symphyllia recta
	Symphyllia sp.
Pectiniidae	*Echinophyllia aspera*
Pocilloporidae	*Pocillopora damicornis*
	Pocillopra verrucosa
Poritidae	*Porites* sp.
	Porites lutea
	Porites lobata
	Goniopora spp.
Siderastreidae	*Pseudosiderastrea tayamai*

Appendix 2. Reef fish species recorded during reef surveys in Jaffna Peninsula, 2005.

Family	Species
Acanthuridae	*Acanthurus bariene*
	Acanthurus mata
	Acanthurus nigricauda
	Acanthurus xanthopterus
Apogonidae	*Apogon angustatus*
	Apogon aureus
	Cheilodipterus macrodon
	Rhabdamia gracilis
Caesionidae	*Caesio cuning*
	Caesio xanthonota
	Pterocaesio chrysozona
	Pterocaesio tile
Carangidae	*Caranx heberi*
	Caranx sp.
Centropomidae	*Psammoperca waigiensis*
Chaetodontidae	*Chaetodon auriga*
	Chaetodon collare
	Chaetodon decussatus
	Chaetodon octofasciatus
	Chaetodon plebeius
	Heniochus acuminatus
Echeneidae	*Echeneis naucrates*
Gerridae	*Gerres* sp.
Gobiidae	*Amblyeleotris* sp.
	Amblyeleotris steinitzi
	Amblygobius sphynx
Haemulidae	*Diagramma pictum*
	Plectorhinchus gibbosus
	Plectorhinchus schotaf
Holocentridae	*Sargocentron diadema*
Labridae	*Halichoeres nebulosus*
	Thalassoma janseni
Leiognathidae	*Leiognathus daura*
Lethrinidae	*Lethrinus lentjan*
	Lethrinus sp.
Lutjanidae	*Lutjanus ehrenbergi*
	Lutjanus fulviflamma
	Lutjanus fulvus
	Lutjanus rivulatus
	Lutjanus sp.

Appendix 2. *continued.*

Family	Species
Mugilidae	*Mugil sp.*
	Liza cascasia
	Parupeneus indicus
Nemipteridae	*Scolopsis vosmeri*
Pomacentridae	*Abudefduf septemfasciatus*
	Abudefduf sordidus
	Abudefduf bengalensis
	Abudefduf vaigiensis
	Amblyglyphidodon leucogaster
	Chromis ternatensis
	Neopomacentrus asyzron
	Neopomacentrus taeniourus
	Pomacentrus chrysurus
	Pomacentrus indicus
Pseudochromidae	*Pseudochromis fuscus*
	Pseudochromis sp 1
	Pseudochromis sp 2
Scaridae	*Scarus ghobban*
	Scarus niger
	Scarus rubroviolaceus
	Scarus sp
Scorpaenidae	*Pterois volitans*
Serranidae	*Cephalopholis boenak*
	Cephalopholis formosa
	Epinephelus caeruleopunctatus
	Epinephelus malabaricus
Siganidae	*Siganus canaliculatus*
	Siganus javus
	Siganus lineatus
	Siganus stellatus
	Siganus virgatus
Sphyraenidae	*Sphyraena jello*
Tetraodontidae	*Arthron hispidus*
	Canthigaster solandri

Impacts of Reef Related Resource Exploitation on Coral Reefs: Some Cases from Southern Sri Lanka

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keywords: Sri Lanka, coral reefs, anthropogenic impacts

ABSTRACT

Coral reefs occur along only 2% of the 1585 km coastline of Sri Lanka. Large extents of these reefs are subjected to numerous anthropogenic impacts, with some reefs showing considerable damage by a single activity that is dominant in the area, frequently well rooted in the local community and contributing significantly to the local economy. This study describes the relationship between reef-related human activity and resultant reef damage d in five coral reef areas in southern Sri Lanka. Comparison of substrate composition between sites showed clear deviations between impacted sites and controls in Bandaramulla, Madiha and Polhena, indicating impact due to coral mining, coir industry and reef walking respectively. Awareness programs, provision of appropriate education to the coastal youths, improvement in law enforcement and alternative livelihood options are proposed in order to find sustainable solutions.

INTRODUCTION

Coastal ecosystems in Sri Lanka are highly diverse and are a valuable resource for the people of the country, particularly for coastal communities (Terney et al., 2005a). It has been estimated that the minimum economic value of coral reefs in Sri Lanka is approximately USD 140,000 – 7,500,000 per km2 over a 20-year period (Berg et al., 1998); this valuation includes the coral, reef associated fish and other marine species. However, reefs face severe stress at present, due to both natural and anthropogenic threats, and are in great danger of being depleted. Natural stresses are unavoidable, potentially devastating and at times prolonged. During the recent 1998 El Niño bleaching event, 90% of the reefs in Sri Lanka bleached (Wilkinson et al., 1999). On the other hand, when compared to naturally induced threats, those of anthropogenic origin tend to be localized and small scale. However, such stresses are much more frequent, or chronic, and hence the cumulative damage is unprecedented. In many cases it prevents recovery from natural stresses and causes long-term reef decline. Destructive human activities such as blast fishing, coral mining, pollution, mineral mining, shipping activities, over fishing and intensive fish collection for the aquarium and live fish trade together with sedimentation due to poor land use practices have degraded most coral reefs around Sri Lanka (Ohman et al., 1993; Rajasuriya et al., 1995; Rajasuriya & White, 1995; Patterson, 2002; Rajasuriya, 2002).

Many of these activities are common along the southern coast of the country. Reef fish collection, coral mining, coir (coconut fibre) production, reef walking and bottom set nets are the most common destructive human activities currently seen. Although some activities such as coral mining, ornamental coral collection for export and blast fishing are banned, these are still practiced and provide livelihoods for a considerable number of coastal dwellers.

The Reef Fishery

Fifteen percent of the total fish catches in Sri Lanka are derived from coral reefs through small-scale fishing operations (Rajasuriya et al., 1995). Food fish are to a large extent consumed locally, while ornamental fish and lobsters are mainly caught for the export market (Perera et al., 2002). De Bruin et al. (1994) identified about 30 reef-associated fish species caught for food consumption in Sri Lanka. This number is now exceeded as fish species previously considered undesirable for human consumption are brought to the market due to depletion of primary target species, such as e.g. soldier fish (*Holocentrus* spp.), squirrel fish (*Myripristis* spp.) and bullseyes (*Priacanthus* spp.) (Rajasuriya 2002).

Reef fish collection for the ornamental fish trade is a comparatively lucrative activity for coastal fisher folk in Sri Lanka. However, almost all fish collection methods used are highly destructive and not sustainable, and as a result some of the most important and ecologically sensitive fish species are highly threatened and in danger of local extinction. On several shallow reefs the abundance of corallivorous butterfly fish (Chaetodontidae) has decreased dramatically (Rajasuriya & Karunarathna, 2000), largely due to overexploitation. A contributing factor is reduced live coral cover, especially loss of *Acropora* spp. (the coral genus most favoured by butterfly fish), as a result of bleaching-related mass mortality as well as direct anthropogenic stress, including fish collection. The principal method used by ornamental fish collectors is the 'Moxy net', a weighted drop-net used to cover coral colonies which are then broken up with a crowbar. Although this fishing gear is banned, it is popular at the Weligama - Kapparatota reef.

Coral Mining

Coral mining from the sea is an age-old practice in Sri Lanka, especially along the south, south western and east coasts. For centuries mined coral has been used for building houses, temples, tombstones and parapet walls to demarcate boundaries. Although illegal, coral mining still occurs, producing lime for construction as well as for the agricultural sector (Terney et al., 2005b, Souter & Linden, 2000). For example, a survey in the south western and southern coastal areas conducted by the Coast Conservation Department in 1984 revealed that 18,000 tons of coral was supplied annually to the lime-producing industry. Out of this amount, 12% consisted of corals illegally mined from the sea and another 30% of coral debris illegally collected from the shore. The major portion, 42%, originated from mining fossil inland coral deposits beyond the coastal zone while 16% was mined on land within the coastal zone (Hale & Kumin, 1992). In 1990 nearly 2,000 persons were dependent on inland and marine coral mining activities within the area between Ambalangoda and Hambantota (Ranaweera Banda, 1990). Terney et al. (2005b) reported that Bandaramulla reef alone supplied 799 tons of illegally mined coral annually. Coral collection for the ornamental trade has almost ceased due to strict law enforcement on live coral sale and export.

Coral mining can include large-scale removal of coral patches manually or blasting of large areas of reef with dynamite. The process not only destroys reefs, but also destroys the whole marine ecosystem on a large scale. In most places, shallow reef flats are mined, resulting in many lagoons being depleted of corals. This reduces the fish biomass and weakens the defence against waves provided by the reefs (Brown et al., 1989). As a result, indirect impacts such as sand erosion, land retreat and sedimentation become inevitable. Due to continued stress and the slow growth of corals a permanent loss of reef areas or phase-shifts may result. Whatever economic benefit the mining industry provided is easily outweighed rapidly by the long-term environmental degradation and the resulting socioeconomic loss to the area.

The Coir Industry

Coir fibre from coconut husks is used for the production of floor mats, brushes, twine, mattresses, erosion control mats, padding etc. The fibre is relatively waterproof, and one of the few natural fibres resistant to damage by salt water. The process of fibre extraction is time consuming and labour intensive. Retting, the soaking of coconut husks to soften them, is carried out in large pits constructed along the coast. Each pit is divided into a number of compartments and each compartment is packed with between 600 and 1200 coconut husks. After retting the fibres are extracted manually by beating with wooden mallets. During the mechanical process, the softened coconut husks are processed to extract fibre using a spinning machine. Fresh water is used to process brown coir. Both seawater and fresh water (or brackish water) is used to process white coir in the saline backwaters along the southern coast of the country. End products of white coir are higher in price than brown coir products but brown coir products are longer-lasting.

Coir production is still common in southern India and in Sri Lanka, and the countries together produce 90% of the 250,000 metric tons of the global annual production. Sri Lanka produces 36% of the total world brown fibre output. 40,000 Sri Lankans, mainly women, work at least part time in the industry, earning almost $ 4 for a day's work - a comparatively good income. Most people engaged in the coir industry are traditional workers and have been involved in it for more than 30 years. It is the only source of income for some and a part time occupation for others.

The coir industry in Sri Lanka suffered heavy losses due to the Indian Ocean tsunami in December 2004. Most husk pits were clogged with debris and much infrastructure and many facilities were destroyed. The industry now shows slow but steady progress towards re-establishing itself and the livelihoods that were lost are being regained.

Coral Trampling

Coral reef trampling caused by fishermen searching for moray eels, lobsters, shellfish and ornamental fish is common, and worsened by the use of crowbars during fish extraction. In addition, villagers who are not actual fishermen walk on reefs in search of octopi. This activity is common when the reef is exposed during low tide and is most common on reefs adjacent to public beaches. For example at Polhena, numerous local visitors walk on the reef daily, the number increasing greatly during the weekends. Reef walkers commonly collect live corals as well as dead corals as souvenirs. Shallow reefs are also affected by inexperienced snorkelers who put their feet down when in difficulties, damaging corals. Coral trampling has become a major problem in Hikkaduwa National Park (HNP), which is often overcrowded with snorkelers in the water and reef walkers on the reef as a result of tourist promotion in the area. The government agency responsible for its management, the Department of Wildlife Conservation (DWLC), maintains a marine park office on the beach adjacent to the marine park.

Bottom Set and Gill Nets

Gill nets, long lines and bottom set nets are commonly used in the Hambantota area during near shore fishing operations. The gill net is the most common type of gear used. It is a light net with a fine mesh size and can be constructed in great lengths. Bottom set nets are deployed on the seabed using anchors or weights in the evening and left overnight to fish passively before recovery the following morning. *Selar crumenophthalmus* (bigeye scad), *Harengula ovalis* (spotted herring) and *Sphyraena jello* (giant sea pike)

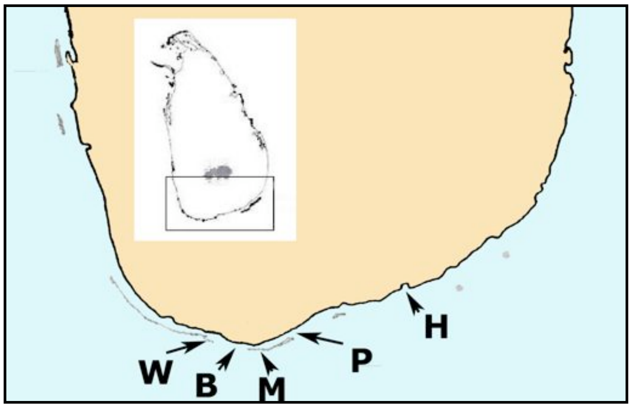

Figure 1. The study areas along the southern coast of Sri Lanka. **W** = Weligama Kapparatota reef, **B** = Bandaramulla reef, **M** = Madiha reef, **P** = Polhena reef and **H** = Hambantota offshore reef.

are the main fish species caught in gill nets together with tiger prawns (Penaeus monodon). Fishing is restricted to the inter monsoon period from November to March, during which time the sea along the southern coast is calm.

The product of this fishery is mainly for local use, except the occasional catches of lobsters and large seashells, which are sold for the export market. While this bycatch is comparatively high, there is also a targeted seashell dive-fishery in the Hambantota area, collecting large shelled molluscs such as *Turbinella pyrum*, *Cassis cornuta*, *Lambis* spp. *Cypraea spp*, *Murex* spp. and *Conus* spp.. These fishermen do not engage in net fishing and their income is relatively higher than that of the traditional fishermen.

This study focused on the above five most common reef-related human activities on the southern coast of Sri Lanka (based on personal observation).

MATERIALS AND METHODS

Site Descriptions

During a preliminary survey in January 2005 covering the southern coast, study areas were selected to represent the reefs most vulnerable as a result of each type of human activity (Fig. 1). These study areas represent different reef types such as sheltered inshore reefs, patchy reef outcrops, shallow fringing reefs, limestone, and rocky outcrops (Table 1).

Weligama reef has the highest live coral cover of all the surveyed reefs. Some of the branching *Acropora* spp. and foliaceous *Montipora* spp. survived the 1998 El Niño and now dominate the coral community. The Bandaramulla reef, extending about 500m across Bandaramulla bay, has been subjected to intensive coral mining over the last 15 years, even exposing scattered sandy patches within the reef. Mining includes the collection of dead corals as well as live coral boulders including e.g. *Leptoria phrygia*, *Favia* spp., *Favites* spp., *Goniopora* spp., and *Porites* spp.. Madiha reef encloses a shallow and narrow reef lagoon, and most of the shoreline is covered by coconut husk pits. Stilt fishing is common here (as well as in Bandaramulla reef lagoon). The Polhena reef consists of a number of reef patches located in a shallow reef lagoon (Terney *et al.*, 2005c). The reef was dominated by an ascidian, *Diplosoma virens,* and the calcified alga *Halimeda* sp. (Terney *et al.*, 2007). Hambantota reef is made up of patchy sandstone and limestone platforms with the occasional granite boulder, down to a depth of 18m. The offshore seabed consists of a mix of sandstone and rocks with scattered dead coral boulders. Most of the hard bottom is covered with numerous species of marine invertebrates. The soft bottom between the rocky areas consists of clean fine-grained sand or sand covered by a thin layer of fine sediments. The water is turbid with visibility not exceeding 7 m.

At all the selected study areas, one readily identifiable human activity was hypothesized to directly impact coral reefs, as indicated in Table 1. Associated activities such as marine ornamental fish collecting centres, lime-kilns, coir industry and lobster and prawn collecting centres were seen established in these areas. In addition to anthropogenic stress during past decades, all the sites were affected by the 1998 El Niño and the 2004 tsunami events (Rajasuriya *et al.,* 2005). However, El Niño damage to Weligama Kapparatota reef and 2004 tsunami damage to Bandaramulla reef was moderate (Rajasuriya *et al.,* 2005; Terney *et al.,* 2005b).

Table 1. Area descriptions. General characteristics, 2004 tsunami impact, 1998 El Niño impact and reef related human activities (damage categories, relative scale according to the damaged area: Very high - 75% - 100% damage; High - 50% - 75% damage; Moderate - 25% - 50% damage; Low - 0 – 25%; N.R. - Not Recorded).

Name of the study area	General characteristics	2004 tsunami impact	1998 El Niño impact	Threat	
				Activity	Potential impacts
Weligama reef	Patchy *Acropora* spp. and *Montipora* spp. dominated Depth 0-3m	Moderate *	High **	Reef fish collection	Mechanical damage to live coral
Bandaramulla reef	Fringing Depth 0-3m	Moderate **	High †	Coral mining	Mechanical damage to the reef structure, increased rubble cover, reduced reef area
Madiha reef	Fringing Depth 0-1.5m	Moderate ††	High ††	Coir industry	Increased rubble cover and algae cover, occasional pollution of lagoon water
Polhena reef	Patchy *Halimeda* sp. and Ascidians dominated Depth 0-3m	Moderate – High *	High **	Reef walking	Mechanical damaged to live coral cover, increased rubble cover
Hambantota off shore reef	Sand stone and limestone Depth 10-18m	N.R.	N.R.	Bottom set netting	Mechanical damage to benthic organisms

*(Rajasuriya *et al.,* 2005); **(Rajasuriya *et al.,* 2002); † (Terney *et al.,* 2005b); †† (Terney pers. obs)

Substrate Cover & Fish Transects

Five sampling sites were selected at each study area, one site located in what was viewed to be the primary impacted area (site number 3), with two control sites to each side (sites 1, 2, 4 and 5). The Line Intercept Transect (LIT) method described by English *et al.* (1997) was used to collect benthic data. Substrate categories recorded were live hard coral (HC), live damaged coral (HCD), dead hard coral (DC), coral rubble (CR), rock (RC), algae (ALG), sand (SA), and invertebrates (INV). Five belt transects were used for rapid visual assessment of fish (English *et al.,* 1997). During sampling, the diver recorded the fish species and number in a 2m wide strip extending 1m to either side of the 25m transect line.

Water Quality Parameters

Water samples were collected from the water column in the Madiha reef lagoon for estimation of Hydrogen sulphide (H_2S), Dissolved Oxygen (DO) and Biological Oxygen Demand (BOD). Three sampling sites were selected: in a coconut husk pit, and 3 meters and 6 meters away from the pit. DO and BOD were determined using the Winkler method, while H_2S concentrations were measured using the Cadmium chloride method (Parsons *et al.*, 1984).

Socio Economic Data

Data regarding human activities that impact coral reefs were collected using questionnaires, including information on the number of visitors during week days, at week ends, the number of reef walkers, the number of husk pits owned by individuals, their income per day, the species caught in gill nets and the by catch and the number of boats used in the gill net and bottom set net fishery. In addition to that,

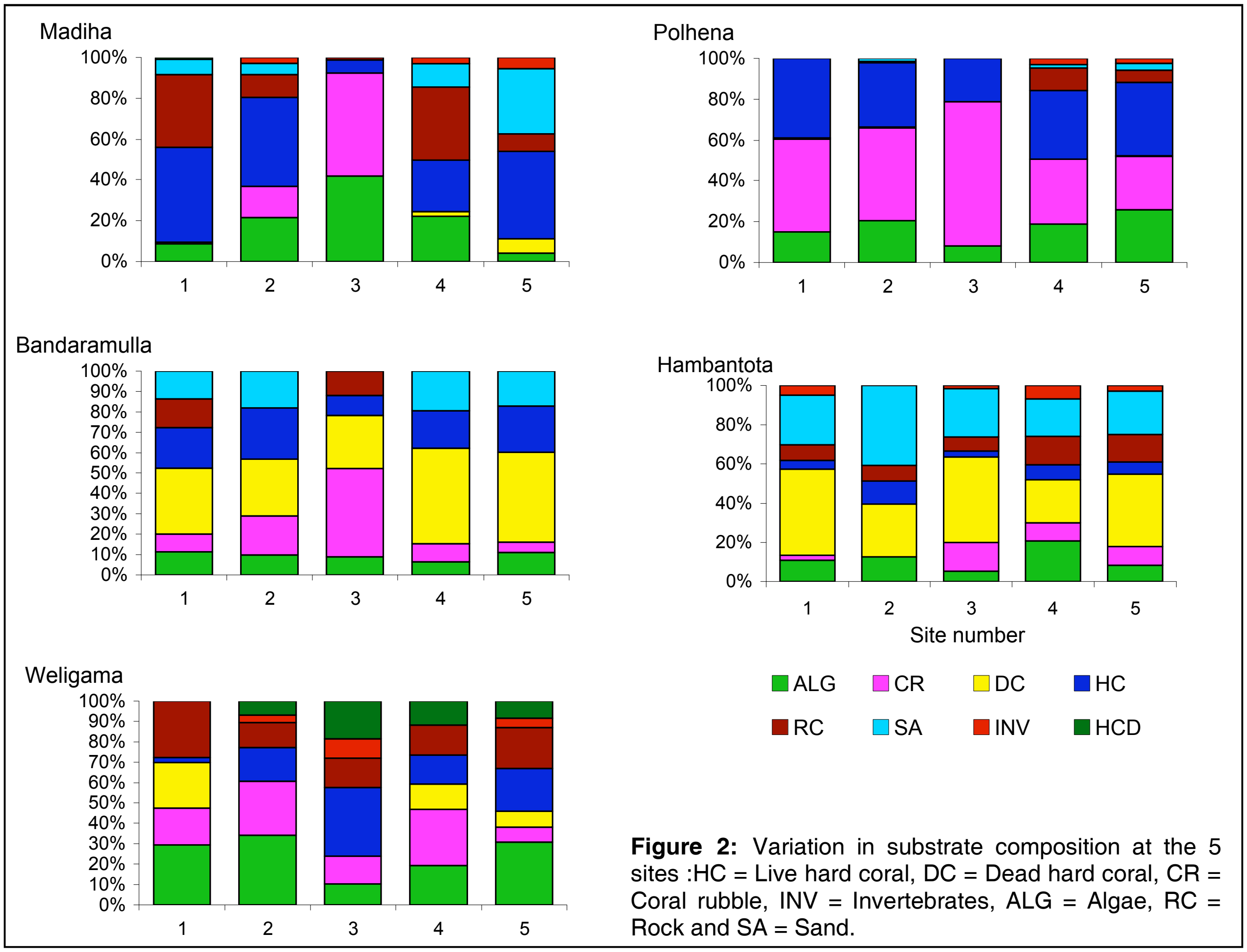

Figure 2: Variation in substrate composition at the 5 sites :HC = Live hard coral, DC = Dead hard coral, CR = Coral rubble, INV = Invertebrates, ALG = Algae, RC = Rock and SA = Sand.

informal on-site personal discussions were conducted at random with individual fishermen and fisher groups at the end of each field visit to collect data on the fate of their by catch, and their awareness of the damage caused by them.

Data Analysis

Differences in the substrate cover were analysed using the Excel statistical software package and PRIMER v6 (Plymouth Routines In Multivariate Ecological Research) for non parametric tests. Percentage values of substrate compositions were used to analyze differences between sites, using Multi Dimensional Scaling (MDS) with fourth root transformation in Bray-Curtis similarity matrix.

RESULTS

At three study areas, Bandaramulla, Madiha and Polhena, there was a marked difference between the impacted site (disturbed by human activities) and the control sites. At Weligama and Hambantota study areas no clear deviation between impacted and control sites were recorded.

Weligama Reef

This reef was dominated by algae, rubble cover and live corals such as branching *Acropora formosa*, foliose *Montipora aequituberculata* and *Pocillopora damicornis*. The benthic composition between sites was mostly uniform. However, at site number 3 the

Table 2. Marine species identified in the by catch of the bottom set gill net fishery at the Hambantota fish landing site.

Phylum	Name	Species	Phylum	Name	Species
Porifera	Sponges	*Acanthella klethra*	Mollusca	Snails & Clams	*Chicoreus ramosus*
		Clathria sp.			*Conus* sp.
		Lanthella flabelliformis			*Cymatium lotorium*
		Phyllospongia lamellosa			*Haliotis asinina*
		Spirastrella vagabunda			*Harpa amouretta*
		Xestospongia testudinaria			*Lambis lambis*
Cnidaria	Hydrozoans	*Halocordyle disticha*			*Pleuroploca filamentosa*
		Lytocarpus sp.			*Pteria penguin*
		Plumularia sp.			*Spondylus* sp.
	Soft corals	*Dendronephthya* sp.	Bryozoa	Lace coral	*Reteporellina* sp.
		Echinigorgia sp.			*Triphyllozoon* sp.
		Sinularia sp.	Echinodermata	Sea star	*Asteropsis carinifera*
		Subergorgia mollis			*Astropecten polyacanthus*
	Whip coral	*Junceela fragilis*			*Fromia monilis*
	Black coral	*Antipathes* sp.			*Linckia multifora*
	True corals	*Acropora digitifera*			*Valvaster striatus*
		Tubastraea micrantha		Feather star	*Comanthus* sp.
		Acropora sp.		Brittle star	*Ophiarachnella* sp.
Arthropoda	Crustacea	*Calappa calappa*		Sea urchins	*Eucidaris metularia*
		Carpilius maculatus			*Salmacis belli*
		Elamena sindensis			*Phyllacanthus imperialis*
		Philyra platychira	Chordata	Ascidians	*Atriolum robustum*
		Portunus sp.			*Didemnum* sp.

damaged live coral cover was 18.6%, compared with a cover of damaged live coral at the control sites of 8.57% ± 6.08 (standard deviation) (Fig. 2).

The most abundant fish species were *Abudefduf vaigiensis*, *Abudefduf sexfasciatus*, *Scolopsis bimaculatus* and *Plectroglyphidodon dickii*. Butterfly fish species collected from the wild seen at the fish-collecting centre were mostly butterfly fish: *Chaetodon auriga*, *Chaetodon decusatus*, *Chaetodon trifascialis*, *Chaetodon trifasciatus* and *Chaetodon vegabundus*. In addition to extensive reef fish collection, corals at the Weligama reef face the additional threat of boat anchors used by fishing boats. This is common throughout the western side of the Weligama bay and extends close to the live coral patch. A further emerging potential threat is coastal construction in the immediate vicinity of the reef.

Bandaramulla Reef

The average coral rubble cover at control sites in the Bandaramulla reef area was 17.05 ± 15.67, while at the site where coral mining is intense (site 3) it was 43.5% (Fig. 2). This site also exhibited the lowest live coral cover, 9.75%. Dead coral cover was higher at

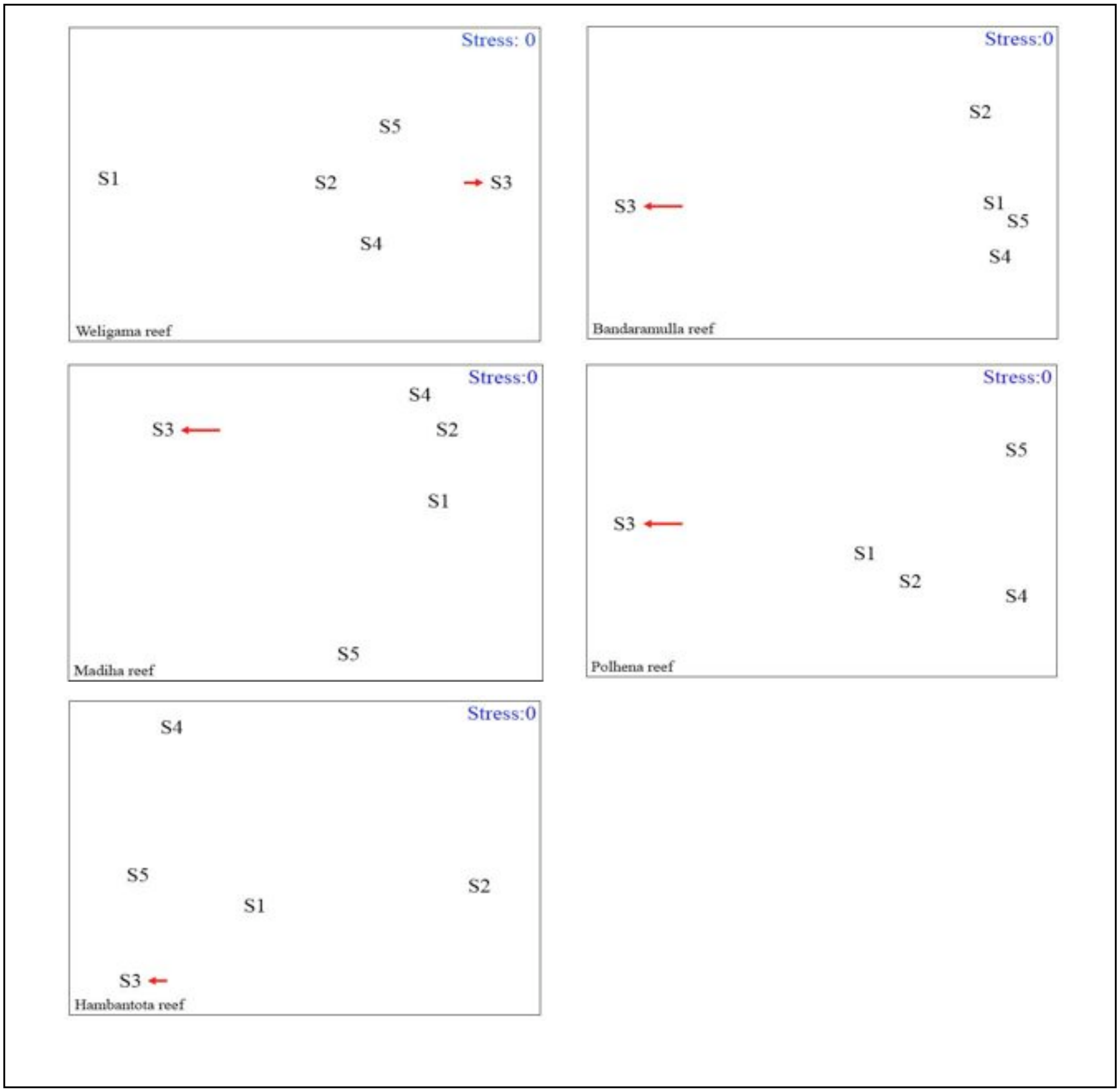

Figure 3: Two dimensional MDS ordinations for five reefs studied. Long arrow indicates a strong deviation and short arrow indicates a weak deviation of the impacted site from the rest.

sites number 4 and 5 than at other sites, 46.7% and 44.25% respectively.

Madiha Reef

At control sites on the Madiha reef, the average live coral, algae and rubble cover was 33.07% ± 17.08, 19.42% ± 14.67 and 33.25% ± 13.25 respectively. At the site closest to the coconut husk pits, the percentage rubble cover and algae cover increased up to 50.6% and 41.8%, while the live coral cover was 6.45%, the lowest cover recorded at Madiha reef (Fig. 2).

H_2S concentration in husk pit water was 0.928mMol/l, while at a distance of 3 meters from the pit it was 0.101mMol/l, and 0.063mMol/l at a distance of 6 meters away into the reef lagoon. DO and BOD values in husk pit water were 0.00 mg/L. DO were 6.938 mg/l and 7.755 mg/l and BOD values were 2.993 mg/l and 2.009 mg/l at distances of 3 and 6 meters from the husk pit. High concentrations of H_2S and BOD values indicated that the seawater in the adjacent lagoon was polluted with H_2S and organic matter. The smell and colour also confirmed the polluted nature of the water in the husk pit and adjacent waters of the reef lagoon.

Polhena Reef

The average number of local visitors to the Polhena reef area was 118 ± 41.9 during weekdays and 776 ± 220.8 during weekends. An average of 19 visitors, or 16% of the total number, walk on the reef on weekdays, while on weekends 81 visitors or 10% of the total number walk on the reef every day. People walk on specific shallow coral patches and these walking areas are well known among the local visitors. In addition to the visitors, about 15 fishermen engage in fish collection on the reef on a daily basis.

Rubble (44% ± 17.23) and live coral (32.24% ± 6.76) cover were the major components of the Polhena reef substrate at control sites. The rubble cover was 70.8% at the site used for reef walking, with live coral cover of 21.2% (Fig. 2).

Hambantota Reef

The fishing fleet in the area consists of up to ten fiberglass reinforced plastic boats manned by about 25 fishermen. Each boat operates with 15 to 20 pieces of net with a mesh size of 4 inches. The height of the net varies from 10 to 12m, the length from 60 to 70 m. These nets target small pelagic fish species.

The entire area of the reef surveyed showed evidence of human impact: broken and dislodged hard coral and other invertebrate colonies were diffusely scattered over the whole area. As damage was not concentrated in a particular area, there was little variation in the substrate distribution pattern (Fig. 2). Damage to the area was also reflected in the benthic fauna brought up in bottom set gill nets (Table 2), recorded during net cleaning and mending. Sea turtles are frequently entangled in nets, but dead turtles were not brought to the landing site due to legal restrictions and no species identification was possible.

At Bandaramulla, Madiha and Polhena reefs, substrate cover was significantly different at sites where anthropogenic stress was more prevalent (Fig. 3). However, at each of these study areas at least one control site also shows a deviation from other sites. Benthic cover at impacted sites (Site 3) at the Weligama and Hambantota reefs were not significantly different from the other sites.

DISCUSSION

Reef degradation in Sri Lanka is the result of years of anthropogenic impact mixed with the destructive effects of natural events, the most recent being the 1998 El Niño event followed by the 2004 tsunami. The 1998 bleaching event had a profound effect on the western and southern coral reefs, while the damage was lower on the eastern coast (Rajasuriya et al., 2004). Tsunami damage was mainly mechanical caused by rubble movement, debris depositions and smothering. The combination of El Niño and tsunami damage makes the evaluation of causative factors of reef degradation complex. However, selective human activity has been concentrated on particular reefs and the effects of this activity are clearly visible. This was apparent in some of the reefs that were monitored during the course of this study.

Ornamental Fish Collecting

At Weligama, damage to live corals was highest at the impacted site that had abundant coral, which formed the habitat of fish targeted by ornamental fish collectors. The collecting methods employed are often destructive and the resulting damage is clearly seen at the impacted sites. The distribution pattern of damaged live coral followed the distribution of live corals. The very high pressure from ornamental fish collecting continues to damage the Weligama reef due to the use of moxy nets, the use of which is illegal in Sri Lanka (Rajasuriya, 2002). As there is correlation between reef fish communities and live coral cover (Bell & Galzin, 1984), such damage to live corals can lead to habitat alteration, which ultimately causes changes in fish assemblage structures (Ohman *et al.*, 1997). Following habitat alteration resulting in low live coral cover ornamental reef fish, especially chaetodontids, may be less abundant than on reefs with high coral cover (Hourigan *et al.*, 1988), and coral feeders may be lost altogether, which has been shown to occur on dead rubble reefs (Sano *et al.* 1987). On the Weligama reef, chaetodontids and other ornamental fish species are still present, though in low numbers, in the depleted live coral patches where divers still continue to collect them (Fig. 4). Increased surface runoff and silt as a result of the building activity on a cliff top overlooking the area has added to the present mix of factors affecting the reef (Fig. 5).

Figure 4. Butterfly fish are held in plastic basins before transferring to polythene bags for export, at the Weligama fish collecting centre. Photo: Anura Kumara.

Coral Mining

The immediate result of coral mining is depletion of live corals and loss of three-dimensional structure of the reef. This is clearly illustrated by the bar charts in Figure 4 showing substrate cover on the Bandaramulla reef. The mining activities at this study site include dislodging heavy coral boulders and reef walking. The direct impact is seen at site number 3 with high coral rubble and low live coral cover. The impacted area was totally devoid of fish life: the low incidence of

Figure 5. Weligama reef showing the cliff top building site and the boat anchorage in the reef lagoon. Photo: Anura Kumara.

algae and the absence of invertebrates are further impacts of coral mining. The dead coral cover is still higher at site number 4 and 5 where the area is still dominated by intact dead coral structures, following the 1998 El Niño event.

Coral mining from the sea has been banned in Sri Lanka for many years as it causes environmental degradation and economic problems by promoting beach erosion and depleting fish stocks. For example, coral mining has increased beach erosion along the west coast, south of Colombo and along the south coast of Sri Lanka (Wilhelmsson, 2002). The government decision to prohibit coral mining has affected the livelihoods of many people, who were dependent on the income from this industry. Inefficiency and corruption amongst law enforcement officers and delayed legal proceedings are major impediments to the effective control of coral mining (Terney *et al.*, 2005b). Banning of coral mining has not prevented the continued exploitation of this resource. Provision of appropriate alternative livelihoods for miners and identification of substitute raw materials for the production of lime for the building industry are important necessary actions if coral mining is to be completely eradicated.

The Coir Industry

The coir industry is one of the leading rural industries in Sri Lanka, employing mostly women. For example, there are more than 2500 workers in the Matara district alone, 90% of them being women. Only a part of this industry is based on the coastal ecosystems, where coconut husk pits are dug along the coastline, frequently in reef lagoons protected by coral reefs (Fig. 6); major coconut growing regions are spread throughout the interior in the north-western parts of the island, and treatment is fresh water based.

When the husk pits are in use, polluted water, grey in colour and rich in nutrients and H_2S, is seen flowing into the lagoon at Madiha. However, even after dilution the H_2S concentration of the water some

Figure 6. Coconut husk pits along the shore. Note the grey coloured polluted water, rich in H_2S, nitrates and phosphates mixing with the lagoon water. Photo: Anura Kumara.

meters away from the pits in the lagoon is above the lethal limit. The BOD values suggest that the lagoon water is moderately polluted with organic matter. During periods of calm weather and low tides, there is little flushing of the lagoon and the polluted water tends to stagnate, especially when the pits are drained during extraction of the retted husks and large volumes of polluted water is released into the lagoon. The effect of pollution is clearly seen in the distribution pattern of live coral on the Madiha reef. Live coral cover was lowest and algal cover highest at the site closest to the pits. Dense algal cover and high amounts of coral rubble hinder the natural recovery of the reef.

Recreational Visitor Pressure

Observations indicate that the impacts of reef visitor pressure are unevenly distributed. Damage is caused mainly by reef walking, aggravated by collection of coral souvenirs. These two factors, coral trampling and live coral collection are the reasons for the scarcity of live corals on the Polhena reef (Terney *et al.*, 2007), in addition to the natural disturbances. The coral recovery rate at this site is low as a result of higher settlement mortalities caused by moving rubble due to the unconsolidated nature of the reef surface. As a result the rate of re growth of the reef remains slow (Tamelander, 2002).

Terrance (1999) reported that the average number of visitors per weekday and weekend to the popular bathing beach that gives access to the reef were 950 and 2375 respectively, of whom about 3% walk on the reef. The number of reef visitors was significantly reduced after the 2004 December tsunami. However, visitors to the beach and of those who climb on to the reef have increased since Terrance's observations, particularly during the last two years. A new destructive activity that adds more pressure on the reef ecosystem has been seen at Polhena in recent months, where local fishermen have begun to collect sea urchins and moray eels in large quantities for the ornamental aquarium trade. There is much destruction of coral in the process of collection.

Bottom Set Net Fishery

Reef fisheries (other than for ornamental species) have been found to negatively influence larger predatory species because they are usually directly targeted (Munro, 1983; Russ & Alcala, 1989). Fishing pressure on Sri Lanka's reefs continues to rise due to the open access nature of the fishery and weak implementation of existing regulations.

The reef at Hambantota showed widespread diffuse and evenly distributed damage from the bottom set nets over the entire area that was surveyed. Bottom set gill nets are considered the most destructive fishing gear that can be used in coral-rich environments (Perera *et al.*, 2002). These nets are relatively unselective as they catch many species of fish, whether desirable or undesirable, as well as most of the bottom dwelling organisms they come in contact with. Included in the catch at times are protected pelagic species such as turtles. These nets not infrequently snag on coral boulders and are abandoned, where they continue to ghost fish.

Sedentary and slow-moving bottom dwelling organisms are either broken off or dislodged by the weights attached to the bottom of the nets and become entangled in the mesh, and brought up as bycatch. An examination of the bycatch gives an indication of the damage caused. All of the by catch is discarded except large gorgonian colonies and shelled molluscs, which are traded or collected as ornaments. In addition to that, traps and hand collecting methods involving scuba diving are used to collect lobsters (*Panulirus homarus* and *Panulirus versicolor*) and crabs. Damage caused by these methods is comparatively small.

An interesting observation was that fishermen engaged in the local pelagic gill net fishery objected strongly to the bottom set net fishery, despite the small number of boats involved. They have realised that this method destroys the bottom cover and in the long term contributes to depletion of the fish stocks on which they depend. They are also unhappy about the turtle mortality due to these nets.

RECOMMENDATIONS

MDS ordination showed clearly the substrate alteration caused by human activities on Bandaramulla, Madiha and Polhena reefs. At Madiha, Polhena and Weligama control sites also showed a deviation. However it is obvious that the deviation is not due to reef damage caused by human activities as disturbance indicators such as increased amounts of rubble, algae and broken live corals were not dominant at those sites. At Hambantota all sites were scattered throughout the MDS ordination, indicating the uniformly disturbed nature of the whole reef. It is noted that although specific human impacts have been identified on some reefs, the sum total of reef degradation is a result of the combined effects of a number of superimposed natural and human impacts.

Reef degradation due to human impact is a complex issue as most of the damage results from the livelihood patterns of coastal communities, socio economics and to some extent political factors. Understanding these complex issues and finding solutions – both long and short term – are among the most difficult tasks faced by reef managers. Reducing the numbers of school leavers who take to fishing or ornamental fish collection and resort to destructive practices that requires the least amount of skill as an easy way out of the employment dilemma would help reduce the pressures on coastal habitats. The solution should provide appropriate education to ensure that school leavers progress to higher education and thence to white-collar jobs or for those with technical aptitudes to progress to vocational training that would suit them for gainful employment, including sustainable fishing. Awareness programs and career guidance should be part of this process. Provision of suitable alternative livelihoods for fishermen who might be displaced from their occupations by the introduction of reef management is equally important. Seaweed culture, fish farming, manufacture of handicrafts and retail business are felt to be possible options. However, the economic feasibility of such alternative livelihoods and the availability of a ready market for goods produced should be assured to attract people into and retain them in new ventures.

Enforcement of the many laws and regulations that define what can and cannot be done in the coastal zone is weak. Strengthening this area is of paramount importance if the biological diversity and productivity of coastal ecosystems is to be preserved. Attention needs to be directed at improving the effectiveness of law enforcement, maintaining an adequate number dedicated to protection of the coastal zone and provision of necessary boats and vehicles for their use. Speedy dispensation of justice through the courts is also a necessary component. An examination of the current laws that apply to this sector with revision if necessary to remove loopholes and make prosecution easier is recommended.

Management of reefs in a proactive fashion is recommended. Unrestricted exploitation, especially if destructive gear and/or practices are employed, spells doom for reefs. Zoning of reefs into areas designated for commercial extraction, recreational diving or sport angling and protected areas can help ensure that areas of reefs remain healthy to support re-populating the part used for an extractive fishery. Monitoring of reefs with the collection of data on reef biota and fishing activities are further recommended to better understand and manage coastal marine resources (Obura *et al*., 2002). Indeed, this is a pre-requisite to zoning and reef management.

This study gives an overall picture of the present level of degradation of the selected reefs, but is in effect only a snapshot. Greater understanding of the forces at work would be possible only with further in-depth study that would include more sampling sites and more data collection and analysis. This needs to be coupled with a well-planned socio-economic survey, the results of which would modify any management options that are considered based on the biological data obtained. We need to constantly bear in mind that the coastal population involved is vulnerable, with very low income levels and very little to fall back on. The right balance between development needs, environmental protection and the rights and needs of the community should be ensured.

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Patterns of Benthic Recovery in the Lakshadweep Islands

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ABSTRACT

The atoll reefs of the Lakshadweep are recovering from a catastrophic mortality of coral following the El Niño-related bleaching of 1998. This event resulted in more than 90% loss of coral, a subsequent loss of structure, and significant alterations of fish communities. Although most reefs showed signs of recovery from 2000 to 2007, the pace of benthic recovery varied considerably between atolls. Additionally, there was a clear difference in the patterns of recovery between eastern and western aspects of the island, driven by local hydrodynamic conditions and post-settlement mortality of hard coral. The cover of macroalgae remained low at all reefs, controlled by abundant herbivore fishes. While benthic recovery appears to be progressing well on the Lakshadweep reefs, it is unclear if the reefs will withstand future mass bleaching events of the magnitude of 1998. The summer of 2007 was unusually hot, and bleaching progressed significantly with time as the summer progressed. Post-monsoon surveys will be needed to confirm what impact this warming had on benthic communities in the Lakshadweep.

INTRODUCTION

An archipelago of 12 atolls in the central Indian Ocean, the Lakshadweep coral reefs are characterised by clear, relatively nutrient-poor waters with high coral and fish diversity. The recent ecological history of these reefs is dominated by the El Niño of 1998, which resulted in a major mass mortality of corals in the Lakshadweep, and a subsequent loss of benthic structure (Arthur 2000), as was reported from atoll complexes further south (McClanahan 2000; Sheppard et al. 2002). Reefs are still recovering from this event, and while the pace of coral regrowth is remarkable at some locations, recovery at other locations is patchy at best. The pace of recovery appears to be dependent on interactions between post-recruitment survival, monsoon-generated hydrodynamics and other local-scale processes (Arthur et al. 2006). Fish community composition also changed in apparent response to benthic recovery, and several trophic groups, including herbivores and corallivores changed significantly with time (Arthur 2005). A relatively healthy fish community was perhaps an essential factor in determining benthic recovery, possibly preventing macroalgae from becoming a dominant element in the recovering reefs.

Much of the observed resilience of the Lakshadweep coral reefs can be attributed to the fact that the local population does not heavily exploit these reefs. With upward of 60,000 people, Lakshadweep has among the highest rural densities in India (more than 2000 individuals.km^{-2}). Although the main protein source for this population is fish, most of the fish caught, traded and eaten consists of skipjack tuna,

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

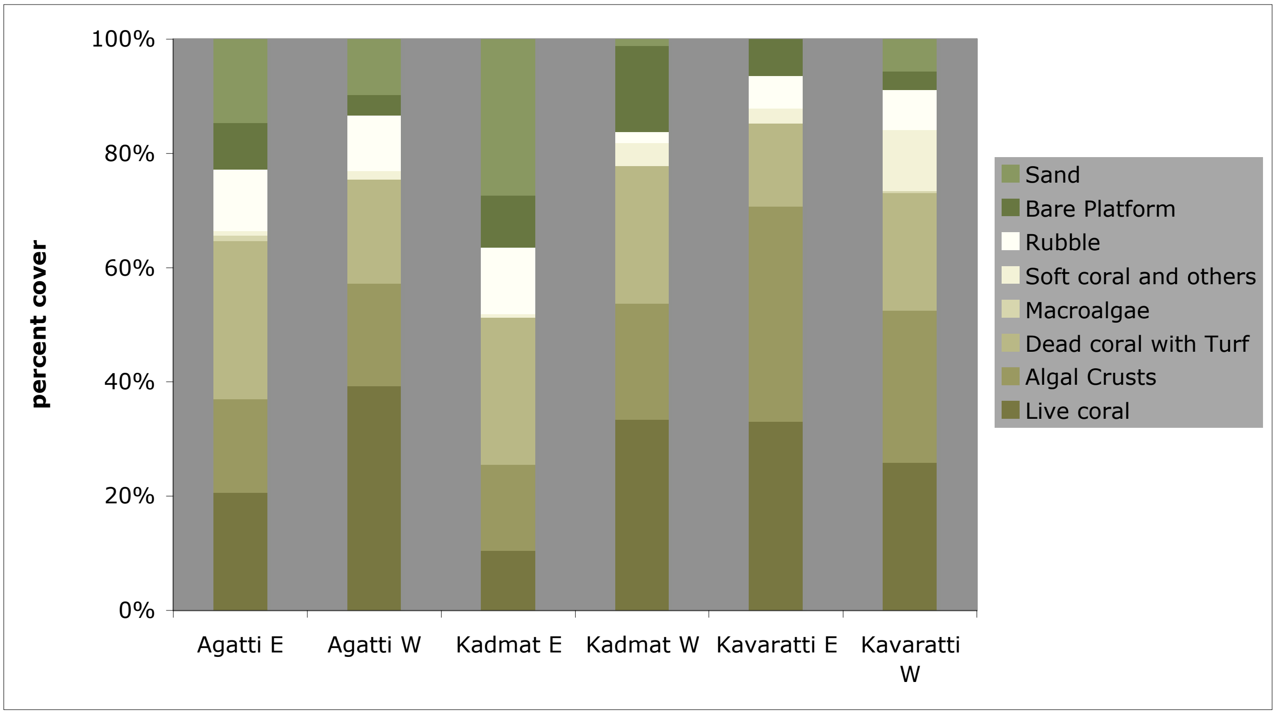

Figure 1. Proportional cover of benthic elements in Lakshadweep reefs, 2007.

caught in the pelagic waters around the islands. A hook-and-line tuna fishery is the main economic livelihood here apart from coconut cultivation. This fishery was introduced to the island group in the 1970s, promoted by the Fisheries Department as an economic development activity, and it has practically replaced more traditional forms of reef and lagoon fishery, which earlier used to support the local population. An upshot of this promotion was to considerably reduce the amount of fishing pressure on the outer reefs of the Lakshadweep (Arthur 2005). This in turn could have contributed, albeit epiphenomenally, to the reef's recovery potential after the mass bleaching of 1998.

Few reliable studies exist from the coral reefs of the Lakshadweep before 1998, making it difficult to determine the impact of the bleaching event, or to comprehensively understand trends in post-bleaching recovery. Three atolls were monitored for benthic condition from 2000 to 2003 (Arthur et al 2006), but there have been no systematic surveys since then. The present survey was conducted to revisit the sites last sampled in 2003 and assess benthic status, and to establish these sites as annual monitoring stations. Sampling was conducted to coincide with a potential bleaching event before the onset of the summer monsoon, to track potential impacts of this event on the reef.

METHODS

Methods employed follow closely those detailed in Arthur et al. (2006). Six sites were located on three atolls (Agatti, Kadmat and Kavaratti). Agatti and Kadmat were the worst affected by the coral mass mortality of 1998, while Kavaratti was relatively less affected. At each atoll, a site was located on the east and west, reflecting important differences in hydrodynamic conditions caused by the summer south-west monsoon. These sites had been monitored annually from 2000 to 2003.

At each location the percent cover was estimated in

1m^2 quadrats located at fixed intervals along a random 50 m line. The 50 m tape was laid between 8 and 12 m depth. Benthic cover was estimated for the following benthic elements: live coral cover, dead coral with turf algae, macroalgae, crustose coralline algae, soft coral and other invertebrates, rubble, sand and bare reef platform. Live coral was identified to the species or genus level. However, for this report, only broad trends in live coral cover are presented. To determine trends in benthic cover, average percent cover values were compared with data from 2000 to 2003.

Sites were sampled at the peak of summer, just before the onset of the summer monsoons, with the possibility of unusually high sea surface temperatures in relation to a developing El Niño in the Indian Ocean. To estimate the potential impact of elevated ocean temperatures, signs of bleaching were recorded in each quadrat. In addition, temperature gauges were installed at each site to determine local-scale variation in ocean temperatures over the late summer and monsoon. Other ad-hoc observations on reef condition were made in extensive free swims at several sites on all three atolls. In addition, I spoke to fishers and community members about trends in reef resource use to determine if this had changed considerably since earlier studies (Arthur 2005).

RESULTS

Recovery patterns between reef sites continued to be variable, and while coral cover was relatively high at some monitored sites, other locations still had low values of coral cover (Fig. 1). Coral cover at west-facing sites continued to recover faster than eastern sites in Kadmat and Agatti; in Kavaratti however, live coral was not different between aspects. The difference in live coral between eastern and western sites was confirmed in spot surveys at several locations in Kadmat and Agatti, and was most clearly evident in Kadmat reefs. Eastern sites in Kadmat continued to show low levels of coral cover in comparison with western locations. Recovery across the sites surveyed

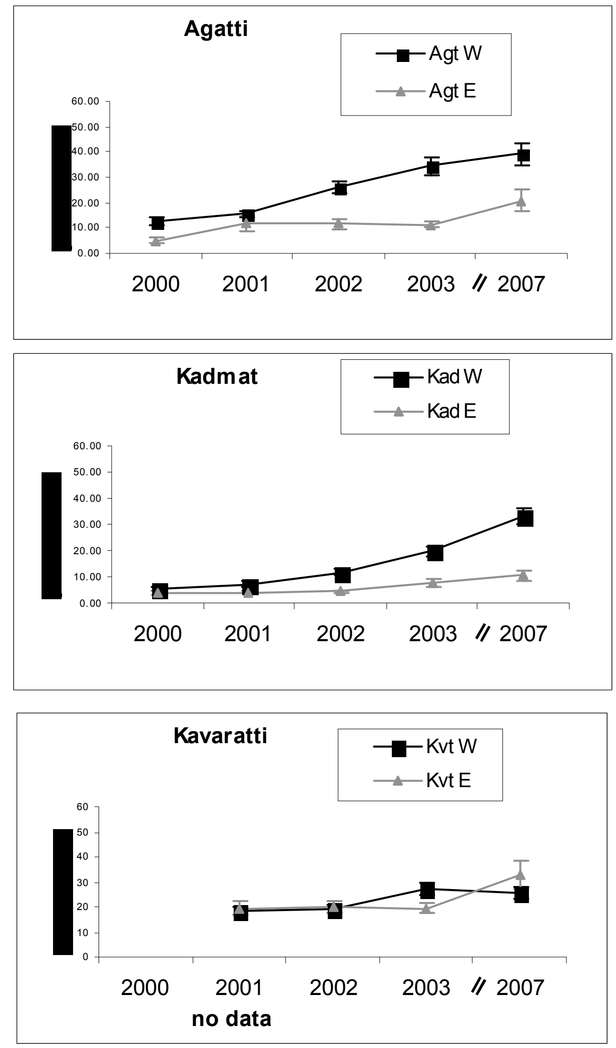

Figure 2. Trends in live coral cover in Lakshadweep islands.

was dominated by several species of tabular and branching *Acropora*, which, particularly at some western sites in Agatti, frequently grew to sizes in excess of 1m in width. In general, benthic cover showed signs of increasing at most sampled locations from 2000 to 2007, apart from Kavaratti West, where there was a mild, possibly insignificant decline in cover from the last sampling in 2003 (Fig. 2). There was considerable variability in the rate of recovery

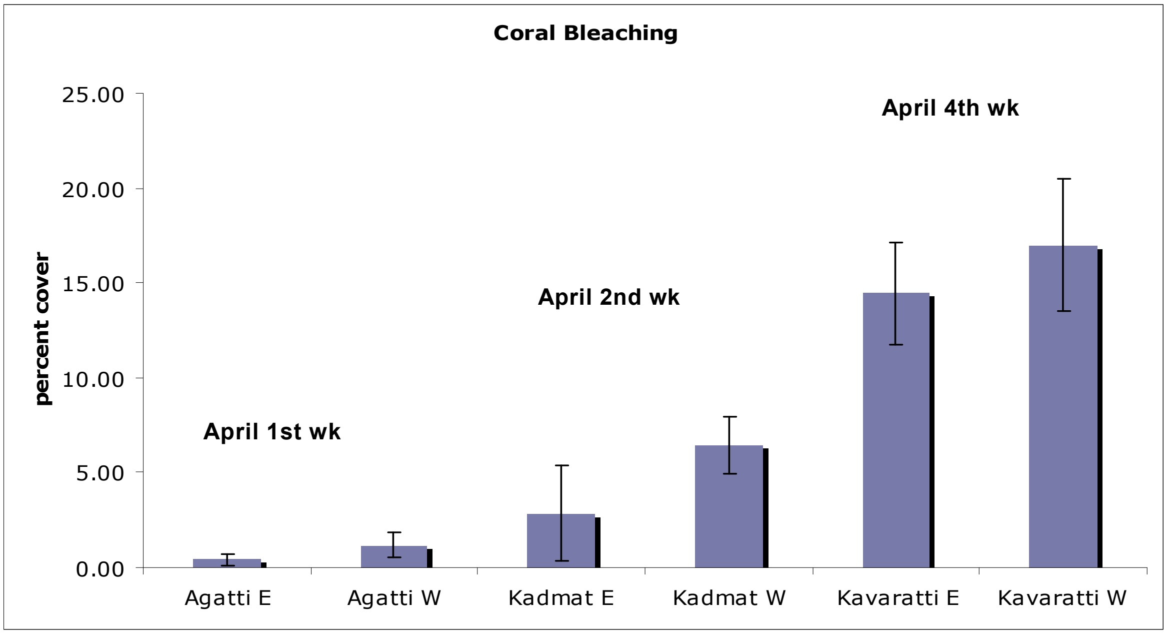

Figure 3. Percentage of bleached coral recorded in the Lakshadweep during the month of April 2007.

between locations, and while some locations showed gradual increases in coral cover, eastern sites at Agatti and Kavaratti, and Kadmat West showed a marked increase in benthic area occupied by coral.

The cover of algal turfs was remarkably consistent across sampled sites, and comprised approximately 20% of the substrate, growing on old dead coral and rubble (Fig. 1). This represents a considerable reduction in cover by turf algae from the earliest surveys done at these sites (in 2000), when algal turf covered between 30 to 50% of the benthic substrate. Macroalgae was recorded at very low values. Crustose coralline algae was relatively similar in Kadmat and Agatti, but was considerably more dominant in Kavaratti (Fig. 1), consistent with earlier surveys.

Pale and completely bleached coral was rare early in April at the beginning of the sampling. However, as sampling progressed, signs of bleaching increased significantly on the transects, and on all dived locations (Fig. 3). Reef sites at Agatti were sampled in the first week of April, Kadmat was sampled during the second week of April and Kavaratti was sampled in the last week of April. Bleaching patterns appear to follow this sampling time, and by the last week of April, more than 15% of live coral was bleached in Kavaratti reefs. This was considerably higher than normal summer bleaching, where between 5-10% of the coral bleach just before the onset of the monsoons.

An additional observation made while sampling and diving at various locations across the island group was that populations of *Acanthaster planci* were high at a few locations. Western sites in Agatti were particularly badly affected, and rough estimates indicate that around 5% of the *Acropora* in the sampled reef had died because of intense *A. planci* predation. *A. planci* was also seen at several locations in Kadmat, although never at the same densities as Agatti West.

DISCUSSION

Much of the difficulty in discussing the impact of the last El Niño event on the marine systems of the Lakshadweep stems from the fact that, prior to 1998, no comprehensive baselines exist documenting the status of benthic communities or fish populations of these reefs. The first reliable in-water studies document reefs already considerably changed by the coral mass mortality of 1998. Given this paucity of prior information, the best that is possible is to examine present trends in the light of conjectured consequences of the El Niño.

By and large, patterns of recovery described by Arthur et al. (2006) appear to be continuing in the reefs of the Lakshadweep. Briefly, coral cover is increasing at most reef sites (Fig. 2), while algal turf and macroalgae were both considerably reduced from earlier studies. As mentioned earlier, these reefs have seemingly healthy populations of herbivorous fish, particularly *Scarids* and *Acanthurids*, and they could play a significant role in keeping algal levels down, facilitating coral recovery (also see Arthur 2005). Many *Acropora* species, particularly *A. abrotanoides*, that were most probably part of the original reef framework are returning to dominance, and are mature enough to be contributing to the local recruitment pool (Wallace et al 2007)

Observations point to a clear increase in coral bleaching through the month of April 2007, at levels higher than normal summer bleaching (Fig. 3). Casual reports from divers diving in early May confirm that this pattern of bleaching was on the increase, with the possibility of some amount of bleaching-related mortality (Sumer Verma, personal communication). The south-west monsoons arrived at the Lakshadweep around the middle of May 2007, and the monsoon rains generally result in a rapid lowering of ocean temperatures, potentially ameliorating the effects of the ocean temperature anomalies on the coral. However, without post-monsoon surveys, it is difficult to predict the extent of bleaching damage. Rapid surveys are planned later in 2007, and will provide a clearer picture of bleaching impacts.

It is perhaps equally difficult to conjecture on the resilience of the Lakshadweep reefs to repeated coral mass mortality impacts. The principal lesson of the 1998 mass mortality was that recovery patterns can often be the result of a complex interaction between local and regional-scale factors (Arthur et al 2006, Wallace et al. 2007), and contingency plays an equally important role in determining the paths each location takes to recovery or decline. The observed difference in recovery between east and west in Kadmat and Agatti is a case in point. These reefs suffered the highest mortality during the 1998 bleaching (Kavaratti was relatively less affected), and by the time the monsoons arrived, most of the bleached coral had already died. The western reefs are on the windward aspect of the approaching monsoon, and by the end of the rains, the strong monsoonal waves had reduced the dead *Acropora* tables and other branching species to rubble, which deposited in large amounts in the lagoon and lagoon mouths. In contrast, the eastern reefs still maintained their structure, and initial coral recruitment was high on both aspects of the island. Arthur et al. (2006) argue that the viability of settlement substrate was markedly different between the two aspects, and, while coral settled on bare platforms or old dead corals on the western lagoons, corals appeared to preferentially choose less structurally stable locations to settle on eastern reefs, where the majority of the settlement was on recently dead *Acropora* tables. These substrates became increasingly unstable with time, and post-recruitment survival was much lower on the east than the west.

What is difficult to know is whether the same processes will play themselves out in the wake of another catastrophic coral mass mortality. To list the unknowns that need to be addressed before a more complete picture can be obtained of the resilience of the Lakshadweep reefs is to outline a full-fledged research programme for the island group. For a start, the importance of long-term data sets on benthic and fish communities cannot be overemphasized. Impacts of unexpected events can only be correctly interpreted against a canvas of background trends, and regular and sustained monitoring is essential to understand these temporal changes. The Lakshadweep is also a region for which no information is available on seasonal trends in coral larval release, or on landscape-level patterns of recruitment. Unraveling the source-sink dynamics of this reef complex will be crucial to understanding how reefs will respond to large-scale mortality.

Recent discussions on managing reefs in the face of global change have focused on the need to identify sites that may be inherently vulnerable, resistant, tolerant or resilient to thermal stress (Obura 2005, West and Salm 2003). It is argued that oceanographic features, geographic position, and characteristics of the surrounding water can all interact to offer various degrees of protection to reef sites from thermal stress and UV radiation associated with increased sea surface temperatures. It is difficult to predict this gradient from a single anomalous temperature event, and only with a series of these events can a reliable gradient of resilience be established (Wooldridge and Done 2004). On the face of it, the Lakshadweep atolls appear to have few inherent protections against ocean warming events. With relatively high water transparency, the 1998 bleaching saw coral bleached even below 30m depth and the flat coral atolls do not provide any shading to the reefs during the hottest days of summer. Oceanographic conditions and local-scale water currents could offer some amount of protection, but these are not clearly understood as yet. We have currently established sampling sites at reef locations that reflect potential differences in water currents, and we are tracking these locations to determine if they respond differently to thermal stress. This may help us understand the patchiness of decline and recovery in bleached reefs.

The prospects of continued reef recovery in the Lakshadweep are closely linked to human resource use of the reefs. Currently, and for the last four decades or so, reef fish have formed only a marginal component of the community diet, and the dominant fishery has focused on fishing pelagic tuna. Interviews conducted recently however indicate that some fishers have begun to target reef fish once again, exclusively for south-east Asian markets. This nascent fishery focuses on bumphead parrotfish, Napoleon wrasse and several species of grouper. This fishery is, in the short term, much more lucrative than tuna fishing, and it may not be long before other fishers tap into this trade as well. This is a worrying prospect for the reefs of the Lakshadweep, since, without adequate controls on fishery in these waters, what resilience to global events that the reefs may possess thanks to these higher herbivores and carnivores could be very rapidly squandered by short-term prospectors.

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Status of Coral Reefs of the Gulf of Mannar, Southeastern India

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ABSTRACT

The coral reefs in the Gulf of Mannar, southeastern India, are important to the lives and livelihoods of coastal people in the area. However, human interference and management shortcomings have put this ecosystem under tremendous pressure. Over 32 km^2 of coral reef has already been degraded around the 21 islands of the Gulf of Mannar. This study provides baseline data on the coral reefs of the area that has been lacking so far. The present average live coral cover is 35%, with 117 coral species, including 13 new records. Dominant coral species are *Acropora cytherea*, *A. formosa*, *A. nobilis*, *Montipora digitata*, *Echinopora lamellosa*, *Pocillopora damicornis* and *Porites* sp. Fifty species of reef associated fishes in 27 families were observed during the study, with the Lethrinidae, Lutjanidae, Siganidae, Chaetodontidae, Ephippidae, Gerreidae, Pempherididae and Gobiidae most common. The surveys further indicate that habitat variables, in particular live coral cover, play a major role in the enhancement of fish diversity. Results on sediment loads and regimes are also presented. This can serve to support and underpin both ongoing and future conservation and management initiatives in the Gulf of Mannar.

INTRODUCTION

Background

India has four major coral reef areas, the Andaman and Nicobar Islands, the Gulf of Kachchh, the Lakshadweep islands, and the Palk Bay and Gulf of Mannar area. The Gulf of Mannar (GoM) is located in Tamil Nadu, on the mainland southeast coast of India (Fig. 1). Coral reefs in the area have developed around a chain of 21 uninhabited islands in four groups (Table 1) that lie along the 140 km coastal stretch between Rameswaram and Tuticorin, at an average distance of 8-10 km from the mainland. Narrow fringing reefs are mostly located at a distance of 100 to 350 m from the islands, and patch reefs up to 1-2 km long and 50m wide rise from depths of 2 m to 9 m.

Pillai (1986) provided a comprehensive account of the coral fauna of GoM, describing 94 species in 37

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

Figure 1. Map of the Gulf of Mannar showoing the location of the 21 islands sampled.

genera, the most common being *Acropora* spp., *Montipora* spp. and *Porites* spp. Patterson et al., (2004) updated the checklist of corals of GoM adding 10 new records, to 104 species. A survey of the entire GoM conducted between 2003 and 2005 further updated the list of corals to 117 species (Patterson et al., 2007). The GoM is also rich in various other biological resources such as 147 species of seaweeds (Kaliyaperumal 1998), 13 species of seagrass (Rajeswari and Anand 1998), 17 species of sea cucumbers (James 2001), 510 species of finfishes (Durairaj 1998) 106 species of shellfishes such as crabs (Jeyabaskaran and Ajmal Khan, 1998), 4 species of shrimps (Ramaiyan et al., 1996) and 4 species of lobsters (Susheelan 1993). During recent surveys of mollusks, 5 species of polyplacophorans, 174 species of bivalves, 271 species of gastropods, 5 species of scaphopods (added for the first time) and 16 species of cephalopods were recorded (Deepak and Patterson, 2004).

In 1980 the Government of Tamil Nadu notified the public of the intention of setting up a Marine National Park in the gulf of Mannar. Subsequent to a re-notification in September 1986, the Gulf of Mannar Marine National Park was declared. The National Park covers all 21 islands, and regulates activities in the area for conservation and management of resources. In 1989 the Gulf of Mannar was declared a “Marine Biosphere Reserve” under UNESCO's Man and the Biosphere Programme, covering an area of 10,500 km2 from Rameswaram to Kanyakumari.

The coral reefs are still the main source of livelihoods for the thousands of small-scale fishers living along the GoM coast. Over 150,000 people live in the coastal zone of the GoM, many of whom (over 50,000) depend directly on reef fishery resources (Patterson et.al., 2007).

Issues

The Gulf of Mannar is under severe pressure from a number of human activities that have degraded the ecosystem. One important reason for this situation is that the coastal areas are densely populated and that both traditional and “modern” activities, e.g. small-scale and industrial fishing, are competing for limited resources. The majority of the coral reefs have been severely damaged by coral mining and destructive fishing practices, and no trend towards decreasing

Table 1. Islands in the Gulf of Mannar. Site number (corresponding to numbers in Figure 1), island name (and number of transects recorded), and brief description of island and reef.

Islands	Land/Beach features	Reef Type
MANDAPAM GROUP		
Shingle (23)	Narrow sandy beach, dead coral rubble on the northeast and southern side; coastal dunes in the middle of the island partly vegetated.	Fringing, extends down to 2 m depth
Krusadai (12)	Narrow sandy beach, coral rubble on the south and southeast windward side; vegetated sand dunes.	Fringing reef extends down to 3 m, with patch reefs to the east
Pullivasal (19)	Narrow sandy beach with coral rubble on the Southwest, South and Southeast sides; vegetated sand dunes.	Fringing reefs to 2.3 m depth with patch reefs to the North
Poomarichan (20)	Sandy beach, coral rubble on the Southwest and Southern shores; sand dunes are covered by extensive vegetation; island height 1.5 m over the mean sea level.	Fringing reef down to 2 m depth with patch reefs to the northeast.
Manoliputti (13)	Narrow sandy beach with coral rubble to the south; Small vegetated sand dunes	Fringing reefs down to 2.2 m depth.
Manoli (25)	Narrow sandy beach, coral rubble on the South and Southeastern side, sand dunes vegetated in the central part of the island	Fringing reefs to 2.2 m with patch reefs to the north
Hare (25)	Coral rubble along the South, Southeastern and Southwestern side; sand dunes with vegetation; depression on the western side of the island filled with water during high tide.	Fringing reef extends to 2.2 m depth; two patch reefs to the northwest 3 m deep
KEEZHAKKARAI GROUP		
Mulli (15)	Broad sandy beach with coral rubble on the southern windward side; vegetated coastal dunes	Fringing reef extends to 3.5m with patch reefs to the southeast and south at 2.9m and 3.2m.
Valai (11)	The Island is an extension of Thalayari Island. A submerged small sand patch separates the islands. Narrow sandy beaches with coral rubble along the southeast and south sides	Limited fringing reefs to 2.9 m
Thalaiyari (18)	Narrow, sandy beach to the North; beach erosions evident; coral rubble to the south; a depression on the western side is filled with water during high tide.	Fringing reefs extending to 2 m depth
Appa (18)	Narrow sandy beach, coral rubble on the northeast to southeast (windward) side; small sand dunes with vegetation on the island.	Fringing reef extends to 3.2 m with patch reefs to the southeast and northwest side at 3.5m.
Poovarasan-patti (14)	Continuous coral mining has made this island completely submerged, 1 m below the mean sea level.	Discontinuous patch reefs found up to 2.5 m depth
Valimunai (25)	Narrow sandy beach, coral rubble to the south and southeast	Fringing reef to 2.5 m depth; patch reef to the southeast at 3.4 m depth.
Anaipar (12)	Narrow sandy beach, coral rubble on the windward southeast and northeast sides, small sand dunes with extensive vegetation.	Fringing reef extends to 2.8 m.
VEMBAR GRUOP		
Nallathanni (20)	Low and narrow beaches, straight on the northwest and northeast side and more irregular elsewhere; coral rubble to the southwest, southeast and northeast, sand dunes with vegetation on the western side with a height of 8 m.	Fringing reef to a depth of 3 m and small patch reefs to the south side down to 3.9m depth
Pulivinichalli (12)	Low and narrow sandy coast, coral rubbles on the south and southeast sides, sand dunes with 0.5 m height on the central part of the island.	Fringing type, extends up to a depth of 2.5 m and patch reefs on the south side at 3.2 m depth.
Upputhanni (16)	Low and broad sandy shores to the northwest and northeast, with narrow rubble beaches to the southwest and southeast; large depression on the southern side of the island fills with water during high tide.	Fringing reef extends to 2.8 m depth with patch reefs to the south and west at 3 m and 3.5 m depths.

fishing intensity can be observed. It has been estimated that the degraded reef areas around the 21 islands is about 32 km^2 (Patterson et al., 2007).

Destructive fishing

Traditional fishers who make up the majority population along GoM have increased in numbers during the last decades. Crowded fishing grounds, increasing demand for fisheries products, and declining catches deprive artisanal as well as industrial fishermen and their families their livelihoods and food security (Deepak et al. 2002, Bavinck, 2003). The fisher communities of GoM are characterized by low literacy, lack of awareness of environmental issues, and low income. There is also reluctance among fisher folk to take up livelihood options other than fishing, which has led to a proliferation of destructive and unsustainable fishing practices, such as shore seining, purse seining and push net fishing, dynamite fishing and cyanide fishing, all of which are illegal in coral reefs areas.

Destructive trawling using indigenously fabricated gears, such as bottom trawl nets with mesh sizes below 10 mm fitted with rollers (roller madi), kara valai (shore seine), pair trawler madi (two boats operating a trawl), sippi valai (modified gill net with more weight on the bottom to catch crabs, lobsters, mollusks and certain demersal fishes) and push net operations are in practice in some parts of GoM. These activities completely sweep the seafloor, deplete the fish stocks, and cause damage to critical habitats, such as corals reefs and seagrass beds (Bavinck, 2003, Patterson et. al., 2007). Cyanide is used to catch reef fishes, in particular groupers, which fetch high market prices, and ornamental fishes like clownfish, dottybacks, damsels, and surgeons. A small section of fishermen are also involved in dynamite fishing, targeting shoaling fishes. Lastly, physical damage to reefs while collecting seaweeds, in particular *Gelidiella acerosa* growing in coral reef areas, as well as retrieving lobster and fish traps on reefs, add considerable impact to the coastal ecosystem, especially in the northern part of the GoM.

Coral mining

Coral has traditionally been collected from the seabed for use in construction or as raw material for the lime industry, as well as for ornamental purposes. For a long time the collection of corals did not pose an obvious threat to the resource as there were large reef areas in good condition in the Gulf of Mannar. However, gradually with increasing populations, the extraction of coral became too intensive and deterioration of reefs obvious. In the early 1970's it was estimated that the exploitation of corals was about 60,000 cubic meters (about 25,000 metric tonnes) per annum from Palk Bay and GoM together (Mahadevan and Nayar, 1972). As a consequence the Tamil Nadu government declared Gulf of Mannar Marine National Park in 1986. However, coral mining continued illegally. By the turn of the millennium, two islands (Poovarasanpatti and Vilanguchalli) had been submerged due to excessive mining and the resulting erosion. Erosion has also been observed on several other islands, including Vaan, Koswari and Kariyachalli. The inclusion of corals in the Wildlife Protection Act, in 2001 (the federal government included all Scleractinia, Antipatharia, *Millipora* sp., gorgonians and *Tubipora musicum* under schedule I of the Wildlife (Protection) Act, 1972, which prohibits collection, possession and trade) was instrumental in reducing the illegal mining by over 75% due to stringent enforcement. All the same a group of poor fishermen continued with the coral mining activity, with the highest number of boats involved in mining during the lean fishing season. The Indian Ocean tsunami, however, made a change in the minds of fishermen, who attributed protection of their villages from the tsunami to the presence of corals reefs and islands. Therefore, the majority of them voluntarily stopped the coral mining activity, particularly on the Tuticorin coast, and today only sporadic mining incidents are reported.

Land-based pollution

Increasing industrialization has also added stress to the coastal marine ecosystem, comparatively more so on the Tuticorin coast, e.g. with the discharge of untreated or partially treated effluents. At present, the major sources of pollution include a fertilizer plant, a thermal power generation plant, and the Dharangadhare Chemical Works Ltd (DCW). Acid wash from shell craft industries and, more importantly, solid wastes and wastewater from ice plants and seafood processing centers have also caused localized pollution (Easterson, 1998).

The 210 MW Tuticorin Thermal Power Station burns up to 2800 tons of coal/day, producing an estimated 560 – 700 tons of ash per day. 750 m^3 of seawater, used to cool the turbines, is discharged into the Tuticorin Bay every hour. The discharged "slurry" is noted from a distance of over half a kilometer away, with a thickness varying from 6 – 70 cm (Easterson, 1998). Though there is little variation in the salinity, pH and the dissolved oxygen content, increased levels in nitrite (0.4 – 0.84 µg N/ l) and silicate (17.6 – 19.8 µg Si/ l) were recorded by Easterson et al., (2000). The discharged seawater is usually 2 – 4º C above the ambient level and can be experienced up to 2 kilometers away (Easterson et al, 2000).

The National Institute of Oceanography (1991) reported that, compared to other coastal regions in Tamil Nadu, Tuticorin is highly contaminated with metals (levels of Cadmium were between 0.4 – 2 µg/l, copper 4 – 5 µg/ l, lead 2 – 7.8 µg/l and mercury 0.1 – 0.12 µg/l). Copper and zinc are also found in high concentrations in seaweeds in the Tuticorin region (Ganesan, 1992). Elevated levels of metals like zinc, iron, copper and lead (> 100 ppb) were recorded among edible gastropod species in the Gulf of Mannar, including *Melo melo*, *Babylonia spirata*, *Hemifusus pugilinus*, *Xancus pyrum* and *Rapana rapiformis*, by Patterson et al., (1997).

While the Tamil Nadu Pollution Control Board together with the industry are making efforts to minimize the effluent discharge from industries, the problems with municipal sewage disposal into the coastal environment are creating a growing challenge. There are several sewage disposal points in the vicinity of coral reef areas, now a major cause for coral reef degradation. The highest sewage production occurs in the Tuticorin region, with elevated biological oxygen demand when compared to the other areas in the Gulf of Mannar, such as Rameswaram, Keelakarai and Mandapam (Ramachandran et al., 1989).

The GoM also faces sedimentation from numerous sources, including monsoonal run off, sewage disposal, industrial discharge, coastal development, etc. The destructive fishing methods used in the area also cause considerable resuspension of sediment. Based on visual observations during close to a decade of diving and surveying in the area, it appears as if sediment loads are increasing (Patterson et.al., 2007). At present, two islands (Kurusadai and Manola islands, and the Harbor patch reef were measured with mean sedimentation rates of 60-72 mg/cm2/day, with most other locations having means ranging from 29-50 mg/ cm2/day (Patterson et.al., 2007).

Major perturbations

During 1998, a significant rise in surface water temperature in the Indian Ocean, as a result of the 1997/98 El Niño Southern Oscillation (ENSO) event (see for example Wilkinson et al. 1999) caused coral reefs over the entire Indian Ocean to bleach. Though bleaching was experienced in Gulf of Mannar (Venkataraman, 2000), subsequent studies in Tuticorin in the southern part of Gulf of Mannar showed little sign of impact of the event (Patterson et al., 2003). The Indian Ocean Tsunami 2004 had no significant impact on the coral reefs of the Gulf of Mannar, nor on associated habitats and resources, apart from some minor transitional damages (Patterson et.al., 2006).

In spite of the obvious and major threats to the coral reefs of the Gulf of Mannar, and to the people that depend on these reefs for a livelihood, available data on reef and resource status is largely piecemeal and not comprehensive. This study was carried out to establish a baseline for the coral reefs of the Gulf of Mannar.

METHODS

Coral Status

Surveys were conducted in all reef areas around the 21 islands between Rameswaram and Tuticorin, from January 2003 to October 2005, to assess the coral status, diversity, abundance and distribution. The duration of the baseline survey was long due to long distances and difficult access to some islands, rough weather conditions for 6 months of the year, and repeated surveys after the Indian Ocean tsunami.

Reefs were mapped using the Manta Tow technique (Done *et al.* 1982), based on which representative sites were selected. Line Intercept Transect (LIT) was used to assess the sessile benthic community of the coral reefs (English *et al.* 1997). 20m transects were laid randomly, at fixed depths at each site (1m-6m) and parallel to the depth contours, based on which the percentage cover of each life form category was calculated. In total 374 transects were recorded, with 11-25 transects per island depending on the size of the reefs..

The plant and animal community was characterized using life form categories, which provide a morphological description of the reef community. Reef condition was assessed based on coral cover, as described by Gomez and Yap (1988), whereby 75-100% live coral cover is “Excellent”; 50-74.9% “Good”; 25-49.9% “Fair”; and 0-24.9% “Poor”.

Reef Associated Fishes

The reef fish composition was estimated using under water visual census in 30m long and 6m wide transects (Fowler, 1987, and English et al.,1994). Surveys were carried out in July and October 2004, and January and April 2005. A total of 109 transects were recorded at eleven randomly selected islands in the four island groups. Fish counts started 5-10 minutes after transects had been laid to reduce disturbance caused by the diver.

Fish abundance was recorded using 7 classes (1; 2-5; 6-10; 11-20; 21-50; 51-100 ;> 100 individuals per transect). The abundance of each species was described in this study by two indices: Relative Abundance (RA; the pooled number of individuals of a given species from all censuses/total number of individuals x 100) and Frequency of Appearance (FA; the number of censuses in which a given species/total number of censuses was noted x 100) for all sites (Alevizon and Brooks, 1975). Species diversity was assessed using the Shannon diversity index (H’) in natural logarithms. Species richness (S’) and evenness (J’) were also calculated using the statistical software Biodiversity Pro (ver.2). Cluster analysis based on Bray-Curtis similarity measures was performed in order to examine similarity between study sites. Fish were divided into trophic groups using literature data (Allen, 1985; Myers, 1989; Russ, 1989).

Correlation between fish and habitat parameters were studied by means of Spearman rank correlation (Conover 1980, Sokal & Rohlf 1995) using the statistical software Biodiversity Pro (ver.2).

RESULTS

Status of Coral Reefs

The average live coral cover in GoM is 35%, with a cover of 37% in the Mandapam Group; 44% in the Keezhakkarai Group; 32% in the Vembar Group; and 29% in the Tuticorin Group. Table 2 provides details of reef status in GoM Island groups and Appendix 1 contains an updated check-list of corals.

Reef Associated Fishes

A total of 50 fish species in 27 families were recorded using UVC in the 4 island groups (see species list, Appendix 2). In the Tuticorin group the most abundant species recorded were *Lutjanus* sp (RA 8.01%), *L. russelli* (RA 7.43%), *Carangoides malabaricus* (RA 7.945), *Siganus javus* (RA 8.58%), and *Cryptocentrus* sp (RA 8.58%). *Arothron mappa* had the lowest relative abundance and the frequency appearance was below 25%. In the Vembar group commercially important species such as *Lutjanus russelli* and Siganus *javus* had the highest RA, of 8.11% and 8.72% respectively, and a 100% frequency

Table 2. Status of coral reefs in the Gulf of Mannar (CC - Live Coral Cover; DCA - Dead Coral with Algae; DC – Dead Coral).

Variables		Condition	Major Threats	Diseases
Mandapam Group				
Coral reef area (km²)		Fair – Shingle, Krusadai , Pullivasal, Poomarichan, Manoliputti, Manoli, Hare	Destructive fishing (Bottom trawling & bottom gill net); Seaweed collection; Lobster trap operation; Shell collection; Holothurian collection; Sewage disposal	Yellow blotch, Black band, White band, Red band, Aspergillosis and Pink blotch
CC&DCA	22.6			
DC	8.5			
DCA	11.4			
Total	42.5			
Coral cover (%)				
CC	36.5±8.3			
DCA	22.1±9.7			
Keezhakkarai group				
Coral reef area (km²)		Fair - Mulli, Valai, Thalaiyari, Poovarasanpatti, Anaipar, Valimunai Good - Appa	Destructive fishing (Bottom trawling, shore sine operation & bottom gill net operation); Seaweed collection; Holothurian collection; and Sewage disposal.	Black Band, Yellow Blotch, White Band, and Red Band
CC&DCA	20.4			
DC	6.7			
DCA	--			
Total	27.1			
Coral cover (%)				
CC	43.6±11.1			
DCA	15.7±5.5			
Vembar group				
Coral reef area (km²)		Poor - Nallathanno Good - Pulivinichalli Fair - Upputhanni	Destructive fishing (Bottom trawling & shore seine operation); Holothurian collection; and Seaweed collection	Black Band, White Pox, Red Band, Yellow Blotch Aspergillosis
CC&DCA	12			
DC	10.7			
DCA	--			
Total	12			
Coral cover (%)				
CC	32.0±24.1			
DCA	48.9±16.2			
Tuticorin group				
Coral reef area (km²)		Fair – Kariyachalli, Vaan Poor - Vilanguchalli Poor - Koswari	Coral mining; Sewage disposal; and Destructive fishing (Bottom trawling)	Black Band, White Band, Red Band and Yellow Blotch
CC&DCA	10.9			
DC	7.5			
DCA	--			
Total	18.4			
Coral cover (%)				
Live coral	29.8±13.4			
DCA	7.8±1.3			

of appearance. Other common species recorded included *Carangoides malabaricus*, *Pempheris* sp. and *Parapericanthus* sp. In the Keezhakkarai group the highest relative abundance was recorded in *Lutjanus* sp. (8.77%), *L. russelli* (8.41%), *Carangoides malabaricus* (8.32%), *Siganus javus* (RA-7.69%) and *Cryptocentrus* sp. (RA-7.5%). In the Mandapam group, the highest relative abundance was found in *Pempheris* sp. and *Cryptocentrus* sp. (8.26%), with commercially important species such as *Lutjanus russelli* and *Carangoides malabaricus* also common. Lethrinidae, Lutjanidae, Siganidae, Chaetodontidae,

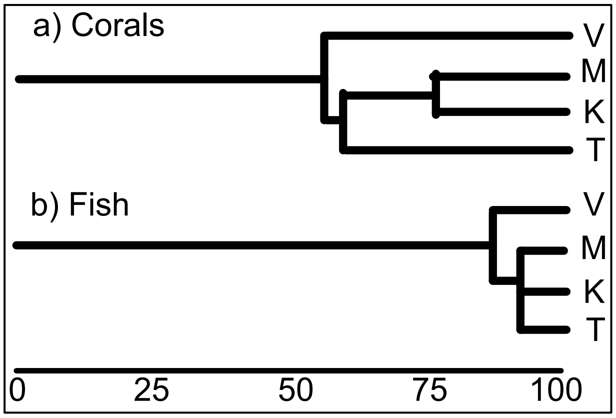

Figure 2. Dendogram of similarity between a) live coral cover and b) fish assemblages between the four island groups: Tuticorin (T), Vembar (V), Keezhakkarai (K) and Mandapam (M).

Ephippidae, Gerreidae, Pempherididae and Gobiidae had a frequency of appearance of 100%.

Community Indices

Only minor variation in community indices was observed, with the highest Shannon diversity index (H') of 1.60 and species richness (S) of 49.30 recorded in the Vembar group. The Tuticorin group showed the lowest H' (1.55) while the Keezhakkarai group showed the lowest S (48.0). No variation in evenness (J' = 0.97) was observed between island groups.

Cluster Analysis

Cluster analyses was applied to benthic cover and fish assemblage data (Fig. 2). The coral community was most similar (75%) between the Keezhakkarai and Mandapam groups, with the Vembar group most dissimilar from the other three (56% similarity). Fish assemblages were much more uniform with the highest similarity between Tuticorin, Keezhakkarai and Mandapam groups of islands (92%), and 88 % similarity between these and Vembar

Correlations

A summary of correlations between fish community variables (total abundance, species richness, Shannon

Table 3. Summary of correlations between fish community and coral habitat variables (significant levels are given as $p < 0.05^*$ and $p < 0.01^{**}$).

	Live coral cover	*Acropora*	Non-*Acropora*	Dead coral cover	Coral rubble	Sand
Total abundance	-0.76 **	-0.29	-0.21	-0.30	-0.50 *	-0.06
Species richness	0.27	0.23	0.06	0.58 *	-0.90 **	0.05
Shannon diversity	0.11	0.81 **	-0.47	0.98 *	-0.54 *	0.65 *
Invertebrate feeders	-0.35	0.77 **	-0.78 **	0.46	0.53 *	0.83 **
Piscivores	-0.04	-0.51 *	0.27	-0.78 **	0.87 **	-0.37
Herbivores	0.63 **	-0.19	0.55 *	0.21	-0.70 **	-0.41
Planktovires	-0.97 **	0.07	-0.62 **	-0.23	0.12	0.37
Omnivores	0.51 *	0.38	0.08	0.71 *	-0.67 **	0.13
Corallivoris	0.42	0.68 **	-0.27	0.61 *	0.44	0.52 *

diversity and trophic groups) and habitat variables (live coral cover, *Acropora*, non-*Acropora*, dead coral cover, coral rubble, and sand) from the reef areas is shown in Table 3. Among the habitat variables, only live coral cover was highly correlated with total fish abundance (though negatively), with coral rubble and species richness also showing significant correlation.

Shannon diversity of the fish population was significantly correlated with habitat variables such as coral cover, *Acropora*, dead coral cover, and sand. The habitat variables *Acropora*, non-*Acropora*, coral rubble, and sand were significantly correlated with invertebrate feeders. Piscivores showed significant correlation with non-*Acropora* and coral rubble, while herbivores showed significant correlation with live coral cover, non-*Acropora* and dead coral cover. Omnivores were found to be significantly correlated with habitat variables live coral cover, *Acropora*, non-*Acropora*, dead coral cover, and sand. Significant correlation was observed between corallivores and all habitat variables except non-*Acropora*.

DISCUSSION

There are numerous reports on the coral reefs and associated resources of the Gulf of Mannar, however predominantly from the Mandpam coast and on taxonomic aspects (Pillai, 1971, 1972, 1977, 1986, 1994 and 1996), and more comprehensive baseline information on the area has been lacking. This study adds to the pool of knowledge on the reefs of the Gulf of Mannar, in view of increasing stress on this ecosystem and in support of conservation and management efforts by state and federal governments and other organizations.

The study found fringing and patch reef common in all islands of the Gulf of Mannar. Keezhakkarai group has the highest percentage of healthy live coral cover, followed by Mandapam, Vembar and Tuticorin groups. The dominant coral species in Gulf of Mannar are *Acropora cytherea*, *A. formosa*, *A. nobilis*, *Montipora digitata*, and *Porites* sp., while *Echinopora lamellosa* and *Pocillopora damicornis* are commonly present in Keelakarai and Mandapam groups respectively. Recruit density, predominantly *Pocillopora* sp., *Montipora* sp., and *Acropora* sp, has increased by about 10-15% in each island since the Indian Ocean tsunami in 2004. Coral diversity has been highly affected by coral mining, which has also led to change in habitat and abundance of reef associated species.

However, in spite of being so vital for the local population, reef fish communities in the Gulf of Mannar are the least studied part of the ecosystem. Reef fishes are strongly influenced by the structure of their habitat, with more complex coral reefs generally supporting more fish (e.g. Sedberry and Certer, 1993; Nagelkerken et al., 2000, and Mateo & Tobias, 2001). Results presented herein indicate higher reef fish species richness in areas with high cover of live coral, as well as areas with dead standing coral with algal growth. This shows that habitat variables play a substantial role in the enhancement of fish diversity. Fish-habitat correlations from various regions (Caribbean, Southeast Asia and Great Barrier Reef) show significant relationship between structural complexity and reef fish diversity (Risk, 1972, Luckhurst & Luckhurst 1978, Carpenter et al., 1981, McCormick, 1994). Distribution patterns of reef fishes have been related to available shelter and food (Williams 1991, Sheppard et al., 1992, Ohman et al., 1993). Refuges may positively influence prey abundance (Hixon and Beets 1993) and the smaller reef fishes rely on branching corals for protection (Sale 1972). Herbivores feed primarily on filamentous algae that grow with a high turnover rate mainly in the shallows between coral colonies and among coral branches (Borowitzka, 1981, Scott and Russ 1987, Choat 1991).

The corals reefs in the GoM grow in an area of chronic sediment supply and resuspension, with the amount of suspended sediment largely controlled by local wind and tidal conditions, as well as water flushing. Sedimentation is high in coastal waters around almost all the islands, with mean rates from 20-70 $mg/cm^2/day$ at all sites measured. Sedimentation rates are high during August because of strong winds in June and July due to the southwest monsoon causing resuspension. In January the calm weather of the northeast monsoon tends to decrease turbidity and sedimentation. The reef biota is accustomed to these local conditions and to the natural variability in the system. In spite of the high rate of sedimentation at Krusadai Island, its reef community appears healthy and diverse, and overall the coral reefs of the Gulf of Mannar presently seem to be in relatively good condition with respect to sedimentation (Patterson et. al., 2007), although some corals with a wide table like shape, e.g. *Acropora cytherea*, tend to trap sediment particles and at times shows signs of stress and bleaching. However, in general, the turbidity and sedimentation regime of the area is believed to be one of the factors limiting reef development, and a possible increase in sediment loads from land is a cause for concern. Krusadai Island, located very close to the mainland, and Manoli Island in the vicinity of a fishing harbor, experience high sedimentation. Boat traffic and port operations may explain high sedimentation at the patch reef close to the mainland and Tuticorin Harbour. The high sedimentation rate around Vaan Island is probably caused by the sewage outlet in Threspuram village (Patterson et al., 2007).

The Gulf of Mannar coral reef ecosystem is stressed because of its proximity to the mainland and coastal populations, urban centres and activities. However, although people once injudiciously exploited and damaged the reefs and associated resources, the necessity for conservation and management for sustainable utilization has become more widely understood in the recent past, providing an opportunity for management and sustainable use of the area. The present average coral cover of 35% in the Gulf of Mannar is to an extent due to the enforcement of illegal coral mining activities before the tsunami. The tsunami itself, although not impacting the reefs directly, made coastal dwellers more aware of the broader benefits of coral reefs and marine and coastal ecosystems in general. There are also several research institutes and non-governmental organizations involved in awareness creation and introduction of alternative livelihood schemes to reduce the pressure of fishing, the impacts of which have been evident in the aftermath of the tsunami. Presently, the Gulf of Mannar Biosphere Trust, which was set up to implement a GEP-UNDP project on biodiversity conservation in the Gulf of Mannar, is also actively involved in awareness campaigns, capacity building for alternative livelihood options, participatory eco-development initiatives and collection of baseline information on various resources. The information on reef distribution, diversity, status, fish assemblages and rate of sedimentation provided herein has strengthened this development, and will support further management and conservation.

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APPENDIX 1 – SCLERACTINIAN CORALS.

Coral fauna of southeast coast of India including Gulf of Mannar and Palk Bay (References: Pillai, 1986, Patterson *et al.*, 2005 and Patterson *et al.*, 2007).

No. of Genera	40
No. of Families	14
No. of species	117
Hermatypic	
Genera	30
Species	106
Ahermatypic	
Genera	10
species	11

*Recorded by: * Pillai, 1986; ** Patterson et al., 2005; ***Patterson et al., 2007*

Family : POCILLOPORIDAE Gray, 1842
1. Genus: POCILLOPORA Lamarck, 1816
Pocillopora damicornis (Linnaeus, 1758) *
Pocillopora verrucosa (Ellis and Solander, 1786) *
Pocillopora eydouxi Milne Edwards and Haime, 1860 *
2. Genus: MADRACIS Milne Edwards and Haime, 1849
Madracis interjecta v. Marenzeller, 1906 *
(= *Madracis kirbyi*, Veron and Pichon, 1976)
Family : ACROPORIDAE Verrill, 1902
3. Genus: ACROPORA Oken, 1815
Acropora formosa (Dana, 1846) *
Acropora intermedia (Dana, 1846) **
Acropora valenciennesi (Milne Edwards and Haime, 1860) *
*A. microphthalma (Verrill, 1869)**
Acropora sp.novo **
Acropora corymbosa (Lamarck ,1816) *
Acropora nobilis (Dana, 1846) *
Acropora humilis (Dana, 1846) *

Acropora valida (Dana, 1846) *
Acropora hemprichi (Ehrenberg, 1834) **
Acropora hyacinthus (Dana, 1846) *
Acropora stoddarti Pillai and Scheer, 1976 **
Acropora indica (Brook, 1893) *
Acropora millepora (Ehrenberg, 1834) *
Acropora diversa (Brook, 1893) *
Acropora brevicollis (Brook, 1893) *
Acropora cytherea (Dana, 1846) *
Acropora hebes (Dana, 1846) ***
Acropora echinata (Dana, 1846) ***
Acropora nasuta(Dana, 1846) ***
Acropora abrolhosensis (Veron, 1985) ***
Acropora pillaii sp. nov **
4. Genus: MONTIPORA de Blainville, 1830
Montipora subtilis Bernard, 1897 *
Montipora digitata (Dana, 1846) *
Montipora divaricata Bruggemann, 1897 *
Montipora venosa (Ehrenberg, 1834) *
Montipora spumosa (Lamarck, 1816) *
Montipora tuberculosa (Lamarck, 1816) *
Montipora monasteriata (Forskal, 1775) *
Montipora jonesi Pillai, 1986 *
Montipora granulosa Bernard, 1897 *
Montipora exserta Quelch, 1886 *
Montipora turgescens Bernard, 1897 *
Montipora manauliensis Pillai, 1969 *
Montipora verrucosa (Lamarck, 1816) *
Montipora hispida (Dana, 1846) *
Montipora foliosa (Pallas, 1766) *
Montipora verrilli Vaughan, 1907 *
Montipora aequituberculata Bernard, 1897 ***
Montipora sp. Novo ***
5. Genus: ASTREOPORA de Blainville, 1830
Astreopora myriophthalma (Lamarck, 1816) *
II Suborder : FUNGIINA Verrill, 1865
Super family : AGARICIICAE Gray, 1847
Family : AGARICIIDAE Gray, 1847
6. Genus: PAVONA Lamarck, 1801
Pavona duerdeni Vaughan, 1907 *
Pavona varians (Verrill, 1864) *
Pavona decussata (Dana, 1846) *
Pavona divaricata Lamarck, 1816 (= *P.venosa*) *
7. Genus : PACHYSERIS Milne Edwards and Haime, 1849
Pachyseris rugosa (Lamarck, 1801) *
Family : SIDERASTREIDAE Vaughan and Wells, 1943
8. Genus : SIDERASTREA de Blainville, 1830
Siderastrea savignyana Milne Edwards and Haime, 1850 *
9. Genus : PSEDOSIDERASTREA Yabe and Sugiyama, 1935
Psedosiderastrea tayami Yabe and Sugiyama, 1935 *
10. Genus: COSCINARAEA Milne Edwards and Haime, 1849
Coscinaraea monile (Forskal, 1775) **
11. Genus : PSAMMOCORA Dana, 1846
Psammocora contigua (Esper, 1797) *
Super family : FUNGIICAE Dana, 1846
Family : FUNGIIDAE Dana, 1846
12. Genus: CYCLOSERIS Milne Edwards and Haime, 1848
Cycloseris cyclolites (Lamarck, 1801) *
Super family : PORITICAE Gray, 1842
Family : PORITIDAE Gray, 1842
13. Genus: GONIOPORA de Blainville, 1830
Goniopora stokesi Milne Edwards and Haime, 1851 *
Goniopora planulata (Ehrenberg, 1834) *
Goniopora minor Crossland, 1952 **
Goniopora stutchburyi Wells, 1955 (*Goniopora nigra*, Pillai,1969) *
Goniopora sp. novo ***
14. Genus: PORITES Link, 1807
Porites solida (Forskal, 1755)
Porites mannarensis Pillai, 1969 *
Porites lutea Milne Edwards and Haime, 1851 *
Porites lichen Dana, 1846 *
Porites exserta Pillai, 1969 *
Porites compressa Dana 1846 *
Porites complanata ***
Porites nodifera ***
III Suborder : FAVIINA Vaughan and Wells, 1943
Super family : FAVIICAE Gregory, 1900
Family : FAVIIDAE Gregory, 1900
15. Genus: FAVIA Oken, 1815
Favia stelligera (Dana, 1846) *
Favia pallida (Dana, 1846) *
Favia speciosa (Dana, 1846) *
Favia favus (Forskal, 1775) *
Favia valenciennesi (Milne Edwards and Haime, 1848) *
(= *Montastrea valenciennesi*)
Favia matthaii Vaughan, 1918 **
16. Genus: FAVITES Link, 1807
Favites abdita (Ellis and Solander, 1786) *
Favites halicora (Ehrenberg, 1834) *
Favites pentagona (Esper, 1794) *
Favites melicerum (Ehrenberg, 1834) *
Favites complanata (Ehrenberg, 1834) *
Favites flexuosa (Dana, 1846) **

17. Genus: GONIASTREA Milne Edwards and Haime, 1848
Goniastrea pectinata (Ehrenberg, 1834) *
Goniastrea retiformis (Lamarck, 1816) *
18. Genus: PLATYGYRA Ehrenberg, 1834
Platygyra daedalea (Ellis and Solander, 1786) *
Platygyra sinensis (Milne Edwards and Haime, 1849) *
Platygyra lamellina (Ehrenberg, 1834) *
Platygyra sp. Novo ***
19. Genus: LEPTORIA Milne Edwards and Haime, 1848
Leptoria phrygia (Ellis and Solander, 1786) *
20. Genus: HYDNOPHORA Fischer de Waldheim, 1807
Hydnophora microconos (Lamarck, 1816) *
Hydnophora exesa (Pallas, 1766) *
Subfamily : MONTASTREINAE Vaughan and Wells, 1943
21. Genus: LEPTASTREA Milne Edwards and Haime, 1848
Leptastrea transversa Klunzinger, 1879 *
Leptastrea purpurea (Dana, 1846) *
22. Genus: CYPHASTREA Milne Edwards and Haime, 1848
Cyphastrea serailia (Forskal, 1775) *
Cyphastrea microphthalma (Lamarck, 1816) *
*Cyphastrea japonica ****
23. Genus : ECHINOPORA Lamarck, 1816
Echinopora lamellosa (Esper, 1795) *
24. Genus : PLESIASTREA Milne Edwards and Haime, 1848
Plesiastrea versipora (Lamarck, 1816) *
Family : RHIZANGIIDAE d'Orbigny, 1851
25. Genus: CULICIA Dana, 1846
Culicia rubeola (Quoy and Gaimard, 1833) *
Family : OCULINIDAE Gray, 1847
26. Genus: GALAXEA Oken, 1815
Galaxea fascicularis (Linnaeus, 1767) *
Galaxea astreata (Lamarck, 1816) (= *G. clavus*) *
Family : MERULINIDAE Verrill, 1866
27. Genus: MERULINA Ehrenberg, 1834
Merulina ampliata (Ellis and Solander, 1786) *
Family : MUSSIDAE Ortmann, 1890
28. Genus: ACANTHASTREA Milne Edwards and Haime, 1848
*Acanthastrea echinata ****
29. Genus: Lobophyllia de Blainville, 1848
Lobophyllia corymbosa (Forskal, 1775) ***
30. Genus: SYMPHYLLIA Milne Edwards and Haime, 1848
Symphyllia radians Milne Edwards and Haime, 1849 *
Symphyllia recta (Dana, 1846) *
Family : PECTINIIDAE Vaughan and Wells, 1943
31.Genus : MYCEDIUM Oken, 1815
Mycedium elephantotus (Pallas, 1766) *
IV Suborder : CARYOPHYLLIINA Vaughan and Wells, 1943
Family : CARYOPHYLLIIDAE Gray, 1847
Subfamily : CARYOPHYLLIINAE Gray, 1847
32. Genus: POLYCYATHUS Duncan, 1876
Polycyathus verrilli Duncan, 1876 *
33. Genus: HETEROCYATHUS Milne Edwards and Haime, 1848
Heterocyathus aequicostatus Milne Edwards and Haime, 1848 *
34. Genus: PARACYATHUS Milne Edwards and Haime, 1848
Paracyathus profundus Duncan, 1889 *
V Suborder : DENDROPHYLLIINA Vaughan and Wells, 1943
Family : DENDROPHYLLIIDAE Gray, 1847
35. Genus: BALANOPHYLLIA Searles Wood, 1844
Balanophyllia affinis (Semper, 1872) *
36. Genus: ENDOPSAMMIA Milne Edwards and Haime, 1848
Endopsammia philippinensis Milne Edwards and Haime, 1848 *
37. Genus: HETEROPSAMMIA Milne Edwards and Haime, 1848
Heteropsammia michelini Milne Edwards Haime, 1848 *
38. Genus: TUBASTREA Lesson, 1834
Tubastrea aurea (Quoy and Gaimard, 1833) *
39. Genus: DENDROPHYLLIA de Blainville, 1830
Dendrophyllia coarctata Duncan 1889 *
Dendrophyllia indica Pillai, 1969 *
40. Genus : TURBINARIA Oken, 1815
Turbinaria crater (Pallas, 1766) *
Turbinaria peltata (Esper, 1794) *
Turbinaria mesenterina (Lamarck, 1816) (= *T. undata*) *

New records in Gulf of Mannar (Patterson *et al.*, 2007)
Acropora hebes
Acropora echinata
Acropora nasuta
Acropora abrolhosensis
Montipora aequituberculata
Montipora sp. novo
Goniopora sp. novo

Porites complanata
Porites nodifera
Platygyra sp. novo
Cyphastrea japonica
Acanthastrea echinata
Lobophyllia corymbosa

APPENDIX 2 – FISH

Lethrinidae
Lethrinus nebulosus
L. harak
Lutjanidae
Lutjanus sp
Lutjanus fulviflamma
Lutjanus russelli

Carangidae
Carangoides malabaricus
Carangoides ferdau
Caranx sp

Serranidae
Epinephelus coioides
Epinephelus malabaricus
E. areolatus
Cephalopholis miniata
Cephalopholis formosa
Cephalopholis sp

Siganidae
Siganus canaliculatus
Siganus javus

Scaridae
Scarus ghobban
Scarus sp

Holocentridae
Sarcocentron rubrum
Sarcocentron spiniferum

Mullidae
Upeneus sp
Parupeneus indicus

Haemulidae
Pomacanthus sp
Acanthorus sp
Plectorchinchous sp

Chaetodontidae
Chetodon sp
Heniochus diphecuts
Heniochus sp

Ephippidae
Platax sp
Amphiprion sebae

Terapontidae
Terapon jarbua

Tetraodontidae
Canthigaster solandri
Arothron mappa

Narcinidae
Narcine timlei

Centropomidae
Psammoperca waigensis

Labridae
Halichoeres sp
Thalassoma sp

Acanthuridae
Acanthurus dussumieri
A. xanthopterus

Ostraciidae
Ostracion cubicus

Gerreidae
Gerres filamentosus

Leiognathidae
Leiognathus sp

Platycephalidae
Platycephalus indicus

Sphyraenidae
Sphyraena genie

Plotosidae
Plotosus lineatus

Scorpaenidae
Pterois volitans

Pempherididae
Pempheris sp
Parapriacanthus sp

Gobiidae
Cryptocentrus sp

Nemipteridae

Status and Recovery of the Coral Reefs of the Chagos Archipelago, British Indian Ocean Territory

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ABSTRACT

Surveys of reef benthos and hard coral recruits were carried out between February and March 2006 at 19 reef sites in 5 atolls of the archipelago. Results showed that all atolls appear to have shown strong recovery in terms of benthic cover after the 1998 bleaching and mortality event. Reef benthos composition varied greatly between survey sites, and highly significant differences in reef composition were recorded between different atolls, and between different depths at all atolls, showing considerable unevenness in recovery.

New coral recruitment is also strong, such that even the lowest of the Chagos recruit densities are an order of magnitude higher than the rates of recruitment of new corals documented at reefs in South Asia, the central Indian Ocean, and the East African Coast. Chagos recruitment is 6 m^{-2} to 28 m^{-2} compared to other reported values of 0.4-0.6 recruits m^{-2} elsewhere.

Despite observations of several subsequent shallow water bleaching events including a substantial, recent localised coral mortality at Egmont atoll within the previous year, evidence of archipelago-wide recovery of reef habitats as notable as this remains unrecorded elsewhere in the Indian Ocean. Significant gaps remain in current understanding of the number and scale of bleaching episodes that have taken place since the 1998 mass mortality event. Given the critical biogeographical role of Chagos in the Indian Ocean marine ecosystem, and the importance of the archipelago as a reference site for studying environmental change in the absence of direct anthropogenic interference, greater levels of long-term monitoring and ecological research are needed to better understand the responses and trajectory of recovery of the region's coral reef communities.

INTRODUCTION

Situated in the central Indian Ocean the Chagos archipelago has been largely uninhabited for approximately 35 years; four of its five islanded atolls remain uninhabited, while a military base exists on the southern atoll of Diego Garcia. The archipelago comprises a further 10 submerged atolls and banks, which together make up a network of reefs across 500 km x 200 km of ocean. Chagos reefs suffered very heavy mortality of corals and soft corals to at least 30m depth following the severe coral bleaching event of 1998, related to anomalously high sea surface temperatures caused by the El Niño Southern

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

Oscillation (ENSO) event (Sheppard 1999, Sheppard *et al.* 2002). Subsequent surveys showed that up to 100% of hard corals died at reef sites in all atolls studied, with shallow reefs particularly heavily impacted.

Whilst most other reef sites in the central and western Indian Ocean also experienced widespread bleaching as a result of this ENSO episode, the maximum depth of reef mortality in parts of the Chagos archipelago, particularly in central and southern atolls, extended deeper than most other locations in the region (Sheppard and Obura 2005). Heavy mortality which reduced previously thriving reef habitats to vast expanses of bare limestone extended to at least 30 m depth in the southern atolls. This may have been a result of the exceptionally clear oceanic water in the isolated archipelago, which enabled greater penetration of incident light. This was exacerbated by a prolonged period of calm seas throughout the 1998 bleaching episode, which led to less surface reflection of light and is likely to have enhanced warming of surface water (Sheppard 2006).

Fast growing corals, in particular *Acropora*, the most diverse and once often the most common genus on Indo-Pacific reefs, were particularly heavily impacted by the 1998 bleaching event, becoming a rare genus in many areas after the mass mortality. Populations of *A. palifera* were almost entirely eliminated from shallow reef areas in Chagos. This species was formerly the dominant shallow water coral in Chagos (Sheppard 1999), commonly forming widespread dense thickets between the surface and 4m depth. The expansive monospecific structures created in shallow reef areas by this species, once the central feature of shallow reef architecture, were almost entirely lost as a result of erosion in the aftermath of the mortality, lowering the height of some shallow reef surfaces by up to 1.5m (Sheppard 2002).

We have observed repeated, though mostly less severe, bleaching events throughout the archipelago in the intervening years. This is in common with many parts of the Indian Ocean where repeated bleaching and some further degree of mortality has been seen, for example in the Seychelles (Sheppard *et al.* 2005), central Maldives (C. Anderson pers. com.), in both Oman and Straits of Hormuz in both 2002 and 2004 (Wilson et al 2002), Rodrigues in 2002 and later (Hardman et al 2004), Mauritius in 2003 (Turner and Klaus 2005) to name some examples. Several further instances of moderate bleaching are reported in Wilkinson (2004) who notes varying degrees of severity from India to Africa, with some island groups being apparently more affected than some mainland areas. Some of the most severe subsequent events appear to have been in the granitic Seychelles where mortality of most juvenile corals has been recorded, in contrast to Chagos where corals appear to have recovered much better (Sheppard 2006). In view of the temperature patterns of the Indian Ocean (see later), further bleaching events are unsurprising. Recovery of the corals must therefore be viewed in the context of repeated setbacks, especially in shallow water, rather than being progressive or as a smooth succession from the very depleted state following 1998.

Chagos reefs, amongst the remotest in the Indo-Pacific, are almost entirely free of direct anthropogenic impacts. With the exception of low levels of illegal fishing on outer atolls and the effects of terrestrial military development on Diego Garcia whose impacts are very localized (Guitart et al 2007 and citations therein), climatic change and broad scale oceanic and meteorological disturbances currently represent the only serious threats to its coral reef health and ecosystem function. Global climate change models predict that the frequency and severity of anomalous ocean surface heating events will increase significantly over coming decades.

Understanding how coral reefs respond to thermal and natural stress in the absence of human disturbance is critical to advising coral reef management, which often focuses on minimising or removing direct human interference at a local level. Opportunities to record responses of coral reefs to climatic change in the absence of direct human pressures are, by comparison, rare. Owing to its geographical isolation

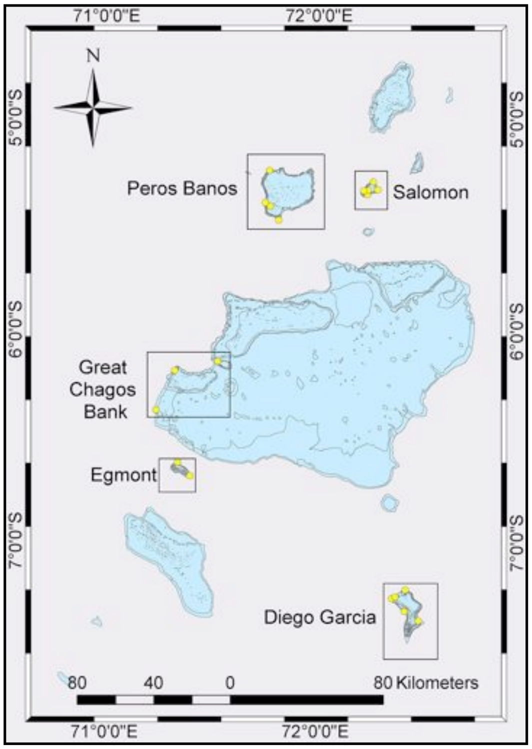

Figure 1. Location of atolls visited in this study, survey sites marked. In addition, lagoon sites were surveyed in the two northern atolls Peros Banhos and Salomon.

and current political status the Chagos archipelago provides an effective natural marine reserve and a natural 'control' site for monitoring specific responses and recoveries of coral reefs to natural disturbances and climate-related mass mortality events in the absence of local human impacts.

METHODS

All islanded atolls in the Chagos archipelago were surveyed for coral reef recovery. Surveys of reef benthos composition and hard coral recruit generic diversity and abundance were carried out by SCUBA diving between January and March 2006. Surveys were carried out at 19 reef sites visited in 5 atolls of the archipelago. From north to south the atolls visited were (with numbers of survey sites in brackets): Peros Banos (4), Salomon (5), Great Chagos Bank (3), Egmont (2) and Diego Garcia (5)

Surveys were carried out at up to three depths (5m, 15m and 25m) at each of these reef sites, which comprised 17 outer reef slopes and 2 lagoonal patch reefs. Survey sites included reefs studied by previous research expeditions to enable temporal comparisons of results, as well as previously unvisited sites, notably in Diego Garcia atoll. At each depth at each survey site up to 6 replicate 10m point intercept transects (PIT) were deployed to record biotic cover on the substrate.

Surveying of recruits was carried out by recording size and genus *in situ* of all hard coral recruits found within randomly placed $0.11m^2$ (33cm x 33cm) quadrats. Sampling was replicated up to 46 times at each of the three survey depths at each of the 19 sites across all the atolls. Recruit sizes were recorded in 10mm categories from 0-100mm, measured as total distance across the surface of each colony along the longest axis of the colony.

Analyses of benthic community composition matrices were carried out using non-metric Multi-Dimensional Scaling (MDS) ordinations based on Bray-Curtis dissimilarities of root transformed multivariate sample data. Transformation was used as a means of down-weighting the importance of highly abundant benthos and substrate types (such as scleractinia), so that community similiarities depended not only on their values but also those of less common ('mid-range') categories (such as alcyonidae). ANOSIM was used to identify significant differences between groups of samples defined by factors *a priori*, including depth, atoll and geomorphological class of reef. The same analytical procedure and factors were used to identify differences in hard coral recruit density and diversity (recruits per genus m^{-2}) between samples.

The SST monthly data used is HadISST1, from 1871 to 2006 inclusive (http://hadobs.metoffice.com/hadisst/). Nine cells cover Chagos, which are averaged here. The SST trend is shown as differences from the 1960-1989 mean value.

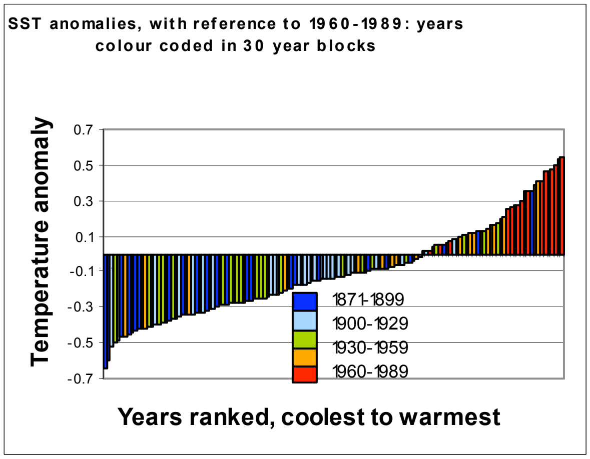

Figure 2. Chagos annual average sea temperature, shown as difference in °C from average 1960-1989 (following Hadley convention). Years are ranked, coolest to warmest. Colours code for 30 year block as shown in the key, except for the most recent block which is 1990 onwards (red bars) which has 17 bars. Data is HadISST1 monthly data from 1871-2006 inclusive, average of the 9 cells which cover Chagos archipelago.

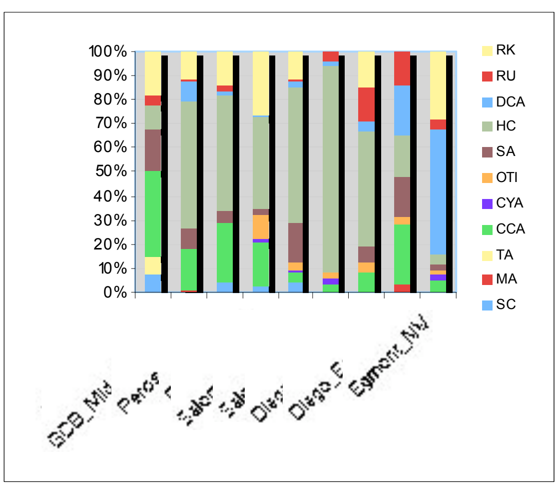

Figure 3. Mean average benthos composition values derived from PIT surveys at 5m depth. Survey codes used in results are as follows: RK (coral rock); RU unconsolidated rubble); DCA (uncolonised dead coral); HC (hard coral); SA (sand); OTI (other acroin-vertebrate); CYA (cyanobacteria); CCA (calcareous encrusting algae); TA (turf algae); MA (macroalgae); and SC (soft coral).

RESULTS

Sea Surface Temperature

Figure 2 presents the rising trend in annual average SST for this archipelago, over the past 135 years, showing that the six warmest years have all occurred during the last 10 years. No sub-surface temperature

Figure 4. Thriving *Acropora cytherea* table corals at Ile Anglais, Salomon atoll, 8m depth.

recorders were in place over that time, so details of the critical warm periods at different depths are not available, but from the HadISST1 data (in prep), the years 2003 and 2005 both showed warm peaks extending above 29.5°C, which are the second and third warmest values after the 1998 value of 29.9°C.

Benthic Composition

With very few exceptions (most notably Egmont atoll), at all sites and depths living substrate far outweighed non-living substrate, and hard coral was the most dominant form of living benthos. Figure 3 shows, as an example, sites from 5 m depth,

Reef sites at Peros Banos, Salomon and Great Chagos Bank atolls had greater cover than Egmont or Diego Garcia atolls, with significantly higher levels of hard coral cover, as well as greater prevalence of larger, older corals. In many sites, coral cover appears to have recovered almost completely (Fig. 4).

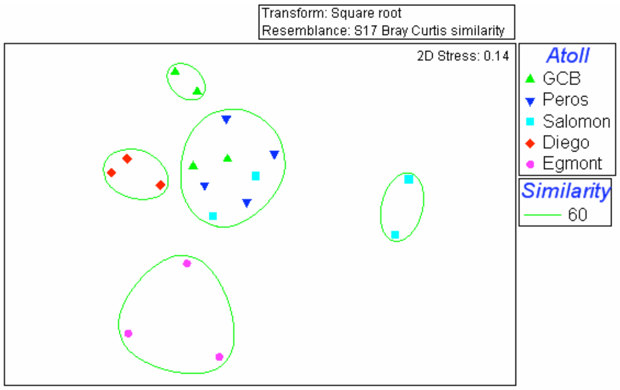

Figure 5. MDS ordination of samples (all atolls) based on benthic community data from 5m survey sites. Index is Bray-Curtis, grouping boundaries are 60% similarity (GCB = Great Chagos Bank).

Average hard coral cover at survey sites ranged from values as low as 6% at Egmont to 87% at Diego Garcia. Soft coral ranged from being entirely absent at several sites to 30% cover at Peros Banos.

Benthic cover varied among atolls for all depth

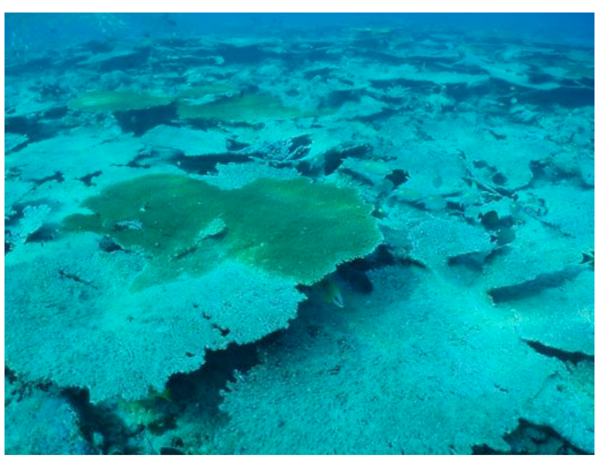

Figure 6: Widespread mortality of *Acropora cytherea.* at Egmont atoll, 8m depth. Living sections of some tables are a green-brown, while the dead tables are grey.

samples, illustrated for 5 m samples in an MDS ordination plot of benthic composition, showing Bray-Curtis similarity clusters at a 60% level (Fig. 5). Egmont sites were most dissimilar from other sites, Diego Garcia sites clustered closely together, while sites from the other islands were mixed amongst each other. Two-way crossed ANOSIM testing for differences between depths and atolls confirms separation of samples between depths also (global $R = 0.48$, $p < 0.1\%$) and atolls (global $R = 0.42$, $p < 0.1\%$). This result suggests that different characteristic patterns of benthic composition are found consistently within the different groups. Egmont sites had been affected by a severe mortality event which appeared to have taken place in the 12 months prior to surveying. This event killed over 95% of hard coral on shallow reefs as well as dramatically reducing hard coral

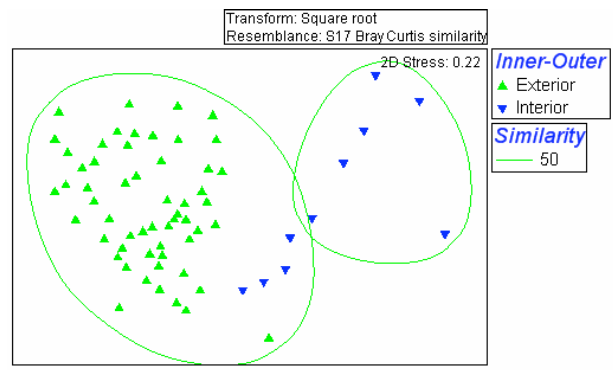

Figure 7. MDS ordination of samples (all atolls) based on coral cover from 15m sites showing dissimilarities of lagoonal patch and outer reefs with Bray-Curtis grouping of samples at 50% resemblance (lagoonal patch = interior; outer reef = exterior).

recruitment. The substrate was covered almost entirely of large dead *Acropora cytherea* and some *A. clathrata* table corals up to 3.75m in diameter (Fig. 6). The collapse and erosion of these tables was also observed to cause further mortality by scouring of other corals on the outer reef slope down to 15m depth. Diego Garcia's reef communities showed higher levels of soft corals and sponges, and generally lower coral cover except at one deep site where *Pachyseris* provided over 75% cover. The eastern side of Salomon atoll showed less recovery than the west side; this site was previously dominated by soft corals which appear in

Figure 8. Size class frequency distributions of hard coral recruit genera at 5, 15 and 25m depths (pooled data from all genera at all atolls). Size categories in incremental 10mm intervals from category 1 (0-10mm).

all sites to have recovered much less successfully to date than have the stony corals. Such patchiness could be due to effects of localised environmental conditions such as cool upwellings (which are observed off Diego Garcia and which have led to some *Caulerpa* dominated sites), and localised current patterns.

Lagoonal patch reefs and the peripheral reefs fringing islands had also recovered well, and all those observed were dominated by tabular or staghorn forms of *Acropora,* in shallow water. Broad differences

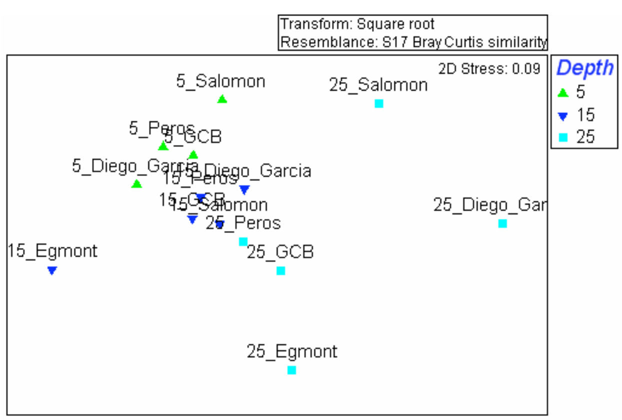

Figure 9. Non-metric MDS ordination of samples (all atolls, all depths) based on hard coral recruit community data (number of recruits per m^2 per genus) (GCB = Great Chagos Bank).

between lagoonal patch and outer reef slope communities were observed during the study (two-way crossed ANOSIM, global R = 0.72, p < 0.1%), as shown for 15m survey sites by the MDS ordination in Figure 7. In addition, lagoonal patch reefs showed generally higher hard coral cover at 25m than did outer reef slopes.

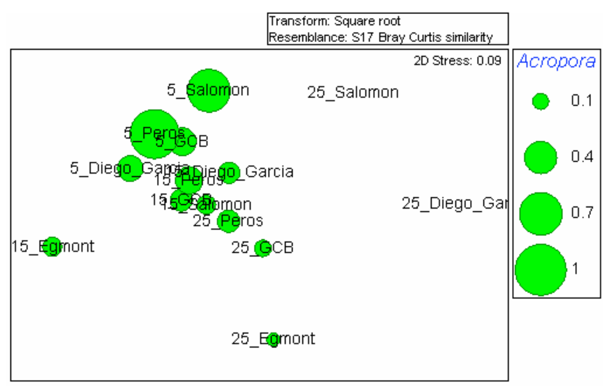

Figure 10. Bubble plot showing variation in relative density (recruits per m^2) of *Acropora* recruits within MDS ordination of Figure 8 (GCB = Great Chagos Bank).

Recruitment

Two thousand six hundred and three hard coral recruits and juveniles from 35 genera were surveyed within 1,159 quadrats of $0.11m^2$ sampled at three survey depths within the 19 reef sites, equivalent to sampling a total reef area across the three depths of 129m^2. Recruit density varied from 6 m^{-2} at Egmont atoll (5m) to 28 m^{-2} at Salomon atoll (15m). Across all genera the frequency of hard coral recruits increased from size category 1 to 3 (0-10mm and 20-30mm respectively, then decreasesd with increasing size (Fig. 8). However the shape and nature of this decrease varies widely between different genera and between groups of genera. Shannon Wiener diversity (H') of recruits at genus level was lowest for Egmont and Diego Garcia sites at all depths (with the exception of Diego Garcia at 15m). Analysis of hard coral recruit density and diversity (recruits per genus m^{-2}) by depth and atoll shows significant differences between depths (ANOSIM, Rho = 0.75, $p < 0.05$, Fig. 9), however there was no differentiation between atolls (Rho = 0.122, $p < 0.3$). Superimposing univariate genus-specific hard coral recruit density values on the multivariate MDS plot shown in Figure 9 provides a means of identifying variations in the density of recruits of individual genera across all of the samples. Common genera segregated into four groups according to recruitment by depth (e.g. Figs. 10, 11):

- Those favouring shallow depths (5m)– *Acropora*, *Porites*, *Acanthastrea* and *Hydnophora*;
- Those favouring medium depths (15m)– *Galaxea*, *Physogyra*, *Oxypora*, *Platygyra* and *Mycedium*;
- Those favouring deep depths (25m) – *Pachyseris*, *Podabacia*, *Seriatopora*, *Leptoseris*, *Gardineroceris* & *Stylocoeniella*;
- No clear depth preference – *Pavona*, *Favia*, *Favites*, *Psammocora*, *Fungia*, *Montipora*, *Pocillopora*, *Goniastrea*, *Leptastrea*, *Lobophyllia* .

DISCUSSION

Recovery

All atolls have shown strong, vigorous recovery after the 1998 bleaching and mortality event. However the extent of this recovery, and the composition of reef benthic communities around the archipelago, varied enormously between survey sites. Highly significant differences in reef composition were recorded between different atolls, and between different depths at all atolls. The higher coral cover observed at all depths at lagoonal reefs than at outer slope reefs in Chagos may be due to adaptation of corals to higher sea temperatures in these environments. Lagoonal reefs are more sheltered than outer reef sites, with more restricted water exchange, and are likely to experience warmer water conditions during calm conditions than the more exposed seaward slopes (Pugh and Rayner 1981).

The ability of Chagos reefs to 'bounce back' to rich reef communities after experiencing severe bleaching-related mortality in recent years has not been recorded in other reef environments in the Indian Ocean. Generally in the Indo-Pacific, recovery has been much poorer: Bruno and Selig (2007) assess 6000 surveys carried out over the past 40 years, finding that average decline both continues and varies on average from 1-2% per year, with average cover 5 years after the 1998 event being just 22%. This is similar to findings in the Caribbean (Gardner et al 2005). In contrast, many Chagos reefs have recovered to benthic cover values similar to that of 25 years ago (Sheppard 1980) with substantial recruitment, indicating a resilient system with unusually high recovery potential.

The recent mortality event documented at Egmont atoll killed almost all hard coral on shallow reefs, and has greatly reduced coral recruitment rates. This event is likely to have occurred in March-April 2005, when a sustained period of abnormally warm sea surface temperature impacted the central Indian Ocean region (in prep and see Fig. 2), and may have caused significant bleaching and the observed mortality. It is currently unknown why Egmont's reefs were more susceptible to bleaching and mortality in 2005 than any of the other atolls, but it could be due to the unusually shallow lagoon at Egmont, which may have acted as a basin for heating lagoonal water.

Recruitment

There is a general paucity of published data on temporal changes in coral recruit densities in the Indian Ocean post 1998. Data from Kiunga in northern Kenya show negligible recruitment in 1999 immediately following the widespread mortality event, increasing to 2 recruits m^{-2} in 2000/01 and 1-1.5 recruits m^{-2} in 2003/04 (Obura, 2002). These results are similar to the low recruitment measured on shallow sites in Egmont. Even the lowest of the Chagos recruit densities are an order of magnitude higher than the rates of recruitment of new corals documented at reefs in South Asia, the central Indian Ocean, and the East African coast, where 'substantial' rates of coral recruitment of 0.4-0.6 recruits m^{-2} have been recorded in recent years (Souter and Linden 2005). Other sites, such as marginal reefs in South Africa, have shown years where no recruitment of new corals was recorded at all.

The lack of between-atoll difference in recruitment may be explained in two ways. Firstly, within atoll differences are substantial, and may simply mask any between-atoll differences. But equally, present-day benthic cover values depend largely on recruitment that took place several years previously, when recruitment is likely to have been much more patchy from the very sparse adults which survived the 1998 event. While a certain degree of patchiness is always inevitable, greater evenness is likely to emerge as succession continues. Reproduction of survivors leads to broad-scale dispersal and settlement of new planulae enabling recruitment and recolonisation of reef areas affected by mortality. This pattern is only broken if, as is seen in Egmont at present, further intervening mortality takes place.

The abundance of juvenile corals in Chagos observed during this study indicates that recruitment is not currently a limiting factor for recovery of Chagos reefs. Recruitment, notably of previously dominant *Acropora*, has been identified as a limiting factor preventing reef recovery at marginal reef sites in East Africa, and at reefs influenced by cool currents in northern Kenya (Souter and Linden 2005). However the observed high levels of recruitment of *Acropora* spp. in Chagos do not rule out the ability of *Acropora* species, including the decimated population of *A. palifera*, to regain their original dominant shallow water coverage in this group of atolls.

Differential Responses of Species

A number of authors have discussed recent evidence of differential susceptibility of coral genera to warming since the 1998 bleaching and mortality episode (Obura, 2001, Grimsditch and Salm, 2005, Sheppard, 2006).

Relative increases in the abundance of faviids and massive *Porites* species following the 1998 bleaching event have been recorded at other sites in the Indian Ocean, and especially in the Persian Gulf, to the extent that faviids, as enduring survivors, are now the most common family on many reefs, often occupying reef space created by mortality and subsequent disappearance of *Acropora* (Obura 2001, Riegl 2002, Sheppard 2006). This is not the case in Chagos, where despite experiencing repeated bleaching events, *Acropora* has recolonised most reef sites, both lagoonal and seaward. Given the extent of mortality recorded in the aftermath of 1998, most colonies are likely to be less than 8 years in age. Studies undertaken after the 1998 mortality at numerous other heavily impacted Indian Ocean reef sites have led to predictions that repeated exposure to lethal sea surface temperatures may alter reef succession towards a permanent alternative stable state. These concerns do not currently appear to apply for Chagos reefs, where stable *Acropora* dominated communities appear to have 'bounced back' within a matter of 4-6 years.

Sheppard (2006) noted that members of the genus *Montipora*, commonly smaller and more encrusting members of the acroporidae than are most *Acropora*, were not disturbed to the same degree and survived better than *Acropora.* This conclusion was not supported by observations during this study, where *Montipora* remained extremely uncommon on all reef sites. It is possible therefore that this genus has suffered significant disturbance in the 2 years since the last detailed marine surveys were undertaken in Chagos.

One additional striking absence was of the faviid *Diploastrea heliopora*. Once noted as common in Chagos lagoons, this massive faviid was entirely absent in all surveys undertaken in this research. It is indeed possible that this monospecific genus may be one of the first candidate species for local extinction.

Recommendations for Future Research

Data recorded in this study suggest that Chagos reefs have followed a different trajectory to many other reef communities in the Indian Ocean following 1998. The high resilience and re-seeding capacity of Chagos reef systems may be a result of their undisturbed nature, although additional factors should also be considered. These include the complex geomorphology of this oceanic archipelago as well as its proximity to the south equatorial current, down-stream from the outflow of coral larvae emanating from the highly biodiverse reef ecosystems of the south east Asian archipelagos.

Understanding ecological change in the marine environment of Chagos is severely restricted by limited opportunities for sampling in the archipelago. The irregular monitoring of Chagos reefs has prevented more detailed study of the successive phases of reef recovery, prohibiting sufficient understanding of the processes of regrowth of coral communities. It is likely also that there is an insufficient picture of the scale and number of bleaching-related stress and mortality events that have impacted the archipelago's reefs in recent years. Following observations of recent localised mortality episodes at Egmont atoll, future analyses of archipelago-wide recovery therefore must not assume recovery from a more or less 'clean slate' following 1998, but must take into account the further smaller but important episodes of warming since then. As a result of the importance of Chagos' marine systems, both as a stepping stone for regional marine biodiversity and especially as a globally important reference site for monitoring responses of undisturbed reef systems to climate-related stress, it is important that long-term monitoring of both biophysical variables and reef community is increased to track and quantify temporal changes in reef health. Given that sub-lethal warming is likely also to severely reduce reproductive output of coral populations, better knowledge of the size frequency abundance of juvenile scleractinia would provide better insight into possible lethal and sub-lethal stresses to reefs too. Greater monitoring becomes increasingly important given the most recent predictions of SST rise in tropical locations (http://ipcc-wg1.ucar.edu/wg1/wg1-report.html, Sheppard 2003). It is most important that future bleaching events in this area are not overlooked.

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Status of Carbonate Reefs of the Amirantes and Alphonse Groups Southern Seychelles

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ABSTRACT

Indian Ocean reefs were badly affected by the global 1997-98 ocean warming event, suffering up to 90% coral mortality. This paper reports the present status of reefs of the Amirantes and Alphonse groups of the southern Seychelles. Fifteen islands and surrounding reefs, covering a total area of 270 km^2, were mapped in January 2005 using airborne remote sensing. Benthic surveys were conducted at selected localities using video transect techniques and percentage cover for ten benthic categories was calculated. A hierarchical classification scheme was devised for the islands. Results are presented as large-scale habitat maps. Typically, reef-flats of the Amirantes were dominated by *Thalassodendron ciliatum* and *Thalassia hemprichii* seagrass communities and fore-reef slopes were dominated by bare substrate, with substantial coverage of macroalgae (*Halimeda* spp.). Live coral cover on the fore-reef slope ranged between 7-26% and was dominated by *Porites* and *Pocillopora*. The large sizes of many *Porites* colonies present indicates that these survived the 1997-98 ocean warming event and the high abundance of *Pocillopora* is a typical response following a large scale disturbance event. The southern Seychelles islands and surrounding reefs were not seriously affected by the 2004 Asian Tsunami; the waves were not amplified around the islands due to their position in the western Indian Ocean and surrounding deep water. Amirantes reefs are recovering in terms of live coral cover following the 1997-98 ocean warming event, but on-going monitoring is required to gauge time-scales for these reefs to regain their former coral diversity.

INTRODUCTION

The Seychelles archipelago, western Indian Ocean (5º-10ºS; 45º-56ºE) is made up of 42 granitic islands and 74 coralline islands. The total land area of 455 km^2 lies within an Exclusive Economic Zone (EEZ) of 1,374,000 km^2 (Jennings *et al.*, 2000). The Amirantes islands lie immediately to the south-west of the ancient (~750 Ma) granitic microcontinent of the Seychelles Plateau (Plummer, 1995). The Group comprises 24 islands and islets (including the atolls of St. Joseph and Poivre), stretching ~155 km from 4º53'S (African Banks) to 6º14'S (Desnoeufs) on the arcuate Amirantes Ridge, which separates the Amirantes Trough and Somali basin to the west from the Amirantes Basin to the east (Plummer, 1996). A basalt sample recovered from the western flank of the Ridge has been dated at 82 ± 16 Ma (Mid – Late Cretaceous) (Fisher *et al.*, 1968); this volcanic

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Developmen in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

Figure 1. The islands of the Amirantes and Alphonse Group, Seychelles, showing 1,000 m and 2,000 m depth contours.

basement is overlain by shallow water carbonates of less than 1 km in thickness (Stoddart, 1984b). Water depths are greatest (~70 m) in the centre of the Ridge, shallowing to a peripheral rim at -11 to -27 m. The majority of reefs and shoals lie along the eastern and southern margins of the Ridge. The emergent islands are of Holocene age (< 6 ka; Stoddart, 1984a) and composed of 'bioclastic sands thrown up by wave action from reef platforms which have accumulated to sea-level' (Braithwaite, 1984: 27). In some cases, however, these cays record more complex histories with the presence of raised reefs, bedded calcareous sandstones and extensive beachrock (Baker, 1963). The atoll of Desroches lies to the east of the main ridge (Stoddart and Poore, 1970) and 95 km further south are the atolls of Alphonse and St. François which form, with Bijoutier, the Alphonse Group (Fig. 1).

Plate 1. Marie-Louise looking from the north.

The Seychelles lie in the South Equatorial Current and Seychelles reefs are influenced by the persistent south-east trade winds, with typical windspeeds of 6-9 m s-1 for 8-10 months of the year (Stoddart, 1984b). This influence is particularly marked south of 10°S (Sheppard, 2000), resulting in the strong differentiation of windward and leeward reef structures at higher latitudes. Mean annual rainfall in the Seychelles decreases in a south-westerly direction, with the north-eastern islands experiencing approximately twice as much rain as the south-western islands (Walsh, 1984). The reefs of the southern Seychelles receive few terrestrially-derived nutrients, and although the surrounding oceanic waters show typically low primary productivity, the atolls may induce upwelling and thus enhanced local productivity (Littler et al., 1991). Sea surface temperatures in the Seychelles show a typical annual range of 26°C to 31°C and open ocean salinities vary from 34.5 ppt to 35.5 ppt (Jennings et al., 2000). Many of the Amirantes islands are uninhabited and several, such as Etoile and Boudeuse, are protected as bird reserves. The islands of Desroches and Alphonse have small hotels (20 and 25 rooms respectively) and tourist dive centres. Anthropogenic impacts on reefs of the Amirantes are therefore relatively low. However all Seychelles reefs were severely affected by the 1997-98 ocean warming event which induced ~60% coral mortality in the Amirantes (Spencer et al., 2000).

A collaborative expedition between the Khaled bin Sultan Living Oceans Foundation, the Cambridge

Plate 2. Alphonse Island looking from the south-west.

Coastal Research Unit, University of Cambridge and the Seychelles Centre for Marine Research and Technology – Marine Parks Authority to the southern Seychelles was conducted onboard M.Y. Golden Shadow from 10th – 28th January 2005

METHODS: FORE REEF SLOPE BENTHIC SURVEYS

Quantitative underwater surveys were conducted in January 2005 at four islands (Marie-Louise (Plate 1), Boudeuse, Poivre and Alphonse (Plate 2)) using well-established video transect methods (Christie *et al.,* 1996). The video data recorded was a plan view of a rectangular section of the benthic reef community measuring 20 m x ~ 0.3 m; by recording both sides of the transect line, double this area was covered (i.e. 20 m x ~ 0.6 m). Transects were variously placed at shallow (5 m), mid-depth (10 m and 15 m) and deep (20 m) water depths, as allowed by local bathymetry.

Video transect footage was analysed using the AIMS 5-dot analysis method (Osborne and Oxley, 1997). Ten benthic categories were identified: sand; rubble; bare substrate; dead standing coral; pink calcareous algae on bare substrate; pink calcareous algae on dead standing coral; scleractinia; non-scleractinia; macroalgae; and others (e.g. zooanthids, molluscs, bivalves). Scleractinia, non-scleractinia and macroalgae were identified to genus level and the relevant genera recorded. Percentage cover was calculated for each of the ten benthic categories.

METHODS: HABITAT MAPPING FROM REMOTE SENSING IMAGERY

Airborne remote sensing data were acquired over 15 islands in the Amirantes from the seaplane 'Golden Eye', covering an area of 270 km^2 across 133 pre-determined parallel survey lines. Reflectance data were collected over the 430-850 nm region of the electromagnetic spectrum using a Compact Airborne Spectrographic Imager (CASI) sensor.

Raw data were geocorrected by collecting ground control points on areas of strip overlap and applying a first order polynomial model to correct for the linear offset, with nearest neighbour resampling. Strips were mosaiced and a band-wise linear colour balancing model was applied to minimize across-track variance, with histogram matching to adjust for radiance offsets. Training areas were used to derive reflectance measures over a number of spectral subclasses in order to build up a statistical population of each reef habitat class in feature space. A total of 910 signatures were collected and evaluated for the dataset as a whole before being merged into 24 habitat class populations. A maximum likelihood classification assigned each pixel of the image to the most likely class on the basis of statistical probabilities (Mather, 2004).

A habitat scheme with a hierarchical structure (Table 1) was developed to accommodate user requirements, field data availability and the spatial and spectral resolution of the CASI sensor.

RESULTS

Fore-Reef Slope Benthic Surveys

At reefs on the south-east fore-reef slope of Marie-Louise (Fig. 1, Plate 1), live coral cover was 21% at a depth of 15 m and 16% at a depth of 10 m. Macroalgae (principally *Halimeda* spp.) dominated the benthos at both depths (31-36% cover), followed by bare substrate (24%). Coral rubble accounted for only 2-6% of the benthos. The coral community was comprised of 13 genera. *Pocillopora* accounted for 40% of the coral community at the 15 m site and 60%

Table 1. Two-tier habitat classification scheme for the Amirante Islands.

First tier	Second tier
1. Terrestrial vegetation: trees and shrubs	1.1 Coconut woodland 1.2 Other trees and shrubs
2. Herbs and grasses 3. Saline pond 4. Cleared/ bare ground 5. Littoral hedge 6. Mangrove woodland (Plate 3)	
7. Coarse beach material & rocks	7.1 Coral sandstone/ Raised reef 7.2 Coral boulders 7.3 Beachrock
8. Beach sand 9. Rock pavement 10. Reef-flat sand	
11. Seagrass (Plate 4)	11.1 Low density seagrass/ macroalgae 11.2 Medium density seagrass
12. High density seagrass 13. Lagoon patch reef 14. Lagoon sand	
15. Fore-reef slope material or structure. Not sand.	15.1 Coral rubble with coralline algae 15.2 Fore-reef slope coral spurs with coralline algae 15.3 Rocky fore-reef slope 15.4 Fore-reef slope rubble and sand 15.5 Fore-reef slope with coral
16. Fore-reef slope sand	

of the coral community at the 10 m site. *Porites* was the second most dominant genus, accounting for 20% of the live coral cover at 15 m and 10% of the live coral cover at the 10 m depth.

At Boudeuse (Fig. 1), live coral cover typically accounted for only 7% of the total benthic coverage, being comprised largely of *Porites* (33%), *Favites* (16%), *Montipora* (9%) and *Acropora* (9%). At this site the dominant benthic category was bare substrate (32%), followed by rubble (23%), sand (15%) and macroalgae, specifically *Halimeda* (15%).

Plate 3. Rhizophora mucronata mangrove off the south coast of Poivre.

The fore-reef slope off the west coast of Poivre (Fig. 1) displayed higher live coral cover at deeper sites (19% cover at 20 m, 26% cover at 15 m) than at shallower sites (9% cover at 10 m, 11% cover at 5 m). At 20 m, 15 m and 5 m depths, the coral community was dominated by *Porites* (39%, 48% and 24% cover respectively) and *Pocillopora* (21%, 20% and 19% cover respectively). At 10 m water depth the blue coral *Heliopora coerulea* dominated (35% cover), followed by *Pocillopora* (28% cover).

The fore-reef slope of Alphonse displayed an average of 22% live coral cover and only 1%

Table 2. Direct comparison of 1999, 2001 and 2003 percentage benthic cover by community for 1 example site at -10 m on the north-west fore-reef slope of Alphonse. Benthic categories data from video surveys. CA = Calcareous Algae, BS = Bare Substrate, DS = Dead Standing.

	1999	2001	2003
Sand	7.4	10.2	11.0
Rubble	30.5	26.7	18.4
Bare Substrate	11.1	13.8	18.6
Dead Standing	1.0	2.6	0
Pink CA on BS	25.3	17.7	18.1
Pink CA on DS	2.4	2.2	0
Scleractinia	10.5	12.6	23.4
Non-Scleractinia	3.2	9.1	9.2
Macroalgae	8.5	4.7	1.3
Other	0.1	0.4	0.1

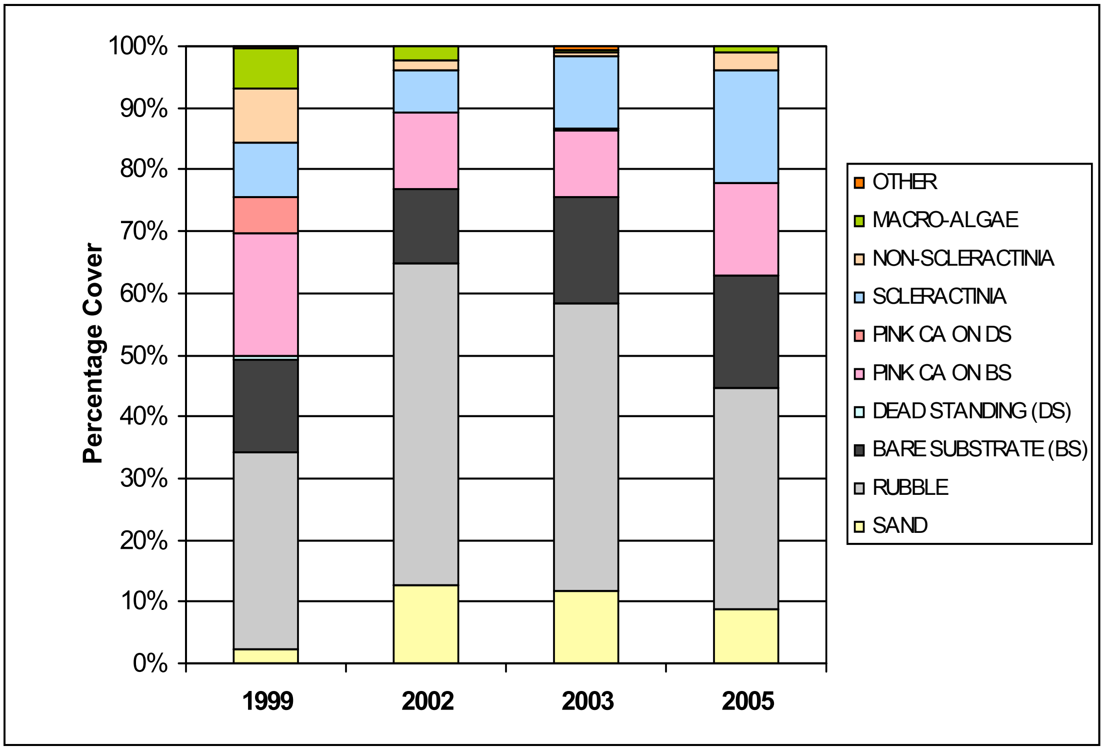

Figure 2. Direct comparison of 1999, 2002, 2003 and 2005 percentage benthic cover at -15 m on the north-east fore-reef slope of Alphonse. Benthic categories data from video surveys. CA = Calcareous Algae, BS = Bare Substrate, DS = Dead Standing.

macroalgal cover at sites with water depths of 5 to 17 m in 2005. Repeat surveys at Alphonse between 1999 and 2003 indicate a good level of recovery following the bleaching event, with average live coral cover increasing from 10% of total benthic coverage in 1999, to 12-17% in 2001/02, and to 23% in 2003 (Hagan and Spencer, 2006). Over the same period, both non-scleractinian and macroalgal cover decreased. Thus whilst macroalgal cover almost equalled scleractinian cover in 1999, by 2003 it only represented 1-2% of benthic community coverage (Table 2).

Between 2003 and 2005, although percentage cover of bare substrate remained constant, scleractinian cover at Alphonse increased. At one example site on the north-east fore-reef slope, scleractinian cover increased by 7% in this two year period and macroalgal cover remained minimal (Fig. 2).

Plate 4. Seagrass on reef-flat at Alphonse

In 2005, *Porites* was the dominant genus at all survey sites and all depths, except for one 5 m depth site off the south-west of the atoll where the dominant

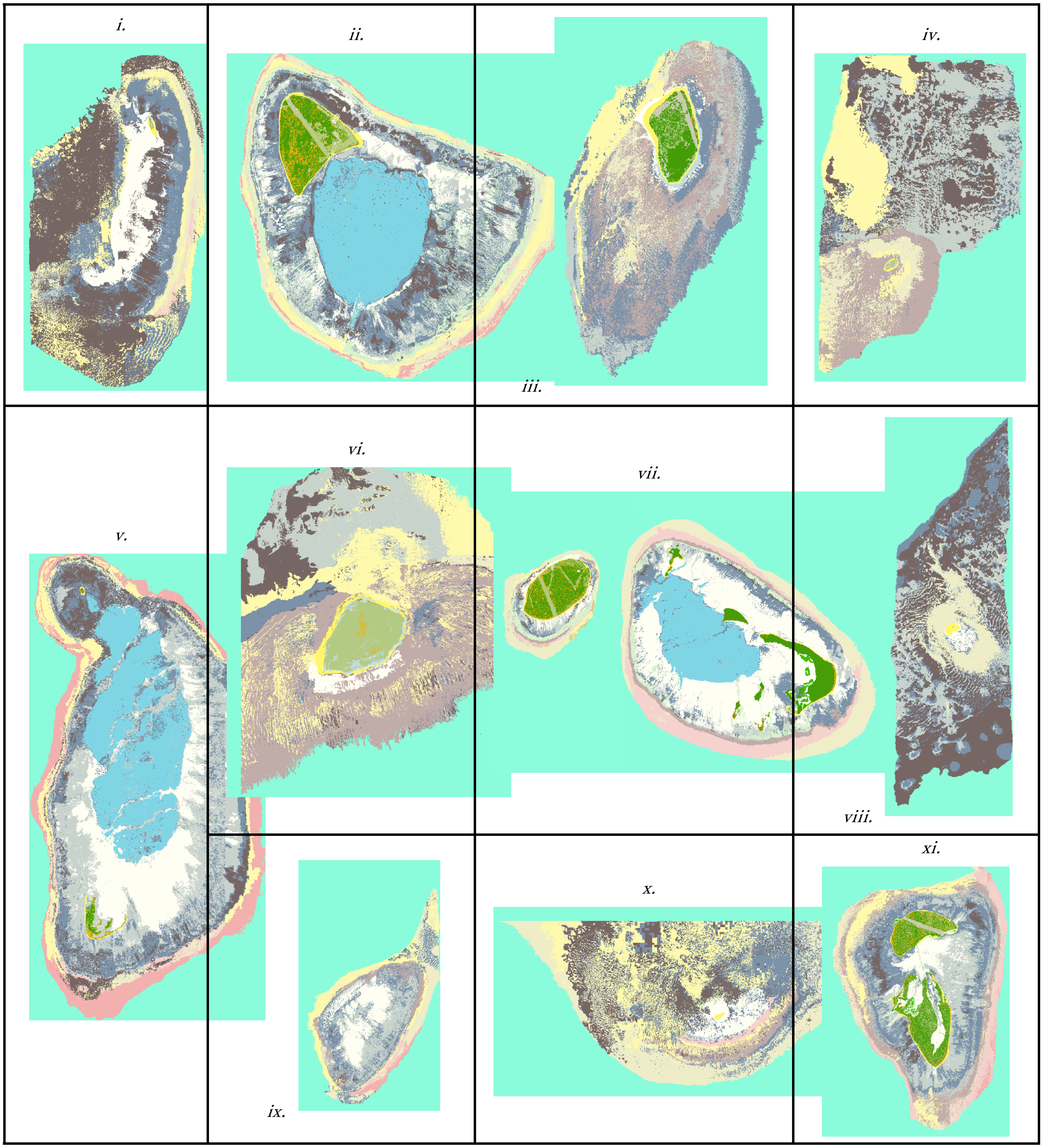

Figure 3. Provisional habitat maps of the Amirante Islands: i. African Banks, ii. Alphonse, iii. Marie-Louise, iv. Boudeuse, v. Bijoutier & St. François, vi. Desnoeufs, vii. D'Arros & St. Joseph, viii. Etoile, ix. Remire, x. Sand Cay, xi. Poivre.

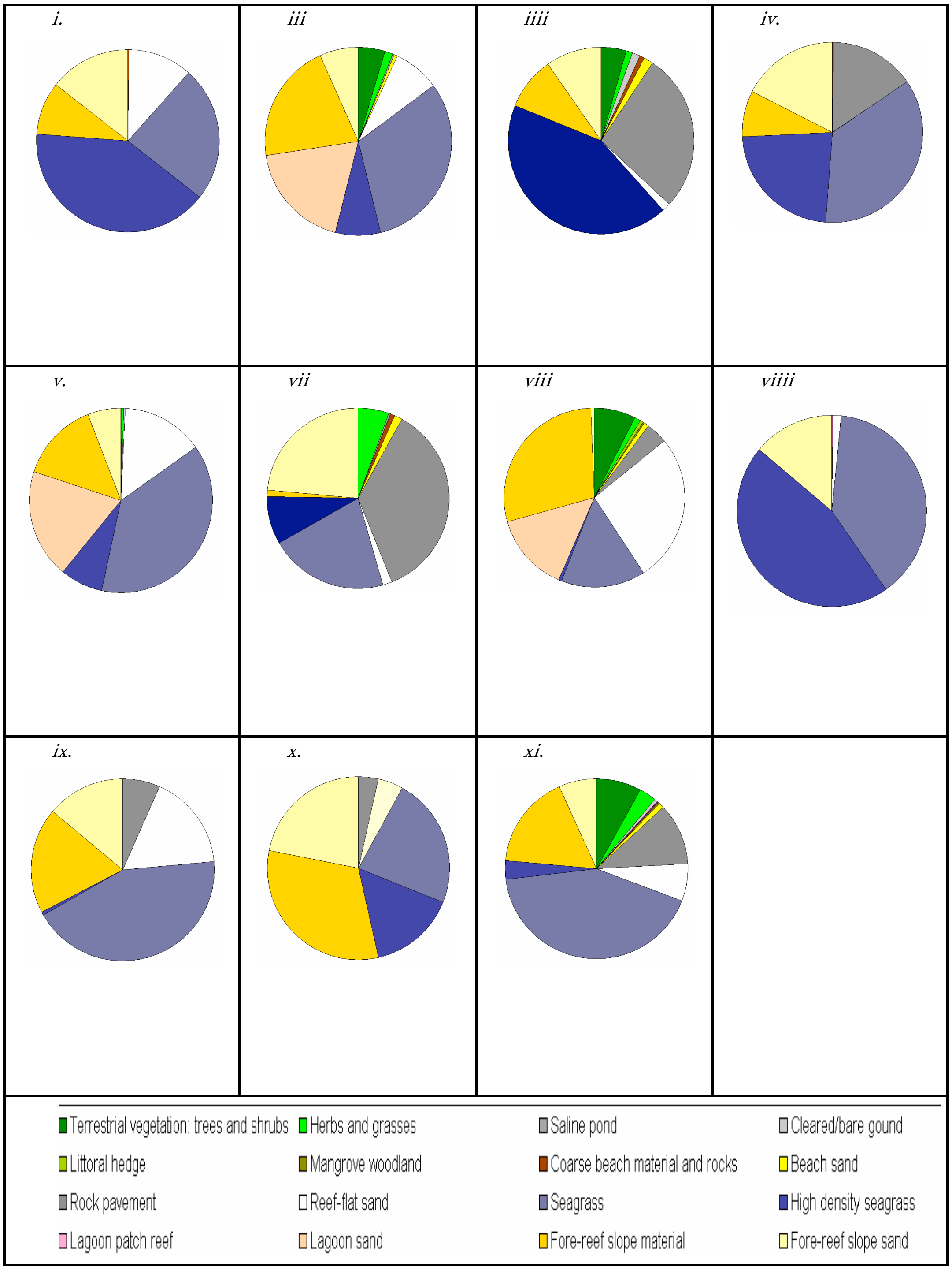

Figure 4. Provisional tier 1 breakdown of habitat coverage in the Amirante Islands: i. African Banks, ii. Alphonse, iii. Marie-Louise, iv. Boudeuse, v. Bijoutier & St. François, vi. Desnoeufs, vii. D'Arros & St. Joseph, viii. Etoile, ix. Remire, x. Sand Cay, xi. Poivre.

genus was *Montipora* (50% of live coral cover). On the west side of the atoll, *Porites* accounted for 55%, 65% and 39% of the live coral community at 15 m, 10 m and 5 m respectively. On the east side of the atoll, *Porites* accounted for 49%, 57% and 63% of the live coral community at 15 m, 10 m and 5 m respectively. *Pocillopora* accounted for 11% of the coral community at 15 m depth on the west side and 30% of the coral community at 15 m depth on the east side. No *Pocillopora* was recorded at shallower survey sites on the west side of the atoll, but *Pocillopora* accounted for 19% and 14% of the live coral community at 10 m and 5 m respectively on the east side.

Casi Mapping

Little variation was apparent within the defined classes and the output maps from the 2005 survey had an average thematic producer's accuracy of 75.7% for first tier habitats (Congalton, 1991). Overall, the maps provided a clear representation of the heterogeneity apparent in the raw imagery (Fig. 3).

Seagrass (Plate 4) was the most well-represented habitat class, encompassing low and medium density communities, as well as various macroalgal species. Fore-reef slope material, reef flat sand and lagoon sand coverage was also considerable. Alphonse had the highest number of tier 1 habitat classes, with Bijoutier and St. François and D'Arros and St. Joseph also supporting a wide range of habitats. Conversely, Sand Cay, Remire and Etoile supported lower numbers of habitat classes, with a dominance of fore-reef slope material, seagrass and high density seagrass respectively (Fig. 4). Of the islands mapped, 7 were vegetated, primarily with coconut woodland or a mixture of trees and shrubs; three of these vegetated islands, Marie-Louise, Boudeuse and Desnoeufs were situated upon an intertidal and shallow subtidal rock pavement.

The maps remain provisional at the present time, being subject to validation by experts in the Seychelles. It is the intention that final versions of the maps will be available in an electronic format in due course.

DISCUSSION

Seagrass beds were a conspicuous and often dominant feature of the habitat maps produced for the islands of the Amirantes Ridge and the Alphonse Group. *Thalassodendron ciliatum* and *Thalassia hemprichii* are common in subtidal areas at water depths of up to 33 m throughout the Seychelles (Green and Short, 2003). The two species are typically found at densities of 540-627 and 1123-1761 shoots per m2 respectively (Ingram and Dawson, 2001). Appropriate conditions for seagrasses include an adequate rooting substrate, water depths that preclude subaerial emergence at low tide and light levels to maintain growth (Hemminga and Duarte, 2000). Within these broad environmental limits, organisation of seagrass communities on the islands of the Amirantes ranged from closed canopy meadows, commonly found on the reef flat and covering deeper platforms, to sparse seagrass patches in areas of greater water movement and shallower water depths.

The outer fore-reefs of the Amirantes and Alphonse Group were dominated by bare substrate and macroalgae, with low-coverage scleractinian communities being dominated by a small number of genera. The 1997-98 coral bleaching event had a very severe impact on the reefs of the Indian Ocean. The high level of both macroalgal cover and bare substrate on reefs of the Amirantes suggests that this recent bleaching event may have led to a benthic community with reduced scleractinian cover and increased macroalgal cover, as has been hypothesised elsewhere (e.g. Done, 1999). However, although the granitic Seychelles islands in the north suffered over 90% coral mortality during the 1997-98 ocean warming (Wilkinson, 2000), the southern islands were less severely affected, with an average mortality of around 60% (Spencer et al., 2000). It is suggested that this difference was due to the moderating influence of the South Equatorial Current at the southerly locations, in contrast to the heating of shallow waters, and long water residence times, on the Seychelles Plateau.

At some sites in the southern Amirantes, such as Marie-Louise, it is surprising that there was little rubble present on these reefs during the 2005 surveys, as coral rubble is a typical sign of recent coral mortality (Rasser and Riegl, 2002). The lack of rubble present suggests that pre-1998, some of these reefs were most probably dominated by massive, rather than branching, corals. This certainly appears to have been the case in January 1993 when the Netherlands Indian Ocean Programme expedition conducted one SCUBA transect on the north-west fore-reef slope at Alphonse. They found acroporids constituted only 1.8% of the scleractinian community, pocilloporids constituted 10.8% and massive *Porites* spp. constituted 80% (van der Land, 1994). These results from Alphonse are consistent with data from 2005, where *Porites* was the dominant genus, constituting up to 65% of the live coral community.

Further north in the Amirantes, coral cover was ~ 20% or more in water depths of 15 – 20 m at Poivre. Furthermore, the presence of large amounts of coral rubble suggests that the 1997-98 bleaching event may have led to post-bleaching reef framework disintegration of the coral community at this location. Interestingly, The Netherlands Indian Ocean Programme reported 41-50% live coral cover on the northern reef-slope at Poivre in December 1992. Although *Porites* was the dominant genus recorded in these surveys, there was a significant presence (20-40% of the coral community) of branching acroporids and pocilloporids (van der Land, 1994).

Elsewhere in 2005, the two most prevalent scleractinian genera at 15 m and 10 m at Marie-Louise and at 20 m, 15 m and 5 m at Poivre were *Porites* and *Pocillopora* At Boudeuse at 10 m, Porites dominated, with *Pocillopora* ranking 5th in dominance. Likewise, van der Land (1994) reported 38% *Porites* spp., 24% pocilloporids and 6.1% *Stylophora mordax* at the neighbouring island of Desnoeufs in 1993.

Pocillopora damicornis has been described as an opportunistic species, due to its rapid reproductive cycle, widespread larval dispersal and fast growth rate on settling, enabling it to quickly occupy any newly available space (Endean and Cameron, 1990) such as that available following the 1997-98 coral bleaching event in the Amirantes Group. *Pocillopora* colonies in the Amirantes typically measured 10-30 cm in diameter, sizes which could have been attained in the 7 years following the bleaching event. Conversely, the presence of *Porites* as the most dominant coral genus at Poivre, Boudeuse and Alphonse and the second most dominant genus at Marie-Louise suggests t hat these slow-growing, massive colonies survived the 1997-98 bleaching event. Where patch reefs occur within lagoons, at Alphonse Atoll for example, little evidence of ocean warming related mortality was observed, suggesting that these shallow water corals were already acclimatised to waters warmer than occur on the outer fore-reef slope. In cases such as this, lagoon corals may therefore act as larval refugia, and may be an important component in reef regeneration following a major disturbance event in the region.

The January 2005 expedition to the southern Seychelles was conducted shortly after the 2004 Asian Tsunami which devastated islands and reefs throughout the Indian Ocean basin (Obura, 2006). However, no physical damage from this event was observed in either the terrestrial or marine environments at any of the islands visited (Hagan *et al.*, in press). The littoral hedge remained intact and there was no evidence of beach sediment movement or water inundation at island margins. Underwater there was no evidence found of tsunami-related mechanical damage on the reef. Thus, for example, no physical damage to the branching corals (principally *Pocillopora*) that are prevalent on these reefs and no coral toppling was observed. The islands of Alphonse, D’Arros, Desroches, Marie-Louise and Poivre are inhabited. In all cases, island personnel said that there had not been any impact caused by the tsunami and they hardly noticed the event. The lack of noticeable impacts within the southern islands compared to islands further north appears to be related to both reduced tsunami wave heights to the south (due to the ocean basin-scale refraction of the wave from the east – west axis of maximum impact at 0 - 5ºN (Spencer, in press)) and to differences in regional bathymetry, the tsunami being accentuated by the shallow shelf seas of the Seychelles Bank in the north and not amplified around the southern islands which are surrounded by deep water.

Pre-1998 reef status data is not available for reefs of the Amirantes but the time-series available for Alphonse shows significant recovery in terms of live coral cover following the mass bleaching event (see above, Table 2; Hagan and Spencer, 2006). In order for reef recovery to continue and the natural succession of the coral community to progress, it is important that further reef degeneration does not occur. The reefs of the Amirantes have the advantage of being subjected to minimal anthropogenic pressures but ongoing monitoring is essential to gauge time-scales involved in these reefs regaining their levels of coral diversity.

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Mohéli Marine Park, Comoros Successes and Challenges of the Co-Management Approach

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ABSTRACT

Mohéli Marine Park *(Parc Marin de Mohéli, PMM)* was the first Marine Protected Area (MPA) to be established in the Comoros in 2001. Initially regarded as a model for co-management of marine resources, PMM is now operating at a vastly reduced capacity following an end to external funding sources. An assessment of current perceptions of local stakeholders of PMM was recognized as an essential first step in rebuilding its capacity and effectiveness as an MPA. This study aimed to ascertain stakeholders' current perceptions of PMM, using focus group interviews to evaluate six key parameters: (1) basic awareness, (2) value, (3) effectiveness, (4) environmental threats and solutions, (5) stakeholder roles and responsibilities and (6) future aspirations and expectations. It was apparent that most local communities were aware of the importance of PMM, but felt that it had failed to include their needs or consider their input in its management. Concern was expressed for the lack of sustainability or alternative livelihoods; inequitable distribution of benefits; exclusion of women; continuing environmental threats and a concurrent lack of enforcement of regulations. The key recommendations to arise from this work were: (1)

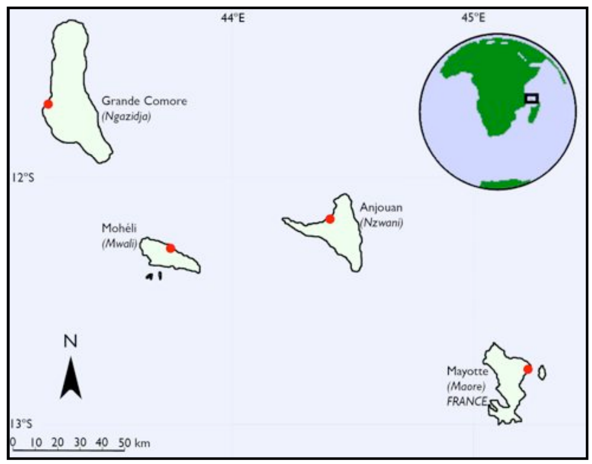

Figure 1. Union of the Comoros and Mayotte.

ensure sustainability through effective financial planning and promotion of low-cost, appropriate management techniques; (2) mobilize local communities to create a truly co-managed PMM; (3) ensure tangible benefits to local communities through realistic alternative livelihood options, particularly for fishers; (4) ensure equitable sharing of benefits and awareness of PMM; (5) involve women in the management of PMM, they are the primary local educators and motivators for future generations; (6)

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008) Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

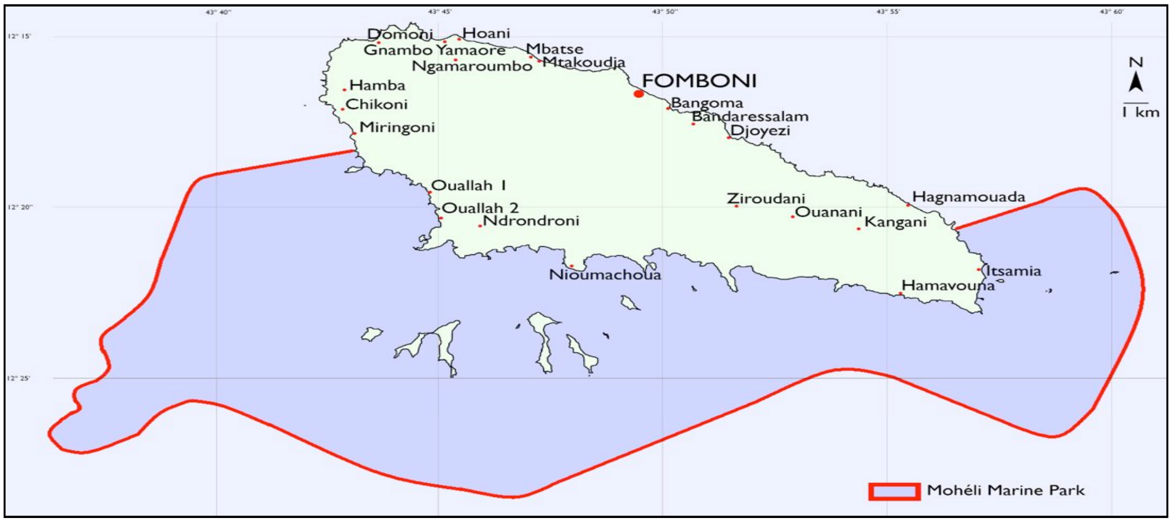

Figure 2. Mohéli showing location of the marine Park.

inform law enforcement officials and members of the justice system to ensure understanding, respect and enforcement of PMM regulations.

INTRODUCTION

The Union of the Comoros is situated at the northern end of the Mozambique Channel, equidistant (approximately 300km) from continental Africa and Madagascar (Fig. 1). It comprises three volcanic islands: Grande Comore, Anjouan and Mohéli. The country is characterized by both high marine diversity and intensive anthropogenic pressure. This combination of attributes underscores the importance of assessing, understanding and monitoring socioeconomic elements to strengthen develop appropriate participatory management and conservation strategies.

The first Marine Protected Area (MPA) in the Comoros, Mohéli Marine Park *(Parc Marin de Mohéli - PMM),* was established on 19th April 2001 (Figure 2) as a major component of the UNDP/GEF-funded project 'Conservation of Biodiversity and Sustainable Development in the Federal Islamic Republic of the Comoros' (Project Biodiversity) (IUCN, 2004). The establishment of PMM was based on its rich biological diversity and the presence of key coastal habitats and endangered marine species (see Ahamada et al., 2004 for a review of the ecological status of coral reefs in the Comoros). The Management Plan for PMM (Gabrie, 2003) anticipated full implication of local stakeholders through co-management. This approach has proved valuable when tackling fundamental socioeconomic factors influencing conservation efforts (Granek and Brown, 2005).

Initially regarded as a model for co-management of marine resources (IUCN, 2002), PMM is now operating at a vastly reduced capacity following the end of Project Biodiversity, and subsequent end in funding (Wells, 2005). Beaches are littered with poached turtle carcasses and fishers regularly use gillnets and other banned fishing methods (Abdou Rabi, pers. comm. 2006). It is thus crucial that the impetus of Project Biodiversity is built upon immediately to ensure that local communities do not become disillusioned and de-motivated. This study was recognized as essential to ensure integration of the perceptions of these stakeholders into current management decision-making and in the identification of future priorities.

Table 1. Positive and negative aspects of PMM identified by focus groups in approximate order of significance.

Positive aspects	Negative aspects
1. Environmental protection and a reduction in environmental destruction	12. Lack of sustainability
2. Increase in fish (size or number)	13. Lack of effective monitoring or enforcement
3. Prohibition of fishing gears	14. Lack of respect of PMM personnel for official agreements
4. Increase in environmental consciousness	15. Poor management of equipment
5. Ecotourism	16. Absence of PMM personnel
6. Increase in coral cover	17. No positive aspects
7. Exchange and increase in information through international interest	18. Prohibition of fishing gears
8. Infrastructure development	19. Lack of collaboration between PMM, external organizations and villages associations
9. Reduction in unemployment	20. Insufficient environmental training, education, and awareness raising
10. Official permission for villages to protect their coastal zone	21. Lack of management of forestry activities
11. Presence of ecoguards	22. False promises of Project Biodiversity
	23. Absence of female participation
	24. Lack of benefits
	25. Lack of motivation
	26. No visible zoning of PMM boundaries
	27. Inequitable distribution of benefits
	28. Environment in a worse state since the creation of PMM
	29. Lack of waste management

MATERIALS AND METHODS

Semi-structured interviews were conducted, following guidelines from Bunce et al., 2000, consisting of 12 questions based on six key parameters: (1) basic awareness, (2) value, (3) effectiveness, (4) environmental threats and solutions, (5) stakeholder roles and responsibilities and (6) future aspirations and expectations. The interview was designed to allow for open discussion in a focus group format and further relevant questions were posed during each interview according to participants' responses to the key questions.

The interviews were carried out between 10th July 2006 and 20th August 2006 in the 10 villages of PMM: Miringoni, Ouallah 1, Ouallah 2, Ndrondroni, Nioumachoua, Ouanani, Kangani, Ziroudani, Hamavouna, and Itsamia (Fig. 2). The interviews were pre-arranged in each village by asking a community leader to assemble two focus groups: one consisting of 10 men and one of 10 women of various ages, occupations, and social status. Male and female focus groups were held separately to ensure that women would feel at ease in voicing their opinions.

Whenever possible, interviews were conducted in private locations to minimize distractions and to ensure effective discussion. Discussion was usually in the local Comorian dialect, ShiMwali, with responses translated by a facilitator and recorded in French by the interviewer. The facilitator was briefed before each interview to ensure their understanding of each question and its purpose and to ensure that they did not make leading comments or prompt responses. Answers were repeated if necessary for clarification and accuracy.

RESULTS AND DISCUSSION

Achievements of PMM

'PMM's objectives are good in terms of conservation but they do not concretely address the issue of how we can both protect and consume resources within PMM.' - Man from Ouanani

All focus groups interviewed believed that PMM was important, citing the following reasons: (1) conservation of natural resources and the rich environment of Mohéli for future generations; (2) environmental education and awareness; (3) ecotourism development; (4) fisheries enhancement and food security; (5) protection of endangered species; (6) leverage of external funding (Table 1). These correspond closely to the MPA's initial objectives (Gabrie 2003): (1) to ensure the independent function and management of the park and to sustain the management structure; (2) to ensure the conservation of marine and coastal biodiversity, habitats and endangered species; (3) to encourage the development of ecotourism and other income-generating activities; (4) to ensure the sustainable use of marine resources; (5) to reinforce environmental education, training and communication. Thus, PMM has partially succeeded in creating awareness of its objectives and importance amongst local communities. However, the 18 negative aspects (Table 1) reported by PMM stakeholders illustrate that to date it has failed to some extent in successful implementation of these objectives in a co-management context.

Lack of Sustainability

Lack of sustainability was identified as the primary negative aspect of PMM (Table 1), although there were originally plans to address this issue, it seems that none was fully realized. Project Biodiversity laid the groundwork for a Biodiversity Trust Fund for the Comoros, including management of protected areas (Bayon, 1999). However, a longer time-scale and greater level of capitalisation than originally envisaged were required to set up the Fund (Wells, 2005). In the absence of the Trust Fund to cover the base management costs of PMM, no contingency plan for sustainable funding and no lower-cost alternative for its management, PMM's financial situation was uncertain following the end of Project Biodiversity in 2003. This was clear to local communities who remarked on the reductions in management effectiveness, activity and levels of enforcement following the end of Project Biodiversity.

Alternative Livelihoods

'PMM told us that we could no longer use uruva (a poison) *because it was bad, but in our village we saw the opposite happen, now there are less fish since it was banned!' - Woman from Miringoni.*

Most focus groups (85%) believed that they had received no benefits or only one benefit from PMM. Thus, PMM has failed to provide adequate incentives to its stakeholders to ensure their continuing motivation for biodiversity conservation.

Ecotourism

Ecotourism was one of the key objectives of PMM Gabrie, 2003) and was recognized by communities as a positive aspect (Table 1). However, tourist arrivals have declined since the creation of PMM and communities complained that they were inadequately trained to host tourists and provide guides, accommodation and other services. Local capacity and infrastructure must be considerably improved for ecotourism to provide a significant alternative income on Mohéli (C3-Comores, unpublished data).

Gear alternatives for fishers

Prohibitions on fishing gear (gillnetting, spearfishing, dynamiting and poisoning) were identified as a constraint by several communities (Table 1). The main concern was the reduction in catch as a result of restrictions, particularly during rough weather. There was also no consensus among communities on the actual effects of these regulations on fisheries yields. Without demonstrated fisheries-enhancement effects, PMM will be unable to win over fishers who have lost income following gear prohibitions.

Some villages respected regulations but felt that their efforts were futile because fishers in other villages continued to use banned methods and benefit from higher catches. As a result, many fishers felt that they had not received adequate compensation to date, such as alternative sources of income or alternative fishing methods. This problem was recognized in 2001, when the gillnet and spear fishers of Nioumachoua expressed their dissatisfaction that Nioumachoua's alternative income-generating scheme (ecotourism facilities) had failed to provide them, the 'victims' of PMM, with any benefits (Loupy, 2001). Motorized boat donations have also proved inadequate and have caused conflicts in the villages involved.

There is a clear need to directly address these issues and provide realistic alternatives for these fishers. All fishers requested training in the use of alternative fishing gears. Women appeared to have been the most innovative in experimenting with new fishing methods (e.g. catching fish in baskets or *shiromanis* (traditional cloths) at low tide or using a hook, bucket, and wooden stick to catch octopus at high tide).

Inequitable Distribution of Benefits

A lack of transparency in the management of PMM and an inequitable distribution of its benefits were major concerns voiced by local communities (Table 1). Stakeholders felt that benefits were being concentrated in Nioumachoua, the headquarters of PMM or villages such as Itsamia that host more conspicuous marine attractions such as turtles. These views regarding distribution of benefits were a root cause of the ubiquitous feelings of resentment towards PMM. This dissatisfaction and distrust have clearly contributed to stakeholders' non-compliance with PMM regulations and their unwillingness to actively participate in effective co-management.

It became evident through focus group interviews and discussion with PMM staff that Ndrondroni and Hamavouna were the most socially and economically-marginalized villages within PMM as well as the most excluded from its activities. Unsurprisingly, they were also the two PMM villages most notorious for turtle poaching and a lack of compliance with PMM regulations, which was blamed on their Anjoaunais origin (Boinali, pers. comm. 2006). Furthermore, as both villages have poorer infrastructure and services when compared to the other eight villages, they are less likely to gain any direct benefits from tourism. As a result, if PMM is to function effectively as a whole, great efforts need to be made to equally include all villages and attempt to share benefits throughout the park.

It was also expected that there would be a lack of environmental awareness in Hamavouna and Ndrondroni as well as villages located further from the coast or the PMM headquarters but this was not so. Women in Itsamia and Nioumachoua were classified as having no awareness of PMM. This was unexpected since PMM headquarters, PMM's technical staff and two ecoguards are located in Nioumachoua. Itsamia is the only other village with more than one ecoguard and is known throughout the Comoros as a pioneering village in terms of turtle conservation and its dynamic village association, ADSEI. The lack of awareness in these villages could be because (1) less emphasis was placed on environmental education as it was assumed that information would be automatically disseminated through the physical presence of PMM personnel or (2) because of the strong PMM presence, less effort was made to develop community co-management since PMM personnel were expected to directly take on these responsibilities.

Exclusion of Women

'We know nothing about PMM except for the activities that are now prohibited and the names of the PMM personnel that work here – we don't even know what these personnel do.'- Women of Nioumachoua.

Participation of women in coastal resource use is rarely appreciated and tends to receive little, if any, economic remuneration (Van Ingen et al., 2002). Great disparity in knowledge and awareness of PMM was noted according to gender, with women showing much lower levels of awareness (Fig. 3). The vast majority of women (in 70% of villages) felt that they had not played any role in the creation of PMM and four female focus groups also remarked that they

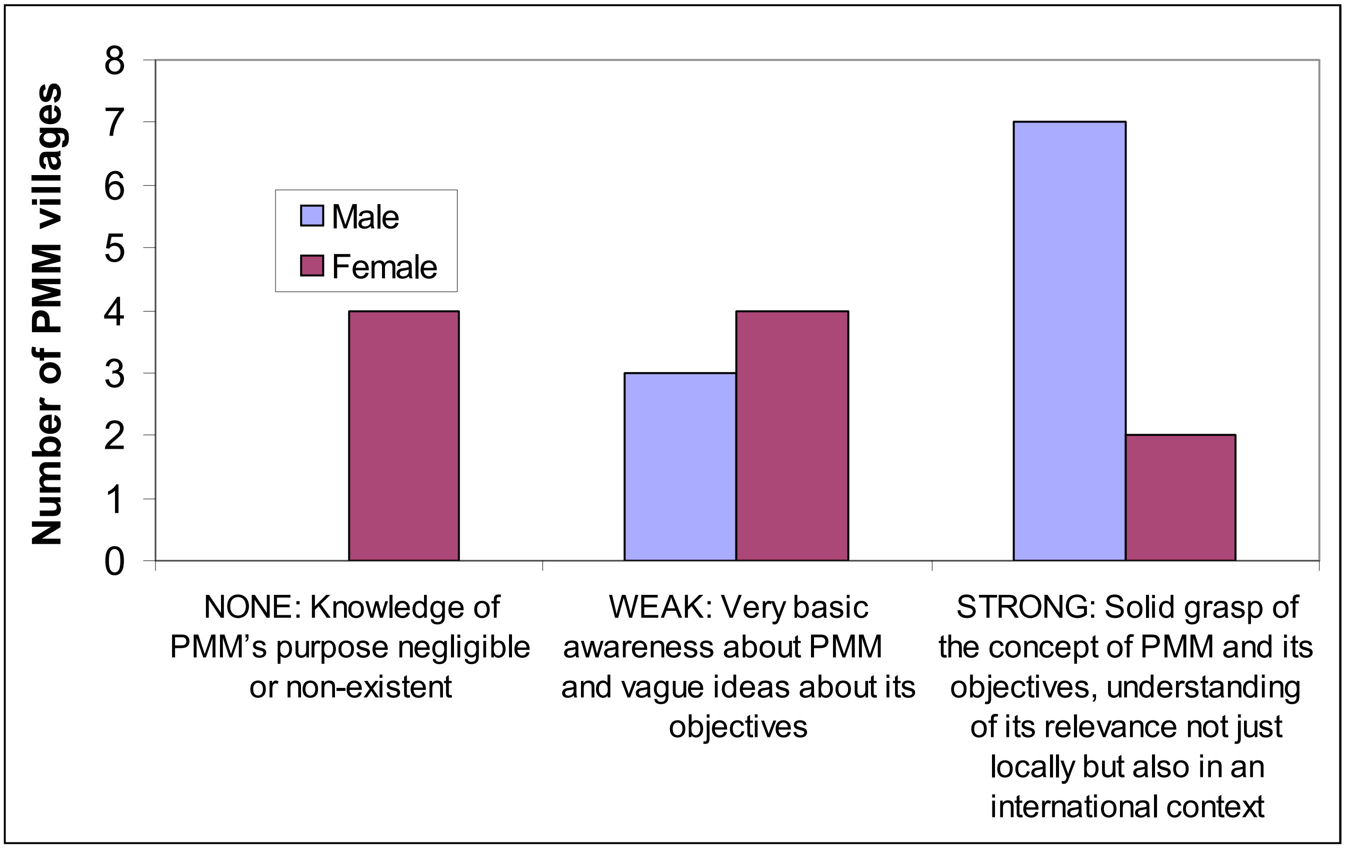

Figure 3. Stakeholder awareness of PMM in male and female focus groups.

remained uninformed and ignorant of park activities as well as conservation in general. In spite of this, the women who participated in the focus group interviews were motivated and inspired; they were eager for training in all conservation activities, including nightly surveillance of beaches for turtle poachers.

Environmental Threats

Turtle poaching

Turtle poaching was the most commonly cited threat within PMM (Fig. 4). Communities felt that poaching of endangered species was a serious problem and had a negative impact on the environment and tourism. The motivation behind hunting turtles for meat was for its taste, low cost, and because consuming turtle meat is believed to bestow strength.

Destruction of coral and octopus fishing

The destruction of coral was also regarded as a significant problem within PMM (Fig. 4). This was an issue often raised by female focus groups, as it is more common for women to collect octopus or other marine species at low tide (a fishing technique known locally as mtsohozi), thus they directly witness impacts on coral. Coral damage was frequently identified as a result of octopus fishing practices; particularly through the use of iron rods *(ntshora)* or rocks to smash coral and extract the octopus. While the use of iron rods was not officially banned under PMM regulations, it has been regarded as an infraction as a form of spearfishing (Loupy, 2001).

Walking on coral at low tide was identified as another cause of destruction. Some groups also noted the collection of coral for construction, although this

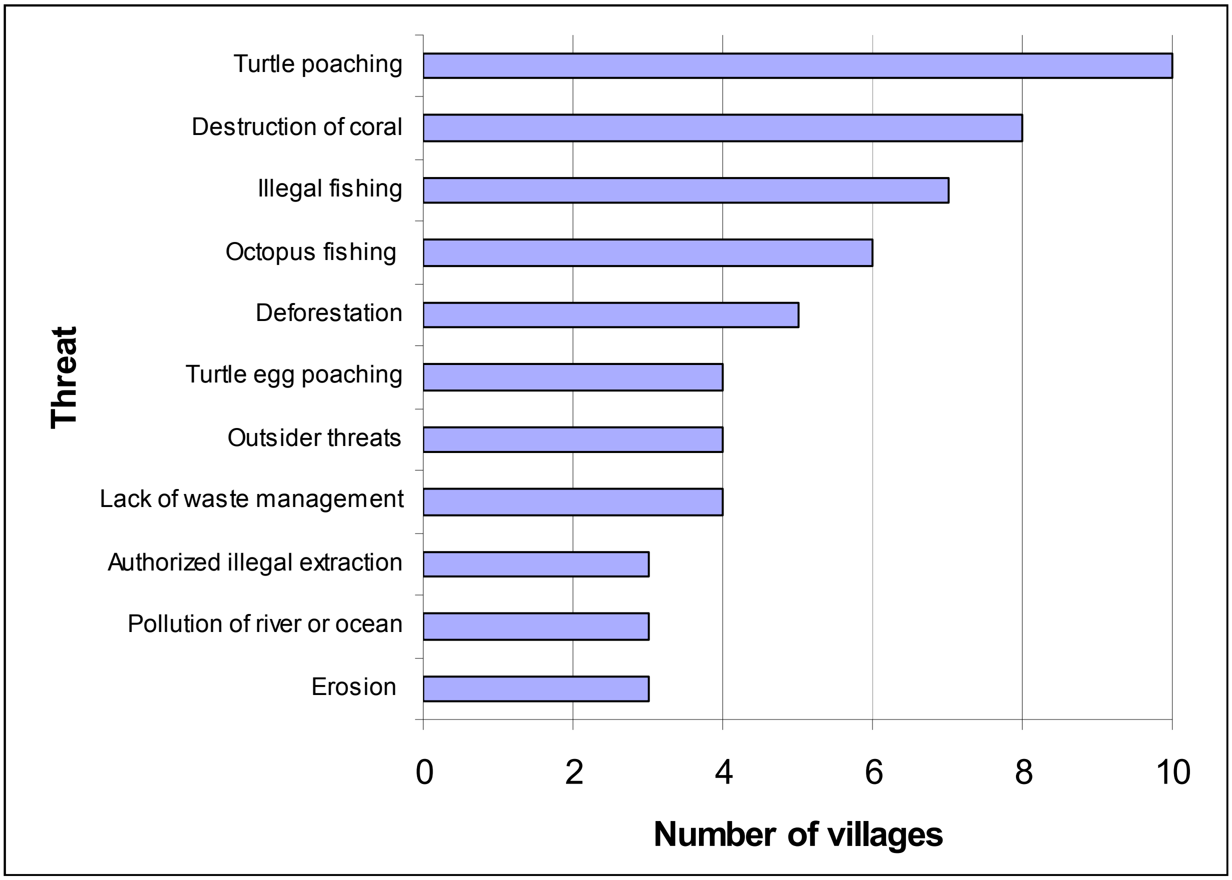

Figure 4. Environmental threats identified during focus group interviews in order of priority.

has been less frequent in recent years. The men of Ndrondroni claimed that before PMM, they mined coral and it grew back quickly; but now it does not return. The source of these perceptions could be the 1998 coral bleaching event which resulted in severe levels of mortality throughout the Indian Ocean (Obura, 2001).

Illegal fishing

Although knowledge of the prohibitions on fishing methods was widespread throughout PMM, stakeholders from the majority of villages (70%) stated that the use of prohibited fishing gears continued to be a problem within PMM (Fig. 4). These methods were used openly, in hiding, and/or by fishers from neighbouring villages. Many focus groups were particularly concerned with the damaging effects of gillnetting, such as coral damage and by-catch. The authorization of gillnetting within PMM during the month of Ramadan in 2005 caused conflict and radiated mixed messages; some men stated that they felt that this authorization negated their conservation efforts. Many fishers also remarked that they have never been aware of the location of the PMM no-take zones and that PMM personnel did not enforce these zones.

Deforestation

Deforestation, the fifth most important concern, (Fig.4) was considered a result of cultivation practices that involve felling large numbers of trees and swidden agriculture. Erosion was recognized as the most damaging result of deforestation, leading to sedimentation and damage to coastal habitats such as seagrass and coral reefs, particularly during periods of high rainfall. Deforestation of mangroves was not cited as an extensive problem on Mohéli since mangrove wood is not widely used. Communities also expressed fear of mangrove areas because of evil spirits.

Monitoring and Enforcement

'The fishermen here are doing poachers a favour by protecting the turtles so that they can come here to kill and eat them' – a Nioumachoua fisher.

Lack of effective monitoring or enforcement ranked second for negative aspects of PMM (Table 1). This issue was raised in 8 villages where respondents stated that the lack of permanent monitoring and enforcement was leading to a continuation of turtle poaching and destructive fishing practices. As a result, local communities have become de-motivated. Resentment has arisen from the fact that those that do respect regulations gain no benefits, while those that do not respect regulations gain increased benefits. Lack of enforcement has also led to the perception that PMM no longer exists and thus, people may carry out illegal activities with no fear of incrimination.

CONCLUSIONS AND RECOMMENDATIONS

The objectives of PMM were clearly envisaged, although their implementation has not yet been fully realized. PMM must act urgently in order to realign its management activities and re-establish itself as an effective MPA. The most pressing points of action identified by this study are:

(1) ensure sustainability through effective financial planning and promotion of low-cost, appropriate management techniques

An effective business plan and trust fund or other means of sustainable finance should be developed and there is a need to move away from external funds, and focus on low-cost, appropriate management that can continue if there are financial problems in the future

(2) mobilize local communities to create a truly co-managed PMM

All decisions are currently being made by one or two people who are not representative of PMM communities; the Management Committee must be fully involved and their power of authority reinforced as representatives of the 10 villages for decision-making in PMM.

(3) ensure tangible benefits to local communities through realistic alternative livelihood options, particularly for fishers.

A frame survey and socioeconomic assessment of fisheries are essential first steps, followed by research and implementation of alternative gears and livelihoods.

(4) ensure equitable sharing of benefits and awareness of PMM

An initial focus on Hamavouna and Ndrondroni is required, involving an intense awareness-raising and education programme to instil a new understanding in these communities for their natural resource and ecotourism benefits must be equally distributed.

(5) involve women in the management of PMM, they are the primary local educators and motivators for future generations

This may be achieved through targeted awareness raising programmes, training of female ecoguards, ecoguides and community trainers and promotion of sustainable alternative livelihoods for women (from artisanal craft-making to new fishing methods).

(6) inform law enforcement officials and members of the justice system to ensure understanding, respect and enforcement of PMM regulations.

Targeted training workshops in the ecological and economic importance of natural resources will help to ensure the effective application of environmental regulations, particularly through the community reward system for the reporting of PMM infractions.

'We want youth to be involved with PMM. We want them to become motivated and to forget about all the past negative aspects associated with PMM. We want them to be able to gain the benefits. Our generation has failed, but we should look to improve

the situation for the following generations.' – Man from Ndrondroni

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Coral Reef Monitoring in Marine Reserves of Northern Madagascar

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keywords: Madgascar, coral reef monitoring, coral bleaching, marine protected areas

ABSTRACT

This study has provided detailed biophysical information on shallow to mid-depth coral reef habitats for the existing National Marine Parks at Masoala and Mananara and for the recently designated Sahamalaza National Park, all located in northern Madagascar. Data indicates that large scale disturbance events such as severe tropical storms are a major influence on shallow and mid-depth coral reef habitats in the marine parks. Differences in benthic composition were also governed by differences in marine habitat according to exposure gradients. A preliminary investigation of the effects of management practices on coral reef fauna did not reveal any significant differences between park zones, such as higher reef fish biomass in protected compared to unprotected reefs. Low to moderate fishing pressure on reefs adjacent to marine parks is likely to be a primary contributing factor to this lack of difference in marine resource availability between management zones.

INTRODUCTION

Considering the length of the Malagasy coastline,

Figure 1. Map of Madgascar, showing the MPAs monitored in the text: 1) Sahamahalaza, 2) Masoala (containing the 3 reserves Tanjona, Cap Masoala and Tampolo), and 3) Mananara Nord.

estimated to be more than 5000 km (Cooke et al., 2003) there are very few marine protected areas in Madagascar. At the national level, Madagascar currently has only two fully established national parks with a marine element to them; Nosy Atafana marine reserve in the Mananara Nord Biosphere Reserve and Masoala National Park which contains three marine reserves; Tampolo, Masoala and Tanjona. There are other smaller marine reserves at Nosy Ve in the south-west and Nosy Tanikely near Nosy Be in the northwest. However Nosy Ve is not yet recognised at the national level although it is protected by local law (Dina). Nosy Tanikely has some national conservation status in that fishing is prohibited within 300 metres of the island but this is poorly enforced with infringements known to occur (Cooke et al., 2003). Monitoring of coral reefs in and around these protected areas has varied. The most comprehensive programme is in the Masoala National Park conducted by the National Parks Authority (ANGAP) in collaboration with the Wildlife Conservation Society (WCS). Monitoring of one or two sites in each of the three reserves at Masoala began in 1998 and was expanded from 2002 onwards. At other sites patchy data has been recorded and some baseline assessments completed (Wilkinson 2000, Randriamanantsoa and Brand 2000).

As part of the National Environmental Action Plan (NEAP) three further marine parks were designated for establishment at the end of 2005. One of these is the Sahamalaza marine park which already has UNESCO Biosphere Reserve status. The others are Nosy Hara archipelago in the far north-west and Nosy Ve, near Anakao in the south-west of Madagascar. The proposed parks will be managed by ANGAP in collaboration with the following international NGO's and national institutions; SAGE at Sahamalaza, WWF at Nosy Hara and IHSM at Nosy Ve. The primary aim of this study was to expand coral reef monitoring in Madagascar at two of the existing and one of the proposed marine reserves and to extend monitoring to deeper depths. This paper summarizes some of the main points of the full monitoring report (Harding and Randriamanantsoa, 2006). Socio-economic monitoring from the same sites is also reported in Cinner et al. 2006 (and Cinner & Fuentes, 2008).

Coral reefs in Madagascar are under threat from climate change induced events such as mass coral bleaching and more direct anthropogenic induced impacts of sedimentation and overfishing. Corals on shallow reefs (<10 metres depth) in south western Madagascar were dramatically affected by the 1998 bleaching event, north-western Madagascar was not significantly affected and the north-east was intermediate between these (McClanahan and Obura, 1998). The main large scale disturbance events that occur in northern Madagascar are severe tropical storms which mainly occur between December and April, affecting both eastern and western sides. There have been three major cyclones in the north of Madagascar since 2000: Hudah (April 2000), Gafilo (March 2004) and Indlala (March 2007).

METHODOLOGY

Study site locations were selected so that surveys were conducted both within marine protected areas of each marine park or reserve and in unprotected areas open to fishing pressure adjacent to the marine parks. In Sahamalaza 12 sites were sampled, mostly on offshore submerged barrier reefs at 11-13 m depth, with one site each on inshore patch and island fringing reefs at shallower depths. At Tanjona, Cap Masoala and Tampolo in Masoala 4-5 sites each were sampled on the seaward spur and groove and fringing and patch reef areas at 5-10 m depth. At Mananara Nord 4 sites were sampled on fringing reef areas at 8-12 m depth.

Ecological monitoring of coral reefs and associated systems followed standard methodology as used by the Global Coral Reef Monitoring Network (GCRMN) and outlined in Hill and Wilkinson (2004). The majority of sites were assessed using fixed, haphazardly placed transects for benthic composition, reef fish biomass and invertebrate density.. Benthic cover was recorded using the point intercept transect method (PIT, 20 cm between points) on 4 replicate transects

Table 1. Benthic composition at marine park locations in northern Madagascar (mean values of percentage cover + standard error. n = 16).

Benthic Category	Sahamalaza		Tanjona		Cap Masoala		Tampolo		Mananara	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Sand	8.2	2.0	1.1	0.5	0.9	0.4	9.3	1.9	4.1	1.0
Bedrock	5.8	1.6	2.3	0.6	2.4	0.6	1.9	0.4	1.3	0.2
Rubble	6.8	1.8	0.3	0.1	2.2	0.5	0.9	0.3	3.9	0.7
Turf Algae	24.9	2.6	20.4	1.7	30.7	2.3	36.4	1.6	28.6	3.0
Macroalgae	2.3	0.8	9.7	2.0	0.8	0.2	4.8	1.1	2.4	0.7
Calcified Algae	16.4	1.8	29.9	2.7	36.7	2.4	10.6	1.4	34.9	2.8
Sponge	2.6	0.5	0.6	0.2	0.8	0.3	1.7	0.5	1.6	0.3
Other Invertebrates	0.6	0.3	0.4	0.2	1.5	0.9	1.1	0.5	0.4	0.2
Soft Coral	14.1	2.2	23.0	2.7	10.8	1.1	7.8	2.3	8.9	1.7
Acropora Corals	1.7	0.5	1.4	0.4	4.3	1.3	1.1	0.5	0.6	0.3
Non-*Acropora* Corals	14.8	2.4	10.7	1.2	8.6	0.9	23.2	3.4	12.8	1.7
Live Hard Coral	16.4	2.5	12.1	1.1	13.0	1.6	24.3	3.5	13.4	1.7

of 20 metres in length. Sessile organisms were recorded to genus 'in situ' when possible and confirmed using digital photographs using Veron (2000), Fabricus and Alderslade (2004), Littler and Littler (2003) and Richmond (2002).

Sixteen fish families were selected for monitoring, representing the main trophic groups of reef fish occurring in the study regions and the main fish families targeted by local fishers. At each site two replicate belt transects 50 metres in length, 5 metres wide and 5 metres deep were used. Individual fish were recorded in 5 cm size classes between 0 and 50 cm total length (TL) or 10 cm size classes between 50 and 100 cm TL. Fish length estimation at Sahamalaza and Tanjona used slightly different size class categories. For these sites fish were counted into six size categories as follows: 0-20 cm, 20-35 cm, 35-50 cm, 50-65 cm, 65-80 cm and more than 80 cm TL. Biomass for each family was calculated using biometric equations derived from moderately fished reef fish populations sampled in Kenya (McClanahan, unpublished) and converted to kilograms per hectare of reef area. Selected macro-invertebrates were recorded in the 50 x 5 metre belt transects, identified to species when possible. Commercially harvested (sea cucumbers, octopus, lobster), rare (large gastropod molluscs) or ecologically significant (herbivorous urchins) invertebrates were the main taxa selected for monitoring.

RESULTS

Between October 2005 and February 2006 a total of 24 sites were surveyed using fixed transects at the three national parks. Sites were located both within the marine protected areas of the reserves and in adjacent unprotected areas. At Masoala National Park and Sahamalaza, sites inside the parks were positioned in the core 'no-take' areas where all fishing is prohibited. For inter-park comparison 4 survey sites were selected at each park that represented the main reef type assessed for each park location in this study. For intra-park comparisons the four sites were then split into two groups depending on their location either inside or outside the marine park (see Harding and Randriamanantsoa, 2006 for details).

Benthic Composition

Benthic composition varied considerably between parks and often between sites within the same marine park location. Sahamalaza was characterised by relatively high levels of abiotic substrata (20.8%) consisting mainly of sand and coral rubble (Fig. 2, Table 1). Turf and calcified algae were the main components of the benthos with a combined cover of 41.2%. Macroalgal cover was low at the four sites combined (2.3%) but higher on the inshore patch reef (Site 1) at 20.5%. Coral cover on the top of the submerged barrier reef was just over 30% of the available substratum and was evenly split between hard (16.4%) and soft (14.1%) corals.

Marine parks on the more exposed east coast of Madagascar, with the exception of Tampolo, were characterised by a high cover of calcified algae mainly crustose coralline algae (CCA) but also branching calcified reds which included *Amphiroa Lithophyllum* and *Neogoniolython* spp. Calcified algae cover ranged between 29.9% and 36.6% for marine park locations at Mananara, Cap Masoala and Tanjona (Fig. 2, Table 1). The second largest component of the benthos was turf algae ranging between 20 and 30%. Macroalgal cover was low at both Mananara and Cap Masoala and did not exceed 3%. Higher cover of macroalgae was

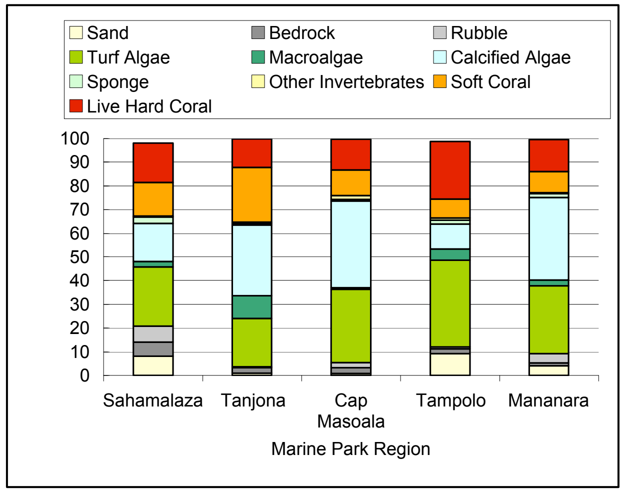

Figure 2. Benthic Composition at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

recorded at Tanjona (10.0%) and was mainly attributed to loosely attached spherical clumps of the red alga *Galaxaura subverticillata*.

Total coral cover (octocorals and hexacorals) for east coast parks ranged from 22.3% at Mananara to 35.1% at Tanjona. The latter location differed from other marine parks on the east coast by having a higher proportion of soft coral cover than hard coral. Soft corals made up 23% of the benthos while hard coral cover was 12.1% at Tanjona. Hard coral cover at Cap Masoala (13.0%) and Mananara (13.4%) was similar to levels recorded at Tanjona. Tampolo sites had the highest hard coral cover of any park location (24.3 %) but also highest standard error (3.5) indicating that inter-site variation was greatest at this location.

Cover of other sessile invertebrates was low across all marine park locations. Sponge cover was highest at Sahamalaza (2.6%) and less than 2 % at all other parks. Cover of other sessile invertebrates (zooanthids, anemones, coralliomorphs, giant clams and ascidians) ranged between 0.4 and 1.5%.

Closer examination of hard coral cover reveals that the genus *Acropora* was occasionally or rarely recorded on transects at the marine park locations (Table 1, Fig.

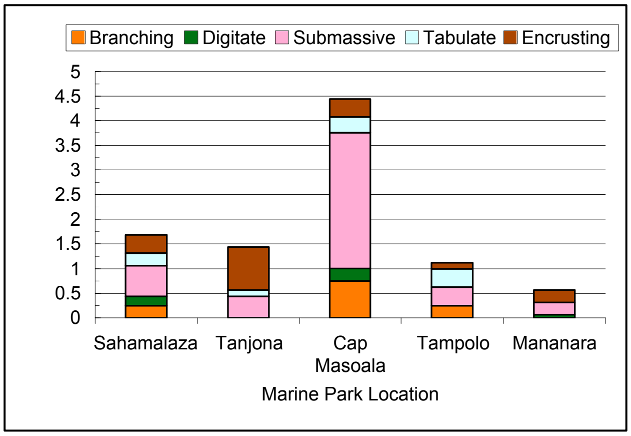

Figure 3. Percentage cover of *Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

3). Mean *Acropora* cover was less than 1.7% at all marine parks with the exception of Cap Masoala (4.5%). The main *Acropora* lifeforms present were submassive and encrusting and were more prominent at the more exposed locations of Mananara, Cap Masoala and Tanjona. Non-*Acropora* corals made up the bulk of hard coral cover at all sites but total cover for this category varied considerably between marine park locations (Table 1, Fig. 4). Mean total cover remained between 8 and 15% for all park locations

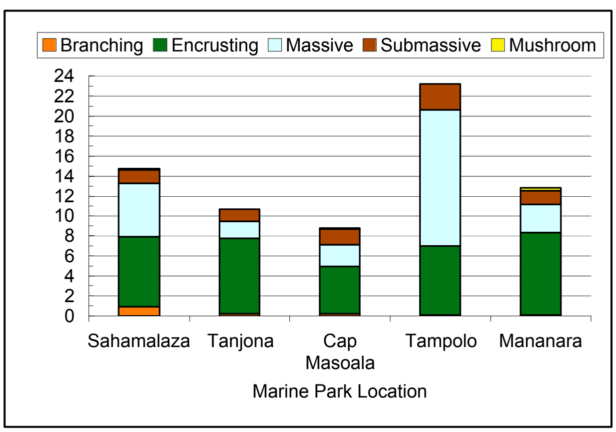

Figure 4. Percentage cover of Non-*Acropora* lifeforms at Marine Parks in northern Madagascar (mean values of four sites combined, n = 16).

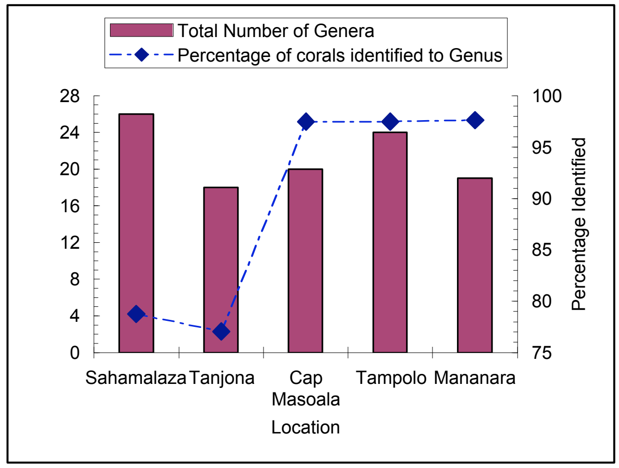

Figure 5. Comparison of hard coral diversity between marine park locations.

except for Tampolo (23.2%). The vast majority of non-*Acropora* corals were either encrusting or massive forms with submassive colonies also recorded at all locations. Branching lifeforms were rarely recorded, with a maximum cover of 0.9% at Sahamalaza but were present at all locations.

The highest number of hard coral genera (26) was recorded at Sahamalaza (Fig. 5) even though the proportion of colonies identified to genus at this location was low (78.8%) compared to other parks (except Tanjona). On the east coast of Madagascar hard coral generic diversity was similar at Mananara, Tanjona and Cap Masoala (18-20 genera) while Tampolo had a higher diversity with 24 genera recorded. Porites was the most abundant genus at Sahamalaza, Tampolo and Mananara and dominated the hard coral fauna at Tampolo. Large *Porites* massive colonies were frequent at Tampolo but encrusting forms were dominant at Mananara and Tanjona. Branching forms of *Porites* were rare but were recorded more often at Sahamalaza. Faviids (*Favia*, *Favites* and *Platygyra*) were a regular and significant component of the hard coral fauna at all park locations and were particularly prominent at Mananara and Tampolo. Mussids such as *Lobophyllia* were also important components at these two

Table 2. Reef fish biomass at marine park locations in northern Madagascar (Mean values of kg/ha. + standard error). N = 8 x 50 m transects except Sahamalaza (n = 6) and Cap Masoala (n = 4 x 100 m transects).

Family	Sahamalaza		Tanjona		Cap Masoala		Tampolo		Mananara	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Acanthuridae	441.5	240.6	258.6	40.2	144.8	48.4	312.4	111.6	261.0	62.8
Balistidae	13.4	2.7	9.3	9.9	9.1	8.5	0.9	1.0	2.3	1.6
Caesionidae	193.7	119.6	35.9	37.8	32.4	37.4	51.6	20.3	65.2	34.3
Carangidae	20.5	19.2	0.0	0.0	0.0	0.0	59.5	61.8	0.0	0.0
Chaetodontidae	23.9	14.4	13.4	7.0	4.0	1.7	5.4	0.9	10.7	1.9
Haemulidae	11.8	9.6	0.0	0.0	0.0	0.0	7.0	4.9	5.5	4.7
Labridae	73.1	13.0	69.9	18.8	69.0	20.5	71.4	27.9	96.5	13.2
Lethrinidae	33.1	19.2	1.0	0.5	0.0	0.0	2.2	2.3	2.8	2.3
Lutjanidae	14.4	11.0	0.0	0.0	0.0	0.0	1.2	0.7	0.0	0.0
Mullidae	6.5	2.2	0.6	0.4	0.6	0.6	4.1	2.6	6.2	2.7
Pomacanthidae	14.4	7.1	6.7	6.2	18.8	13.3	16.4	6.9	3.5	3.4
Pomacentridae	6.8	1.0	17.8	4.9	18.5	4.8	19.7	3.9	23.2	4.6
Scaridae	54.5	16.6	121.5	42.7	44.2	5.8	25.2	12.3	95.1	35.7
Serranidae	5.7	4.2	51.3	46.8	133.4	88.9	27.0	16.9	47.8	17.6
Siganidae	15.6	10.0	0.0	0.0	0.5	0.5	21.6	12.1	14.2	10.2
Total	**929.0**	**252.0**	**585.9**	**110.5**	**475.1**	**95.7**	**625.6**	**163.4**	**634.0**	**102.4**

locations. *Acropora* was the most commonly recorded genus at Cap Masoala and also notable at Tanjona and Sahamalaza. The latter two park locations contained the highest cover of *Turbinaria* spp. Encrusting forms of *Millepora* were a prominent part of the hard coral fauna at Tanjona. *Galaxea* was most often recorded at the three park locations around the Masoala Peninsula.

Reef Fish Biomass

Reef fish biomass was calculated for six size categories (0-20 cm, 20-35 cm, 35-50 cm, 50-65 cm, 65-80 cm and > 80 cm). Mean values of total reef fish biomass for 15 families combined were higher on the west coast of Madagascar at Sahamalaza (929 kg/ha) than at east coast locations on the Masoala Peninsula and Mananara (475–634 kg/ha). However, a large variance between sites was found at both Sahamalaza (s.e. = 252) and Tampolo (s.e. = 164), and total biomass estimates were not statistically different between marine park locations (Oneway ANOVA on log(x) transformed data). Cap Masoala had the lowest total biomass values for the 15 recorded families, but the highest biomass for groupers (Serranidae) although variation between counts for this family was also high (Table 2).

Highest biomass was recorded for Acanthurids (144 – 441 kg/ha), which made up 40-50% of total biomass at four of the five park locations and more than 30% at Cap Masoala (Table 3). The second largest component of fish biomass varied between marine park locations and consisted of Caesionids at Sahamalaza, Groupers (Serranids) at Cap Masoala, Labrids at Tampolo and Mananara and Scarids at Tanjona. Biomass of Labrids was similar across all marine park locations (69-96 kg/ha) and this family was consistently ranked highly, as were Scarids and Caesionids (Table 3). Scarid biomass was more variable with highest values recorded at Tanjona (121 kg/ha) followed by Mananara (95 kg/ha). Biomass of

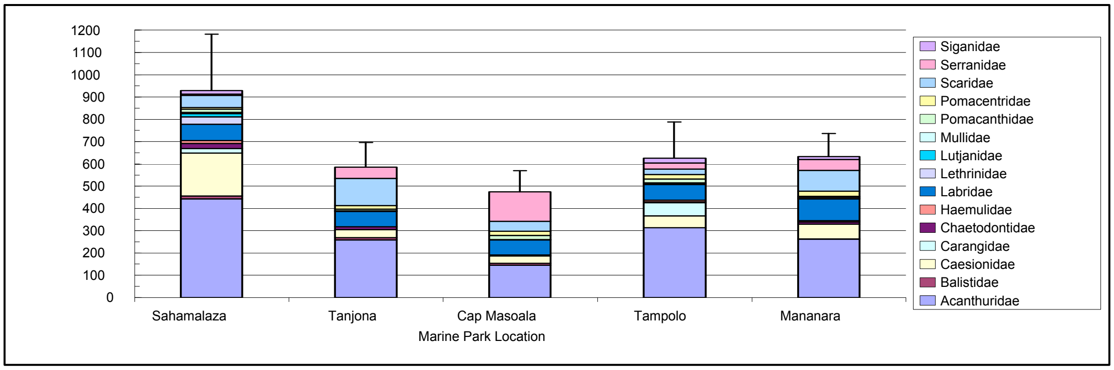

Figure 6. Reef Fish Biomass for Selected Families at Marine Park Locations in Northern Madagascar (Mean values of kg/ha. with standard error shown for total biomass).

Table 3. Percentage contribution of fish families to total recorded biomass and ranking (in brackets).

Family	Sahamalaza	Tanjona	Cap Masoala	Tampolo	Mananara
Acanthuridae	47.53 (1)	44.14 (1)	30.48 (1)	49.94 (1)	41.16 (1)
Balistidae	1.44 (11)	1.58 (8)	1.91 (8)	0.15 (15)	0.36 (13)
Caesionidae	20.85 (2)	6.12 (5)	6.81 (5)	8.24 (4)	10.28 (4)
Carangidae	2.21 (7)	0 (12=)	0 (12=)	9.51 (3)	0 (14=)
Chaetodontidae	2.58 (6)	2.29 (7)	0.84 (9)	0.87 (11)	1.68 (8)
Haemulidae	1.27 (12)	0 (12=)	0 (12=)	1.11 (10)	0.86 (11)
Labridae	7.87 (3)	11.93 (3)	14.51 (3)	11.41 (2)	15.23 (2)
Lethrinidae	3.57 (5)	0.17 (10)	0 (12=)	0.34 (13)	0.45 (12)
Lutjanidae	1.55 (9)	0 (12=)	0 (12=)	0.20 (14)	0 (14=)
Mullidae	0.70 (14)	0.09 (11)	0.12 (10)	0.65 (12)	0.98 (9)
Pomacanthidae	1.55 (10)	1.15 (9)	3.96 (6)	2.62 (9)	0.55 (10)
Pomacentridae	0.73 (13)	3.03 (6)	3.89 (7)	3.15 (8)	3.61 (6)
Scaridae	5.87 (4)	20.74 (2)	9.30 (4)	4.03 (6)	15.00 (3)
Serranidae	0.61 (15)	8.75 (4)	28.08 (2)	4.32 (5)	7.54 (5)
Siganidae	1.68 (8)	0 (12=)	0.10 (11)	3.46 (7)	2.25 (7)

Pomacentrids was considerably lower at Sahamalaza than at other marine park locations (Table 2, Fig. 6). Highest biomass of Chaetodontids, Balistids, Lethrinids, Lutjanids and Haemulids were all recorded at Sahamalaza. The latter three families were not recorded often at sites on the east coast of Madagascar.

Macro-Invertebrates

Herbivorous urchins in three genera (*Diadema*, *Echinothrix* and *Echinometra*) were not recorded at all on submerged barrier reef sites at Sahamalaza but were present on inshore reef sites where *Diadema* was the

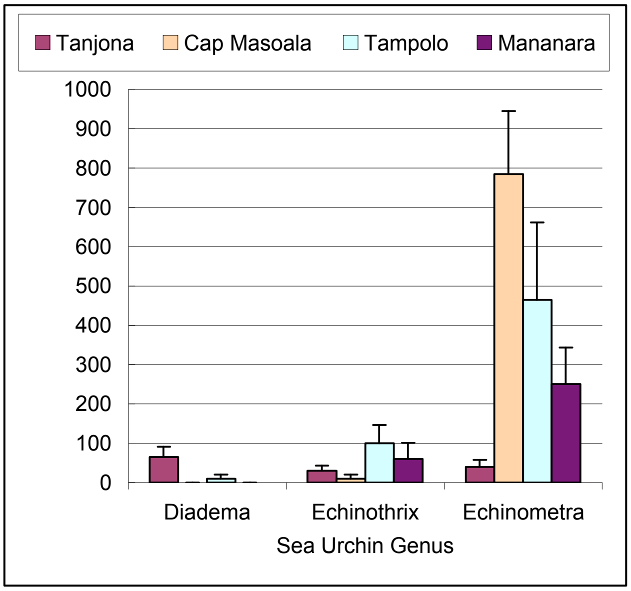

Figure 7. Herbivorous Urchin Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

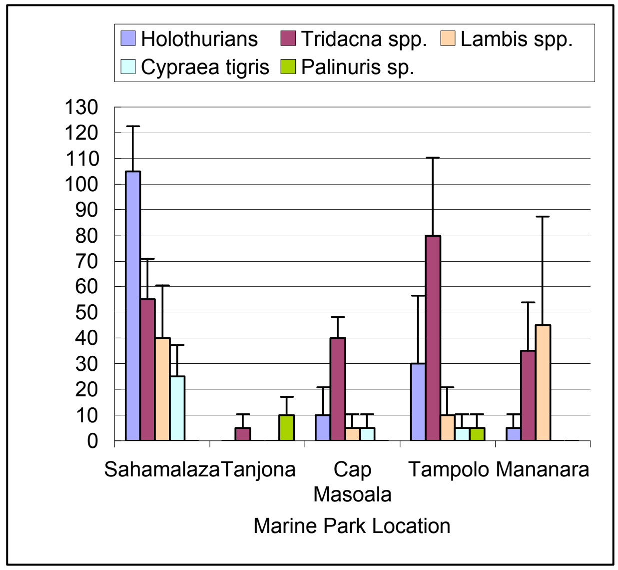

Figure 8. Invertebrate Densities at Marine Park Locations in Northern Madagascar (Mean values + SE, n = 8).

most abundant genus. On east coast sites *Diadema* and *Echinothrix* densities were low, with less than 100 per ha (Fig. 7). Considerably higher densities of *Echinometra* were recorded at most east coast parks, particularly at Cap Masoala and Tampolo where mean densities ranged from 465 to 785 ha^{-1} with high variation between sites and transects. The small burrowing urchin *Echinostrephus molaris* was present at all locations and often at high densities but was not recorded in this study. Densities of holothurians also varied considerably between park locations (Fig. 8). Holothurians were the most abundant and diverse at Sahamalaza on the submerged barrier reef with a mean density of 105 ha^{-1} and a total of five genera recorded. Densities at the other locations did not exceed 30 ha^{-1} with only one or two genera recorded at each park. Mean densities of giant clams (*Tridacna* spp.) were similar at Sahamalaza, Cap Masoala and Mananara (35-55 ha^{-1}). Highest densities were found at Tampolo (80 ha^{-1}) with few individuals recorded at Tanjona. High densities were also seen at the shallow inshore site on Nosy Berafia at Sahamalaza, where numerous small individuals of *Tridacna squamosa* were present.

Conch shells (*Lambis* spp.) were recorded more often at Sahamalaza and Mananara than at the three locations on the Masoala Peninsula. Tiger cowries (*Cypraea tigris*) were not seen on transects at Mananara or Tanjona, occasionally recorded at Cap Masoala and Tampolo and most abundant at Sahamalaza. Lobster (*Palinurus* sp.) were recorded at low densities at Tanjona and Tampolo but not on transects at the other three park locations.

Other invertebrates not recorded in transects were *Acanthaster plancii* and *Cassis cornuta*. *Charonia tritonis* was observed in Sahamalaza on two occasions on inshore sites (Sites 1 and 5). Another rare species also seen at Sahamalaza but not on transects was *Heterocentrotus mammilatus*.

Marine Park Zones Comparison

There were few significant differences in benthic cover, reef fish biomass and invertebrate density between sites inside the marine protected areas where fishing is either officially restricted (Mananara-Nord

Table 4. Statistical comparison of coral reef indicators inside and outside of marine parks in northern Madagascar (Two-sample T-test on transformed data). Data Transformations used: Arcsin for Benthic Percentage Cover, Log(x) for Fish Biomass and Square-root (x + 0.5) for Invertebrate Densities. Significance levels: * = p< 0.05, ** = p< 0.01, n.s. = not significant, n.t. = not tested, I>O = greater inside MPA than outside, I<O = greater outside MPA than inside.

	Sahamalaza	Tanjona	Cap Masoala	Tampolo	Mananara
Benthic					
Hard Coral	* I>O	n.s.	n.s.	** I<O	** I<O
Soft Coral	n.s.	* I<O	n.s.	* I>O	n.s.
Turf Algae	n.s.	n.s.	n.s.	n.s.	n.s.
Calcified Algae	n.s.	** I>O	n.s.	n.s.	n.s.
Abiotic Cover	n.s.	n.s.	n.s.	n.s.	n.s.
Reef Fish					
Acanthuridae	n.s.	n.s.	n.s.	n.s.	n.s.
Balistidae	n.s.	n.t.	n.t.	n.t.	n.t.
Chaetodontidae	n.s.	n.s.	n.s.	n.s.	n.s.
Labridae	n.s.	n.s.	n.s.	n.s.	n.s.
Mullidae	n.s.	n.t.	n.t.	n.t.	n.t.
Pomacentridae	n.s.	n.s.	* I<O	n.s.	n.s.
Scaridae	n.t.	n.s.	n.s.	n.s.	n.s.
Serranidae	n.t.	n.s.	n.s.	n.s.	n.s.
Total Biomass	n.s.	n.s.	n.s.	n.s.	n.s.
Invertebrates					
Holothurians	n.s.	n.t.	n.s.	n.s.	n.s.
Tridacna	n.s.	n.s.	n.s.	n.s.	n.s.
Echinometra	n.t.	* I>O	n.s.	n.s.	n.s.

Biosphere Reserve) or prevented (Masoala National Park marine reserve no-take zones) and outside of the marine parks, where there are no fishing restrictions (Table 4). Most of the statistical differences were found for benthic categories. Hard coral cover was significantly higher in the core marine park zones of the submerged barrier reef at Sahamalaza than at sites in the controlled fishing zone. However the opposite was found at Tampolo and Mananara with higher hard coral cover outside of the marine parks. Soft coral cover was higher in the no-take zone at Tampolo than outside the marine reserve. Conversely soft coral cover was significantly greater outside the marine park at Tanjona than in the no-take zone. Significantly higher cover of crustose coralline algae (mainly CCA) was recorded in the no-take zone at Tanjona than for seaward reef sites outside the marine park.

There were no significant differences in reef fish biomass between no-take zones and peripheral sites outside the parks with the exception of Pomacentrids at Cap Masoala where biomass for this family was higher outside the park than in the no-take zone.

Table 5. Summary of reef fish observations outside of survey transects at Marine Parks of Northern Madagascar.

Location	Date	Observation
Sahamalaza	17/10/05	1 *Charcharinus melanopterus*, 1 *Cheilinus undulatus*, 8 *Bolbometopon muricatum*
"	19/10/05	Five large Groupers (*Plectropomus* spp.) with three larger than 80 cm TL. Carangids and Haemulids also noted.
Tanjona	16/11/05	Three species of Scarid (*Scarus sordidus, S. niger* and *S. frenatus)* observed in a spawning aggregation.
Cap Masoala	12/02/06	Three large groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*).
"	12/02/06	School of 15-20 large *Scarus ghobban* 30-50 cm TL
"	14/02/06	Large *Plectropomus punctatus*
"	16/02/06	Large *Plectropomus punctatus*
Mananara	25/02/06	Large Groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*) and Haemulids (*Plectorhinchus playfairii*)
"	26/02/06	Large Groupers (*Plectropomus laevis, P. punctatus* and *Epinephelus caerulopunctatus*) and Haemulids (*Plectorhinchus gaterinus*)
"	27/02/06	Large Groupers (*Plectropomus laevis* and *P. punctatus*)

Similarly only one significant difference was found for invertebrates, where *Echinometra* densities were significantly higher inside the no-take zone of Tanjona marine reserve than on reefs outside the park boundaries. No significant differences in densities were found between managed and unmanaged reef sites for holothurians and giant clams at any marine park.

Other Observations

A number of observations were made during survey dives which should be noted. Firstly, although large reef fish such as Groupers were not recorded often on belt transects they were observed at a number of the study sites (Table 5).

DISCUSSION

The data presented in this report provide a detailed snapshot of the status of shallow to mid-depth coral reef habitats for three marine park locations in northern Madagascar. The majority of surveys were conducted at depth bands not previously assessed quantitatively at any of the marine parks thereby significantly adding to the biological and ecological information available for the park locations. Inter-park comparisons revealed notable differences in biophysical characteristics between locations, particularly between parks on the east and west coasts of Madagascar, but also between marine reserves on the east coast such as those located around the Masoala peninsula.

Mean levels of hard coral cover recorded at all marine park locations with the exception of Tampolo were rather low (10-20%) with a range of 2.75 – 23%. This is less than previous measures of hard coral cover for sites in northwest (Webster and McMahon, 2002; Wilkinson, 2002; 2004) and northeast (Wilkinson, 2000) Madagascar for reef slope habitats. A recent study in northwest Madagascar recorded a range of hard coral cover between 2.5 – 70.6% (McKenna and Allen, 2003) with almost two thirds (65.4 %) of sites between 12 and 16 m depth having more than 20% hard coral cover. Surveys on the outer reef slope at Antanambe and Nosy Atafana in 1999 (reported in Wilkinson, 2000) found hard coral cover levels of 83 and 85.7% respectively which differs markedly from our data for these locations where the range was 6-19.25%.

For all marine park locations in northern Madagascar it is likely that the three recent severe tropical storms have reduced hard coral cover in shallow and medium depths at both east and west coast locations. This is backed up by anecdotal observations at Sahamalaza, Mananara, Cap Masoala and Tanjona and evidence of drastic changes that occurred to the shallow marine environment as a result of recent cyclones (Toany and Rafenonirina, 2005). Coral bleaching was not observed during the study but previous bleaching events may have affected benthic composition at one or more of the marine park locations. The major bleaching event of 1998 affected coral reefs in southwestern Madagascar (Quod and Bigot, 2000; Cooke et al., 2003) and in the northeast (McClanahan and Obura, 1998) but was not thought to have influenced reef systems in the northwest of the country (Webster and McMahon, 2002). At the three marine park locations in northeast Madagascar we observed large old dead tabulate *Acropora* colonies in depths of 8–12 metres covered in CCA and fine algal turf. We speculate that the intact *Acropora* tabulate skeletons on seaward reef slopes at east coast sites were killed by an extreme event such as bleaching with 1998 the most likely year that this occurred. A mild bleaching event was also noted in Antongil Bay in March 2005 which affected many hard and soft coral species as well as anemones and giant clams (Jan and Harding, 2005) but subsequent mortality and recovery were not quantified. Low levels of coral bleaching have been reported in northwest Madagascar in recent studies (Webster and McMahon, 2002; McKenna and Allen, 2003).

Reef fish biomass estimates from this study are similar to those recorded for offshore barrier reef sites in southwest Madagascar at Andavadoaka (Harding et al., 2006) and Beheloka (Woods-Ballard et al., 2003) and for moderately fished inshore reefs in East Africa (McClanahan, 1994; McClanahan et al., 1999). The higher biomass recorded on the west coast at Sahamalaza than at east coast locations may be a true result in that the reef fish fauna is generally more abundant on the more extensive west coast reefs than on the east coast, however the difference was not statistically significant.

Measurements of fishing effort by subsistence fishers at the park locations indicate that overall effort is low to moderate (100-400 fishing trips/week) with higher reliance on fishing at Tanjona and low reliance at Mananara and Tampolo (Cinner et al., 2006). At Cap Masoala and Tanjona fishing effort is concentrated on the more sheltered back reef and lagoon habitats with fishing on the outer reef slopes restricted to occasional trips when weather conditions permit. At Mananara, fishing around Nosy Atafana has decreased since a ban on octopus fishing was introduced by ANGAP (J. Brand pers. comm.). In addition to subsistence fishing there are artisanal fishers targeting sharks and Holothurians in all the locations visited during this study. The higher densities of Holothurians recorded at Sahamalaza compared to east coast locations are likely to be attributed to differences in habitat rather than to fishing pressure. The more exposed shallow seaward reefs on the east coast are not a preferred habitat of sea cucumbers compared to the mixed sand and coral habitat in deeper water on the submerged barrier reef at Sahamalaza.

Surveys of target invertebrates indicate that densities of potential pest organisms such as *Acanthaster plancii* are very low for the areas assessed and do not currently pose a management problem. Herbivorous urchin densities were also generally very low with one exception; the shallow fringing reef on Nosy Berafia in Sahamalaza where *Diadema* density exceeded 2000 individuals per hectare. However this density is still considerably lower than densities recorded in East Africa (McClanahan and Shafir, 1990).

Comparison of coral reef criteria measured both inside and outside the existing marine parks did not reveal many significant differences for benthic cover, reef fish biomass or invertebrate density (Table 4). In particular reef fish biomass was not statistically different for populations in the no-take zones and those recorded outside the marine parks. As mentioned earlier, overall fishing effort is low to moderate at the park locations, coupled with the fact that the majority of sites surveyed are not visited often by fishers due to their more exposed position on the seaward outer reefs (Cap Masoala and Tanjona) or their distance from the coastal fishing communities (Sahamalaza and Nosy Atafana, Mananara). At Tampolo where shallow fringing reefs are more accessible to fishers the number of resident fishers and fishing effort is very low compared to other marine park locations, at <100 fishing trips per week (Cinner et al., 2006).

The high variance between counts and the low number of replicates for reef fish and invertebrate assessments also makes it more difficult to identify any potential differences in abundance or biomass between park zones. There is also the question of whether enforcement of marine park regulations is fully effective at the parks where management is in place (Masoala and Mananara). When the surveys were conducted, Sahamalaza, as a newly designated marine park, did not have a full complement of park management staff in place. Therefore we should not expect there to be major differences in the abundance or biomass of mobile coral reef fauna between the recently designated marine management zones at Sahamalaza.

Although statistical differences in benthic composition were found between management zones at some marine parks these are more likely to be related to differences in site location and aspect coupled with habitat patchiness than to effects of management practices. This is especially so for Tampolo where sites outside the marine park were more sheltered with higher hard coral cover than those within the no-take zone on the more exposed Tampolo Point. Large scale disturbance events such as the intense cyclones in the last decade are likely to exert the greatest influence in shaping the shallow to mid depth (5-15 m) coral reef habitats of northern Madagascar at the present time.

RECOMMENDATIONS

Based on the findings above, a number of recommendations can be made relating to future monitoring and management of these marine parks:

Monitoring of coral reef habitats assessed in this study needs to be continued on an annual or semi-annual basis. The monitoring program should also be expanded to incorporate particular survey methods such as the Timed Swim survey for all marine parks and increase the sampling effort to assess more sites across a range of reef and habitat types (e.g. seagrass beds).

Ongoing monitoring of environmental parameters such as water temperature at the sea surface and at set depth(s) should be instigated at all marine parks using data loggers. Installation of sediment traps on inshore and lagoonal reefs is recommended to determine sedimentation rates and characteristics which can then be compared to land-use practices.

Inshore reefs at Sahamalaza require further investigation to determine whether anthropogenic impacts such as sedimentation are causing habitat degradation. Once impacts are identified then measures need to be taken to mitigate their effect on the inshore marine habitats of coral reefs and seagrass beds.

Existing biophysical data should be combined with socio-economic information to provide a more rounded assessment of the marine parks and the fishing communities that live within them.

It is important to maintain the interest and involvement of the coastal communities within or adjacent to the marine parks in the management process of these coastal regions. Regular meetings and discussions with the communities should go hand in hand with long-term environmental education and awareness initiatives.

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Studies on Reef Connectivity Within the Context of the Transmap Project

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INTRODUCTION

Increased research has been focused in recent decades on the sustainability of marine resource use in East Africa. Resources shared by neighbouring countries have, in particular, become a subject of concern. With this in mind, marine scientists successfully submitted a proposal to gather scientific information needed for the creation of an effective trans-boundary network of marine protected areas (MPAs) in the East African region. This EU-funded project, known as Transmap, is being conducted by an international consortium in the trans-boundary regions of Tanzania, Mozambique and South Africa. The study area thus covers Mnazi Bay and the Rovuma estuary in Tanzania, the Quirimbas group of coral islands and the Machangulo Peninsula and Inhaca Island in Mozambique, and the Greater St Lucia Wetland Park in South Africa. While coastal and marine habitats straddling the borders of these countries are the subject of attention, it is expected that principles emanating from the research will find application elsewhere in the western Indian Ocean (WIO). Five European and five African institutions are involved, each contributing their expertise to the collective goal of generating scientific knowledge to underpin transfrontier MPAs.

The project's overall goal is to establish the type, size and location of reserves needed to maintain ecological function in the trans-frontier coastal environment while creating opportunities for sustainable resource-use and associated socio-economic development. This will be achieved through integration and modelling of a range of strategic issues, including biophysical, socio-economic and governance parameters. All the information is being compiled in a Global Information System (GIS) which will provide the basis for future MPA decision-support and zonation.

An understanding of biotic connectivity within and between the different coastal habitats is clearly needed to meet the project goals and is being approached in a number of ways. Coral reefs have received particular attention in East Africa over the last decade in view of the severe consequences of the 1998 El Niño Southern Oscillation and associated coral bleaching. Reef connectivity is thus being determined through appropriate genetic studies of a number of corals. Mark-recapture techniques are

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

being used to establish fish movement amongst inshore angling fish as well as selected species on reefs subjected to and closed to fishing. Connectivity between other habitats, viz. rocky and sandy shores, mangroves and seagrass beds, is being assessed through measurement of morphometric variations between populations of selected species, the differences being confirmed in genetic studies to exclude those due to environmental adaptation. Trophic linkages within and between these environments is being determined through stable isotope studies. An overview of these approaches is presented here with an outline of the direction that the results are taking.

Morphometric Measurements: Fundação Universidade de Lisboa

Landmarks have been photographed and measured in the Crustacea *Uca annulipes* and *Perisesarma guttatum* as well as the Mollusca *Cerithidea decollata*, *Littoraria glabrata*, *L. scabra* and *Nerita plicata* to determine differences in their geometric morphology. Clear regional differences have emerged in the morphometry of a number of the study organisms. Their validity as indicators of connectivity rather than different expressions of the same genotype is being confirmed through genetic studies. Genetic primers have been optimized for *Uca annulipes*, *Perisesarma guttatum*, and *Nerita plicata*. The development of specific primers has proven necessary for *Littoraria glabrata*, *L. scabra* and *Cerithidea decollata*; these are being tested.

Genetic Connectivity Studies: Oceanographic Research Institute

Early molecular studies at a smaller scale revealed panmixia in a *pocilloporid* coral (Ridgway et al., 2001) found within the Transmap region. Species with differing life-strategies were thus chosen for the Transmap study, *Platygyra daedalea* being a relatively long-lived, broadcast-spawning coral, *Acropora austera* an extremely fast-growing broadcaster with a high population turnover, and *Pocillopora damicornis* a relatively fast-growing coral with known mixed

Figure 1. A close-up of *Acropora austera*, a widely-distributed Indo-Pacific coral under genetic study in the Transmap Project.

reproductive strategies (Ward, 1992). The slow-growing octocoral, *Sarcophyton glaucum*, was also included in the sampling regime. Samples of these corals were collected at representative localities throughout the Transmap region as well as outlier material from the Chagos Archipelago.

DNA has been extracted from the samples for analysis of both the host and zooxanthellar genome. PCR amplification of most of the scleractinian extracts has been completed, using the ITS1-5.8S-ITS2 intron region and a single-copy nuclear marker in the host DNA of *Platygyra daedalea*, and intron markers developed at the Centre for Marine Studies (CMS) at the University of Queensland to amplify a genetically informative region in the *Acropora austera* genome. In both cases, amplified host material was sequenced for further comparison and, where necessary, cloned. Single-copy nuclear markers and the ITS region are being investigated for *Pocillopora damicornis*. ITS haplotypes have been used to establish sub-cladal differences between zooxanthellae sampled from representative colonies of all the species examined in the study.

The results of the animal genome studies completed thus far have revealed relatively little genetic variation in the Transmap region, indicating that they manifest relatively high gene flow. Panmixia has been found and is probably attributable to the current systems in the Mozambican Channel that result in a net southward movement in surface water masses. Thus, the large populations of reef corals in the equatorial parts of Transmap probably provide propagules to reefs in the southern part of the study area at a reasonably constant rate. Sub-cladal differences were found in the symbiotic zooxanthellae, however, and these infer a certain level of heterogeneity and concomitant resilience within the coral population attributable to this diversity.

Stable Isotope Studies: Universidade Eduardo Mondlane

The connectivity of coastal habitats in terms of trophic relationships is being assessed in stable isotope studies of three economically-important penaeid shrimps (*Metapenaeus monoceros*, *Penaeus japonicus* and *Metapenaeus stebbingii*). This is being undertaken in the southern Transmap area in Mozambique. Sample collection was undertaken in the northern (Sangala Bay) and southern (Saco da Inhaca) bays of Inhaca Island in 2006. Penaeid shrimps and their possible sources of carbon (mangrove leaves, sea grasses, epiphytic algae, polychaetes, plankton, benthic micro-algae and sediment) were collected in the main habitats (mangroves, sand flats, mud flats and seagrass beds) in the two bays.

The samples were prepared for stable isotope analysis in the Ecology Laboratory of the Department of Biological Science at UEM and 13C and 15N analyses were undertaken in the Analytical Chemistry Laboratory of the Free University of Brussels (Vrije Universiteit Brussel) in Brussels, Belgium. Interpretation of the analyses is incomplete but the results for the three prawn species are separating out quite clearly, suggesting that differential food-sourcing will emerge. The results are currently being compared with those of the different food sources.

Fish Migration Studies: WWF Mozambique & Oceanographic Research Institute

No-take zones were created in the recently promulgated Quirimbas National Park in northern Mozambique, their need arising because of heavy resource use within this MPA. Fish catches are being monitored in two of these no-take zones as well as the adjacent harvested areas at the islands of Ibo and Matemo. Fish movements were determined using tag-recapture techniques, focusing primarily on *Scarus ghobban*, this species being the most important component of artisanal catches in the Quirimbas National Park. Results of the latter are being used in the Transmap connectivity study.

In total, 195 *Scarus ghobban* with a fork length (FL) ranging between 23 and 44 cm were tagged and 84 were recaptured between September 2005 and September 2006. Of these, a total of 181 were tagged and 68 were recaptured within the Matemo and Ibo no-take zones. Recaptures indicated that the distance travelled by tagged fish was generally less than 500 m, revealing that their range is very limited.

Two different approaches were used to analyse regional fish migrations at the Oceanographic Research Institute (ORI) and have provided illuminating results. In the first, relevant data were extracted from a long-term fish tag-recapture programme that has been running at ORI since 1984. The database was interrogated concerning all fish found and tagged within the Transmap region and these data were analysed concerning individual fish migration. In the second approach, a case-specific study in the southern Transmap region, designed to gain information on fish movement at a finer scale (100 m), was subjected to similar analysis.

The long-term tag-recapture programme, known as the ORI-WWF SA Fish Tagging Project, yielded a list of 41 species, comprising some 70 000 tagged fish, for which a minimum of ten recaptures had been recorded. Of these 41 species, 17 can be considered resident or semi-resident fish that are vulnerable to exploitation as they are easy to target, the balance being more resilient as they are nomadic or migratory. Data for these were analysed for a parameter termed travel range length (TLR), this being the radius within which 95% of the recaptures are recorded (Griffiths & Wilke, 2002). Experimentation has shown that, provided certain conditions are met, protection of three times the TLR provides the optimum no-take zone size for such species (Griffiths & Wilke, 2002). The minimum size of marine protected areas (MPAs) to protect such species can thus be calculated and, in this case, ranged between 3.6 and 91.2 km.

In the finer-scale study, 2965 fish were tagged at Cape Vidal in the Greater St Lucia Wetland Park between 2001 and 2006. Of these, 304 have been recaptured. Data for resident, reef-associated species were subjected to the analysis described above and yielded valuable results. The bulk of reef-associated recaptures (169) were speckled snappers, *Lutjanus rivulatus*, which have shown a high degree of site fidelity and residency. The majority of recaptures (83%) were caught within 200 m of the original position of capture and only ten fish (6%) moved more than 2 km. Interestingly, of these ten fish, all were recaptured more than 5 km away from where they were originally tagged and one fish was recaptured 63 km from where it was originally tagged.

As has been found with many other species of reef fish, this suggests that there is a component of the population more disposed towards a nomadic lifestyle. Clearly such a life history strategy enables a better spread of genetic variability throughout the population. Simultaneously, it also ensures movement of some adult and sub-adult fish out of no-take protected areas, thus improving the yield in adjacent fished areas.

TLR analysis of the above reef fish data yielded minimum sizes of MPAs to protect these species between 1.9 and 63.5 km, results in many ways comparable with those derived from the ORI-WWF SA Fish Tagging Project. The results for speckled snapper, the species for which the greatest number of recaptures were obtained, are believed to provide the most realistic estimate of reserve size needed to adequately protect resident inshore reef fish species, i.e. approximately 20 km of coastline with suitable habitat. The question of connectivity and how far no-take reserves should be spaced apart is more difficult to answer. The fact that most reef fish have pelagic eggs and larvae which are assumed to be widely dispersed by ocean currents further complicates the question of connectivity. However, recent studies have shown that there is a high degree of natal homing in larvae of reef fish species, which suggests that no-take MPAs need to be a lot closer together than previously assumed to ensure their conservation. Biodiversity conservation targets set at the World Summit for Sustainable Development (2002) and World Parks Congress (2003) require that approximately 20% of marine habitats should be protected within MPAs. The provisional no-take MPA size for the protection of inshore reef fish species in the subsequent Transmap modelling process (see below) would thus be 20 km, probably with an absolute maximum spacing of 100 km between the MPAs. Closer spacing will be recommended to ensure protection of less migratory species such as the yellowbelly rockcod and grey grunter.

Figure 2. A tagged spectacled snapper, *Lutjanus rivulatus*, the species for which the most recaptures have been recorded in a mark-recapture programme in the Greater St Lucia Wetland Park.

Modelling Connectivity

The above provides an overview of Transmap research on habitat connectivity within the WIO that will be of interest to the CORDIO community. Implications of the results with regard to habitat connectivity are to be modelled individually and combined with biophysical, socio-economic, institutional and governance parameters in Marxan/Spexan models. The fish movement work is most advanced at this stage but haplotype networks and food web connectivity will, for example, soon be incorporated respectively from the genetic and stable isotope studies. The final product will be complete in mid-2008.

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South African Reefs: Current Status and Research

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INTRODUCTION

South Africa's East Coast subtropical reefs are nodes of biodiversity that are subjected to extractive and non-extractive recreational use. Coral reefs comprise a third of these and lie principally within the Greater St Lucia Wetland Park (GSLWP), a World Heritage Site of great value and importance. Research on the East Coast reef resources has advanced to a point where modelling reef habitat, processes such as accretion *vs* bio-erosion and connectivity has become possible within the context of climatic and environmental change. A five-year research programme has thus been initiated that will supplement earlier reef studies, making them more cohesive. The results will be integrated with earlier findings to elucidate reef processes, latitudinal gradients in coral population genetics, zooxanthellar cladal resilience to coral bleaching, the usefulness of indicators of reef health and aspects of reef modelling.

CURRENT REEF STATUS

Reef mapping and modelling of zonation for use has been completed (Ramsay et al., 2006), providing information on the rich biodiversity on the reefs. Ongoing reef monitoring has yielded results that reveal subtle changes in reef community structure and dynamics (Schleyer et al., submitted). The combined results indicate that the reefs and associated fauna remain in excellent condition and, thus far, have been little affected by ENSO-related bleaching. However, severe storms have lashed the KwaZulu-Natal coastline over the past twelve months (Figure 1). These caused considerable damage to shallow and exposed coral

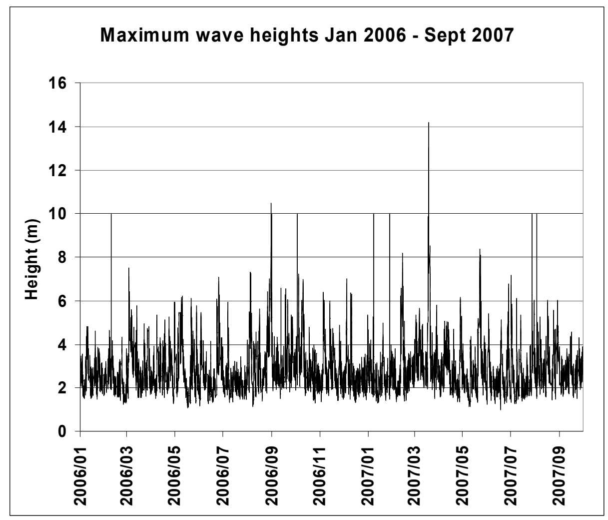

Figure 1. Maximum wave heights recorded between January 2006 and September 2007 at Richards Bay, just over 100 km south of the GSLWP coral reefs. Nine of the ten storms that have generated waves in excess of 8 m occurred in the last twelve months, causing considerable damage to shallow and exposed coral communities.(Data courtesy of National Ports Authority – Richards Bay).

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

communities on reefs subsequently examined in the GSLWP (Schleyer, pers. obs.). Part of the current research programme will focus on this during an assessment of the usefulness of biological and physical indicators of reef health.

CURRENT RESEARCH

The following are currently under investigation:

1. Whether South African reefs are undergoing net biogenic accretion or erosion. This component will include the effect of the major physico-chemical parameters (temperature, pH, aragonite saturation and PAR light availability) on local reef accretion, relative to coral calcification and other physiological processes.
2. Whether biological and physical parameters could serve as indicators of reef health, and threshold levels of these parameters at which intervention would be necessary.
3. Whether an underwater visual census technique can be developed to compare fish populations under different harvesting and environmental pressures.
4. The genetic resilience within clades of the coral-algal symbiosis and whether large scale genetic transfer is taking place between the major reefs. The corals under study are *Acropora austera*, *Platygyra daedalea*, *Pocillopora damicornis* and *Sarcophyton glaucum*.
5. The level of zooxanthellar cladal resilience to coral bleaching amongst South African corals.
6. Whether predictive spatial modelling of reef habitats and ecosystem processes is possible, elucidating reef function and providing a tool for improved resource management.

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Update on Coral Reef Activities In Mozambique (2004-2006)

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INTRODUCTION

The coral reefs of Mozambique are southern continuations of the well-developed fringing reefs that occur along major sections of the narrow continental shelf of the East African coast (Rodrigues et al., 2000). The reefs constitute the major attraction for the growing coastal tourism industry and are fundamental for the livelihoods of coastal communities.

The Mozambique Coral Reef Management Programme (MCRMP) developed four large areas of activity, which were recognized as vital for the achievement of the primary goal of sustainable management of coral reef resources: capacity building; basic and applied research on the ecology of coral reefs; assessment of the integrity and status of the coral reef fishery; and assessment of the coral reef fishery in terms of its significance for coastal communities and for the welfare of the community at large.

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

This note, updates information on coral reef-related work conducted in Mozambique since the last CORDIO Status Report (Costa et al., 2005).

Annual Reef Monitoring

Annual coral reef monitoring has been the main activity of the Mozambique Coral Reef Management Programme and has been going on since its inception in 1999 (Rodrigues et al., 1999). The activities and results of the monitoring programme have been recently reviewed by Costa et al. (2005). Due to financial constraints, monitoring surveys have been conducted in selected reefs (mainly Quirimbas, Bazaruto and Inhaca) during 2006 and 2007 and will be reported elsewhere.

The 2005 Bleaching Event in the Bazaruto Archipelago National Park (BANP)

A widespread bleaching event occurred in the shallow reefs (<5 m) of Bazaruto Archipelago National Park early in 2005. In April 2005, a survey was conducted

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Table 1. Summary results of benthic community composition and bleaching incidence ± SD on each reef surveyed in the BANP, April 2005.

Benthic category	Coral Garden (N=8)	Two-mile reef (N=5)
Benthic Composition		
Acropora branching/tabular	11.3 ± 11.3	5.8 ± 7.0
Branching hard coral	1.5 ± 2.6	5.4 ± 4.0
Encrusting hard coral	4.9 ± 4.3	0.0 ± 0.0
Massive hard coral	14.9 ± 10.0	26.8 ± 14.7
Millepora	0.0 ± 0.0	1.0 ± 2.2
Submassive hard coral	0.6 ± 1.7	0.0 ± 0.0
Total hard coral	33.2 ± 14.8	39.0 ± 14.1
Soft coral	2.7 ± 5.1	0.5 ± 1.1
Total coral cover	35.9 ± 12.7	39.5 ± 13.6
Dead coral and algae	8.6 ± 7.4	15.1 ± 17.2
Rock and algae	42.4 ± 10.2	13.2 ± 5.1
Rubble	5.8 ± 7.7	28.3 ± 10.8
Sand	4.9 ± 5.1	3.4 ± 5.1
Bleached colonies (%)		
Acropora branching/tabular	97.5	16.7
Branching hard coral	0.0	0.0
Encrusting hard coral	0.0	0.0
Massive hard coral	0.0	0.0
Millepora		0.0
Submassive hard coral	0.0	
Soft coral	0.0	55.6
Water Temperature (°C)	28.2 ± 0.3	27.0 ± 0.0

in two previously monitored reefs, to quantify bleaching incidence.

Twenty-meter Point Intercept Transects (PIT; Hill & Wilkinson, 2004) were used to assess benthic cover (based on the growth form categories proposed by English et al., 1994) and bleaching incidence in coral communities of two reefs: Coral Garden (21o 31'05.10''S; 35o 29'15.45'' E) and Two-mile reef (21o 48'17.24''S; 35o 30'07.92''E). Both reefs were dominated by massive hard corals (mainly *Porites* and *Faviids*) followed by branching/tabular *Acropora* (Table 1).

Acroporids were also the most affected by bleaching. Almost all colonies were bleached (97.5%) in Coral Garden (Fig. 1); while in Two-mile reef the percentage was lower (16.7%). Interestingly, half of

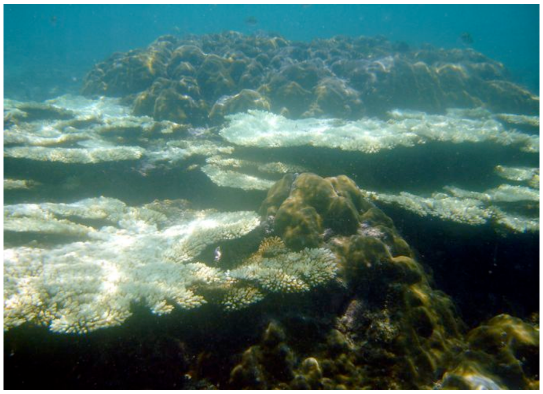

Figure 1. Bleached tabular Acropora colonies at Coral Garden, Bazaruto Archipelago National Park, April 2005. The massive Porites colonies were unaffected (photo: Eduardo Videira).

the soft coral colonies found at Two-mile reef were bleached (Table 1; Fig. 2).

Survey of Selected Reefs in the Primeiras and Segundas Archipelagos, Northern Mozambique

The Primeiras and Segundas islands in northern Mozambique are an almost continuous chain of coralline islands surrounded by atolls. A rapid assessment of the shallow coral reefs (<15 m) on the western side of the islands was conducted using visual techniques for both fish and benthic communities.

Figure 2. Bleached and dying colonies of soft corals (Sinularia sp.) in 2-mile reef, Bazaruto Archipelago National Park, April 2005 (photo: Eduardo Videira).

Figure 3. High-profile reef with a good coverage of both hard and soft corals at Ilha Epidendron, Primeiras archipelago, northern Mozambique (photo: Eduardo Videira).

Cumulatively, 43 genera of hard and 15 of soft corals have been identified in the area. Coral cover ranged from 52.4 to 71.2%, with hard corals usually dominating (Table 2). Branching forms of *Acropora*, *Pocillopora*, *Seriatopora* and *Porites* were the dominant components of the benthic fauna in the most southern islands (Fogo and Epidendron), while massive (*Porites*, *Faviids*, *Lobophyllia corymbosa* and *Diploastrea heliopora*) and submassive (*Porites*, *Goniopora djiboutiensis* and *Acropora palifera*) were conspicuous in the northern ones (Puga-Puga and Mafamede). On all reefs the soft corals were conspicuous with Sarcophyton, Cespitularia and nephthiids being the most abundant (Figure 3).

A total of 199 reef fish species were identified. Surgeonfishes (Acanthuridae), parrotfishes (Scaridae) and butterflyfishes (Chaetodontidae) were the most abundant families. There were signs of over-fishing (especially in the Primeiras islands) with large specimens and species of commercial value absent. These results support previous claims that these are

Table 2. Summary results of the benthic surveys conducted at the Primeiras and Segundas Islands, northern Mozambique. Percentage cover (± SE) of major benthic categories are presented as well as the number of photo-transects conducted per island.

Category	Fogo (n=6)	Epidendron (n=7)	Ndjovo (n=7)	Puga-Puga (n=7)	Mafamede (n=7)
Corals					
Branching	17.5 ± 3.7	25.4 ± 5.6	12.2 ± 1.5	4.4 ± 0.7	7.7 ± 1.0
Digitate	1.4 ± 0.6	1.2 ± 0.6	2.3 ± 0.6	1.3 ± 0.6	0.2 ± 0.1
Encrusting	3.0 ± 0.7	6.3 ± 0.9	3.9 ± 0.8	1.6 ± 0.6	6.0 ± 1.2
Foliose	0.1 ± 0.1	0.0 ± 0.0	0.3 ± 0.3	0.0 ± 0.0	0.5 ± 0.4
Mushroom	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.0 ± 0.0	0.2 ± 0.1
Massive	4.8 ± 0.8	4.9 ± 0.0	7.6 ± 1.3	22.5 ±1.5	9.8 ± 2.8
Submassive	0.3 ± 0.2	1.7 ± 0.6	2.8 ± 1.2	2.0 ± 0.4	23.5 ± 4.9
Tabular	2.6 ± 0.7	7.9 ± 2.0	1.3 ± 0.4	0.1 ± 0.1	1.7 ± 0.6
Fire	0.0 ± 0.0	0.5 ± 0.5	0.0 ± 0.0	0.0 ± 0.0	0.9 ± 0.9
Dead coral	1.0 ± 0.2	1.3 ± 0.3	0.2 ± 0.1	1.0 ± 0.3	1.6 ± 0.3
Dead coral with algae	2.3 ± 0.6	3.0 ± 1.0	1.0 ± 0.3	1.0 ± 0.3	2.6 ± 0.8
Total hard coral	29.8 ± 4.4	48.0 ± 5.2	30.4 ± 1.9	32.2 ± 2.6	50.5 ± 5.7
Soft Coral	22.5 ± 2.3	23.2 ± 3.0	35.8 ± 1.6	22.7 ± 3.7	12.0 ± 1.9
Unidentified coral	0.4 ± 0.2	0.5 ± 0.2	0.6 ± 0.1	0.3 ± 0.1	0.7 ± 0.3
Total live coral	52.4 ± 5.3	71.2 ± 3.8	66.1 ± 2.6	54. 9 ± 2.6	62.5 ± 4.2
Algae and Seagrass					
Macroalgae	2.3 ± 1.1	3.0 ± 0.7	0.6 ± 0.2	0.7 ± 0.2	0.3 ± 0.2
Coralline algae	0.0 ± 0.0	0.9 ± 0.6	0.6 ± 0.2	0.4 ± 0.3	1.4 ± 0.7
Seagrass	0.2 ± 0.1	0.0 ± 0.0	0.0 ± 0.0	0.3 ± 0.1	1.1 ± 0.4
Invertebrates					
Hydroids	0.4 ± 0.1	0.2 ± 0.2	1.0 ± 0.4	0.1 ± 0.1	0.2 ± 0.1
Sponges	0.5 ± 0.2	1.0 ± 0.3	0.6 ± 0.2	0.2 ± 0.1	0.5 ± 0.3
Zoanthids	0.6 ± 0.2	0.5 ± 0.3	0.3 ± 0.1	0.3 ± 0.1	0.2 ± 0.2
Abiotic					
Rock	5.3 ± 0.9	0.8 ± 0.3	2.2 ± 0.9	0.6 ± 0.2	0.0 ± 0.0
Rock and algae	28.3 ± 3.1	15.7 ± 4.2	19.7 ± 2.4	35.3 ± 1.9	25.0 ± 2.9
Rubble	0.6 ± 0.3	0.8 ± 0.4	1.9 ± 0.9	3.4 ± 0.8	2.6 ± 1.2
Sand	4.5 ± 0.9	0.9 ± 0.4	3.6 ± 0.7	1.3 ± 0.3	0.8 ± 0.6

some of the best-developed reefs in Mozambique both in biodiversity and condition (Salm, 1983; Celliers & Schleyer, 2000). This was the second quantitative study ever conducted in the area (but first in its breadth of coverage) and the results will support the ongoing process of declaring a marine conservation area and the establishment of a monitoring programme.

Training Activities

Training has been seen as a major component of the Mozambique Coral Reef Programme since its inception in 1999 (Rodrigues et al., 1999). This has been a continuous effort from various institutions, which have provided funding and other support. Training has included introductory diving courses and coaching of undergraduate or recently graduated students and formal academic training at both the graduate (BSc. Hons.) and post-graduate level.

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Co-Management of the Reef at Vamizi Island, Northern Mozambique

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INTRODUCTION

The province of Cabo Delgado in northern Mozambique still represents one of the most inaccessible coastal regions of East Africa, having been isolated by more than 30 years of war and by its remoteness from the strategic centres of economic activity located south in the country. No longer than 10 years ago, the Querimbas archipelago - called "Maluane islands" before Portuguese times - remained one of the only coastal areas in the region in which biodiversity had never been really documented, although its potential conservation value had previously been suspected (Tinley, 1976). When marine surveys started to be undertaken in the southern Querimbas (Whittington *et al.*, 1998) results indicated that the diversity of corals found there was comparable with the best found along the East African coastline. As a result, the Querimbas National Park was gazetted, encompassing most of the southern section of the Querimbas where coral reefs are monitored regularly (Motta *et al.*, 2003, Costa *et al.*, 2004).

Figure 1. Map of northern Mozambique showing Maluane project areas with Vamizi Island map showing depth contours in metres.

Vamizi island lies in the far north section of the Querimbas archipelago just below the Tanzanian border (Fig. 1), in the area where the South Equatorial Current splits into the Mozambican Current and East African Coastal Current. It appears to be an ancient uplifted patch reef of Pleistocene origin, surrounded by a submerged reef flat with broad terraced slopes

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(Davidson *et al.*, 2006). It is bound eastwards by bathymetric intrusions providing proximity to deep water of the Mozambique channel.

Vamizi is one of the largest islands (12 kms long and 0.5-2 kms wide) of the Querimbas and one of the four islands which always had a resident community since Arabic times, settled in the western section of the island for its easier access to the mainland. The resident population was estimated at 533 people in 1999, the majority being of kimwani and swahili origin with a livelihood based on subsistence fishing (Garnier, 2003). Since the end of the war, an increasing number of itinerant fishermen from Tanzania and other provinces in Mozambique have established a presence on Vamizi, making the total population highly fluctuant on the island depending on the monsoon. Regular movements of fishers between the island and coastal villages on the continent, only situated 4 kms from the island, also contribute to this high flux of people.

After conducting the first socio-ecological surveys in the northern Querimbas (Garnier *et al*, 1999), the Maluane initiative was created in order to ensure the sustainable conservation of the exceptional coastal biodiversity of the northern Querimbas and to support the socio-economic development of local communities, using up-market tourism as the economic engine. As stated in its management plan (Garnier, 2003), the objectives of Maluane are:

- To protect and maintain the biological diversity and natural resources of national and international significance, as well as ecosystem processes;
- To ensure community participation in management decisions and activities;
- To promote sound management practices for sustainable production purposes;
- To contribute to the socio-economic development of local communities;
- To provide opportunities for research and education;
- To develop up-market tourism activities that will ensure the financial viability of the Project.

Table 1. Scleractinian families contributing species to the coral reef communities of Vamizi Island (from Davidson *et al.*, 2006).

Family	Species count	% total (183)	Present in sites
Acroporidae	59	32.24	36
Faviidae	51	27.87	36
Mussidae	11	6.01	36
Poritidae	14	7.65	36
Oculinidae	2	1.09	35
Pocilloporidae	7	3.83	35
Agariciidae	8	4.37	34
Fungidae	9	4.92	34
Merulinidae	3	1.64	33
Siderastreidae	6	3.28	33
Dendrophylli-dae	4	2.19	25
Euphyllidae	2	1.09	23
Pectinidae	6	3.28	22
Astrocoeniidae	1	0.55	5

In order to achieve the objective of a three-fold sustainability (ecological, social and financial), Maluane was developed as a partnership between a conservation organisation (the Zoological Society of London (ZSL)), local communities and the private sector, represented by a group of individual European investors with a strong commitment to conservation. Since 2001, Maluane has developed a number of marine conservation programmes on Vamizi Island that will be succinctly presented below.

Assessment of the Status of Vamizi Reef

Detailed assessments of Vamizi reef were conducted in 2003 and 2006 by Maluane and ZSL and the results presented below are extracted from Davidson *et al.* (2003, 2006) and Hill *et al.* (2003). In order to undertake a full benthic survey of coral communities around Vamizi Island, three methods were used: manta tow surveys, rapid ecological assessment (REA) and SCUBA search. Underwater visual census of reef fish was conducted to obtain abundances of all species

Plate 1. Diversity of coral species at Vamizi reef and extensive habitats.

Plate 2. Grey reef sharks, snappers and reef fishes at a deep fringing reef location.

excluding cryptic and small species. Both surveys were undertaken in collaboration with the Natural History Museum of Maputo and the University E. Mondlane at Maputo, with whom Maluane has developed strong links and which always send Mozambican students for training in conservation management techniques with Maluane. Coral reefs around Vamizi were identified as being very healthy and productive (Plate 1). The average coral cover was 37% (range 22-63%), with low levels of injury (<15%) and death (<10%) of corals. REA of 36 sites within 12 locations identified the presence of 183 coral species in 46 genera from 14 families (Table 1). Each location surveyed has a broad suite of coral species with over 75% locations having over 45% of the total species observed. Locations on the northern slopes of the island scored a higher species richness than other sites, reflecting their semi-sheltered environment

In addition, it had been observed in 2001 that the northern and eastern slopes of Vamizi had not been affected by the 1998 bleaching event, contrasting with the findings of Motta *et al.* (2002) in the southern Querimbas. The resilience of coral communities on these slopes is likely to be associated with the proximity of the reef to cool deep waters and the fast water flow created by currents, both being recognised as factors mitigating thermal stress (Grimsditch & Salm, 2005).

Fish surveys since 2003 around Vamizi identified 401 species of fish – over half the number of reef

Table 2. Comparison of number of reef associated species between national surveys (Pereira, 2000) and Vamizi survey (Davidson *et al.*, 2006).

Family	Number of known reef associated species	
	National	Vamizi
Acanthuridae	31	31
Balistidae	16	12
Chaetodontidae	23	21
Haemulidae	15	10
Labridae	67	52
Lethrinidae	19	16
Lutjanidae	22	10
Mullidae	14	12
Pomacanthidae	12	11
Pomacentridae	45	35
Scaridae	24	20
Serranidae (groupers)	56	31


Plate 3. Bumphead parrotfish.

associated species recorded for the whole country (Table 2, Plates 2 & 3), with large numbers and densities of carnivores normally regarded as vulnerable to fishing. A fisheries survey conducted in local communities using fishing grounds around Vamizi Island showed that the main threat to fisheries was represented by over-fishing and unsustainable fishing practices used mainly by transient fishers (Guissamulo *et al.,* 2003).

Community-Based Management of Marine

Resources at Vamizi

It is well known that the sustainability of resource use and management of natural resources is affected by the degree of involvement and empowerment of local communities in all the processes that contribute to the sound conservation management of an area – from data collection to decision-making, management and monitoring activities (Salm *et al.*, 2000). This strong community involvement, combined with an adaptive and sound, scientifically-based management approach that also builds on local knowledge, represents the foundation upon which Maluane's conservation programme was developed on Vamizi.

One of the first steps undertaken by Maluane was to assess the perception of resource users on Vamizi of the threats to ecosystem productivity. It was clear that a divide existed between itinerant fishers, who did not consider this issue as being relevant to their livelihood, and resident fishers. The latter had a clear awareness and understanding of the concept of sustainability when they explained that traditionally, fisheries could sustain them since they only extracted what they needed for subsistence. They pointed out that increased immigration on the island, combined with the introduction of unsustainable fishing methods had resulted in a significant decline in fish catch and therefore represented the main threat to their livelihood. In addition, the resident community as a whole resented deeply the presence of most itinerant fishers on their island, who they claimed had only brought social disruption, instability and more problems to the island, such as cholera outbreaks. This was reflected by the geographic isolation of the itinerant fishers' camps on the island and the lack of social organisation, leadership and hygiene in these camps (Guissamulo *et al.*, 2003).

Although the divide between resident and itinerant fishers was not as clear as it appeared to be since a number of transient fishers had now settled on the island and integrated the community by marrying locally (Hill, 2005), the resident community asked Maluane to support them in regaining control over access to their marine resources. The fact that they turned to Maluane rather than government can be explained by the solid relationship that Maluane had developed over the years with the Vamizi community and by the tangible benefits that the project had brought to the island (see Socio-economic development and alternative livelihoods), whereas the limited resources of government meant that no socio-economic development had occurred on the island previous to Maluane.

In an attempt to decentralise authority and empower local communities to manage their marine resources, Fishing Community Councils or CCP (*Concelho Comunitario de Pesca*) were legalised in Mozambique in 2006 and given the rights to control access and manage their resources within 3 nautical miles of their coastline. Two CCPs have now been legalised on Vamizi island and in Olumbe, the main village on the coast which also uses fishing grounds

Plate 4. Local monitor being trained to assess reef fish populations.

Plate 5. Turtle monitors tagging and measuring a green turtle.

around Vamizi. In partnership with government and IDPPE (*Instituto das Pescas de Pequena Escala* or Small-Scale Fisheries Institute), Maluane has supported the creation and capacity building of the CCPs, which is still on-going.

In order to develop the CCP capacity to make sound management decisions, training of some CCP members in basic reef monitoring has been initiated in 2006 (Davidson *et al.*, 2006) and their capacity in monitoring fish catch and undertaking fish stock assessment will soon be developed (Plate 4). This will also allow for community-based monitoring of the effectiveness of management decisions, such as the newly formed marine sanctuary that both the CCP and Vamizi community have decided to create around the north-eastern section of the island. The unanimous decision to set aside a no-fishing area for one year was taken once the community had identified the critical issues and priorities and agreed on the solutions to solve these issues. The feed-back sessions on all survey results that were conducted with all stakeholders, combined with the on-going awareness programme on sustainable resource use that is conducted on the island, also contributed to this process.

In addition, a community-based turtle monitoring programme has been developed on Vamizi and Rongui islands since 2002, also raising awareness of local communities on marine conservation issues. This programme has been very successful with a local team of 10 monitors, all originating from local villages, is now conducting this conservation project, from the marking and protection of all nests to the tagging of turtles (internal and external tags, satellite tags) and education and awareness programs (Plate 5).

As a result, more than 700 nests of both hawksbill and green turtles have been protected on Vamizi and Rongui islands and poaching of nests and eggs has now been reduced to nil on these islands. Nesting success on Vamizi and Rongui (>80% hatching and emergence success) was found to be very high, emphasizing the regional importance of these islands as turtle nesting grounds, especially since coastal habitats around the islands also provide developmental grounds for both turtle species.

In order to help develop regional turtle conservation strategies, Maluane has fitted the first satellite tag on a green turtle in Mozambique, which has now migrated to her feeding ground in Malindi, Kenya.

Socio-economic development and alternative livelihoods

Socio-economic and fisheries surveys undertaken in Vamizi show that the livelihood of local communities in the project area is totally dependent on reef-based fisheries, with most local fishermen being unable to

Plate 6. Cultural group of the women's Association performing traditional dances at Vamizi lodge.

Plate 7. Vegetable farm providing farmers with an alternative livelihood.

access adequate fishing gear and being restricted by trade opportunities (Guissamulo *et al.*, 2003). In addition, the increased pressure on marine resources associated with the presence of itinerant fishers often forced resident fishers to become partners with itinerant fishers, thus obliging them to use destructive fishing techniques, such as small-mesh seine nets, mosquito nets and spear guns. A majority of these fishers is just too poor to afford alternative gear and this is their only means of providing food for their families.

In partnership with the Ministry of Environment (MICOA) and GEF, Maluane is supporting the development of small businesses in Vamizi and Olumbe communities for which it is providing both ensured through the needs of the tourism product already developed on Vamizi. They include an association of twenty-nine women that has started to generate revenue by performing cultural activities (crafts making, traditional dances) for the lodge (Plate 6) and a vegetable farm with twenty-two farmers at Olumbe that is producing fresh vegetables for the lodge (Plate 7).

An association of twenty-one fishermen has also just been formed, which will be supported to use sustainable fishing methods.

Although still in the very early stages, some of these small businesses have started to generate revenues and have created alternative livelihood schemes for the two communities that use fishing grounds around Vamizi island. In addition, the project has created significant employment and provided local capacity building in the areas of tourism and conservation, while stimulating the local economy through the purchase of local products (building material, fresh marine products etc).

The introduction of income diversification and alternative livelihood schemes that are environmentally sustainable and economically viable is a well-recognised method to improve the quality of life of coastal communities and to reduce the pressure on coastal ecosystems. Capacity building of the associations has proved to be quite challenging since these communities have been isolated from any form of socio-economic development for decades. One of the major obstacles, especially for women, is their very high level of illiteracy which has started to be addressed by developing literacy programmes on the island. While the capacity building process is still on-going, a monitoring programme of the alternative livelihood programme is being developed to assess carefully its impact.

Another contributing factor to the determination of local communities to self-regulate fishing pressure has been the support of Maluane in improving directly the community's well-being by providing access to social services that were desperately lacking on the island. A health post has been built on Vamizi by the project, while access to education and drinking water will also be addressed by the project.

Financial Sustainability

The socio-economic programmes described above, together with the conservation initiative developed by Maluane have largely been funded by the group of private individuals who have also financed the development of the tourism operation. Charitable organisations and institutional donors are also supporting specific conservation programmes within Maluane, on the basis that the conservation and community programmes will ultimately become financially viable through tourism-generated revenues. A bed levy is already charged to all clients staying at the lodge, who are given the opportunity to participate in most of Maluane conservation activities and to understand better the needs and challenges of the socio-economic programme developed by the project. It has been found that awareness raising on conservation and community issues at the lodge was not only very well received by most clients, but had actually become a necessity for the niche market willing to travel to remote destinations in order to learn and contribute more towards environmental and social issues.

CONCLUSIONS AND RECOMMENDATIONS

The diversity, richness and exceptionally pristine status of Vamizi reef, which is now such a rare occurrence in East Africa, suggests that it deserves a priority status. Placed in a regional context, Vamizi reef also needs special consideration as it is likely to play a vital role as a source in replenishment for other reefs in the region, due to its specific oceanographic environment and resilience to thermal stress. Further research on such resilience is needed while a community-based monitoring programme of the reef is being developed.

The creation of fishing committees on Vamizi and Olumbe illustrates the determination and ability of resident fishers to organise themselves in regaining control over the management of their natural resources. The creation of a marine sanctuary over one section of Vamizi reef represents the first step towards the sustainable conservation of one of the most pristine reefs in Eastern Africa. The on-going monitoring and capacity building of the CCPs will ensure that the pivotal role played by this new community institution is fulfilled.

The creation of alternative livelihoods in Vamizi and Olumbe communities, combined with stimulation of local economy through tourism, has undoubtedly contributed to the determination of local communities to actively protect and manage marine resources and to organise themselves to do so. The real impact of this programme needs to be carefully assessed.

A community-based turtle monitoring programme has been developed on Vamizi island, resulting in the successful protection of nesting grounds and in raising local awareness on marine conservation issues. This programme is also contributing to the development of regional turtle conservation strategies.

The Maluane project still has a way to go, but will be an important case study of whether high end tourism, building on a foundation of thorough scientific research and planning, and explicitly aiming to work in partnership with local communities, can succeed in conservation in the face of growing pressure on the ecosystem (Milner-Gulland, E.J. and Rowcliffe, M. (in press).

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Approaches to Coral Reef Monitoring in Tanzania

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ABSTRACT

Coral reef monitoring (CRM) in Tanzania started in the late 1980s. The main objective was to assess the extent of damage caused by the use of destructive resource harvesting practices, mainly dynamite and drag-nets. The derived information formed the basis for setting up of legislation (control) measures and monitoring of further changes on reef health. Coral reef monitoring has contributed substantial descriptive information and has raised awareness of coastal communities and managers. Analysis of CRM data over the years has provided information on the dynamics of reef health, for example coral cover and composition, and fish and macro-invertebrate abundances. Experience has shown that there are more factors that degrade coral reef now than before. The contribution of natural factors (e.g., coral bleaching events, algal and corallimorpharia proliferation, crown-of-thorns predation) has become more apparent and these factors are acting synergistically with chronic human induced factors such as destructive resource harvesting practices (dynamite and dragnets), mining of live corals, trampling and anchor damage. In order to keep pace with increased reef problems, the Institute of Marine Sciences, Zanzibar, has modified its monitoring protocols. The main emphasis is now on biodiversity changes. Reef corals are now monitored at genus level instead of growth forms alone. Reef macro-invertebrates (sea urchins, sea cucumbers, gastropods) include more sub-groups than before. Coral recruitment (young corals less than 10 cm diameter) is now monitored at genus level. Analysis of the coral monitoring data takes into consideration resilience concepts such as functional redundancy. The improved coral reef monitoring approach will complement community-based monitoring which is being practiced countrywide in Tanzania. This paper discusses critical issues in the past coral reef monitoring program and describes modifications adopted by the Institute of Marine Sciences. Complementarities with community-based coral reef monitoring are also discussed.

APPROACHES TO CORAL REEF MONITORING IN TANZANIA

1. INTRODUCTION

The livelihood of many costal communities in Tanzania depends completely or partially on the artisanal fishery in inshore waters (UNEP, 1989; Muhando and Jiddawi, 1998; Johnstone et al. 1998b; Ireland et al. 2004). Reef-based fisheries contribute about 70 % of artisanal fish catch (Muhando and Jiddawi, 1998; Wagner, 2004). Reef-based tourism is

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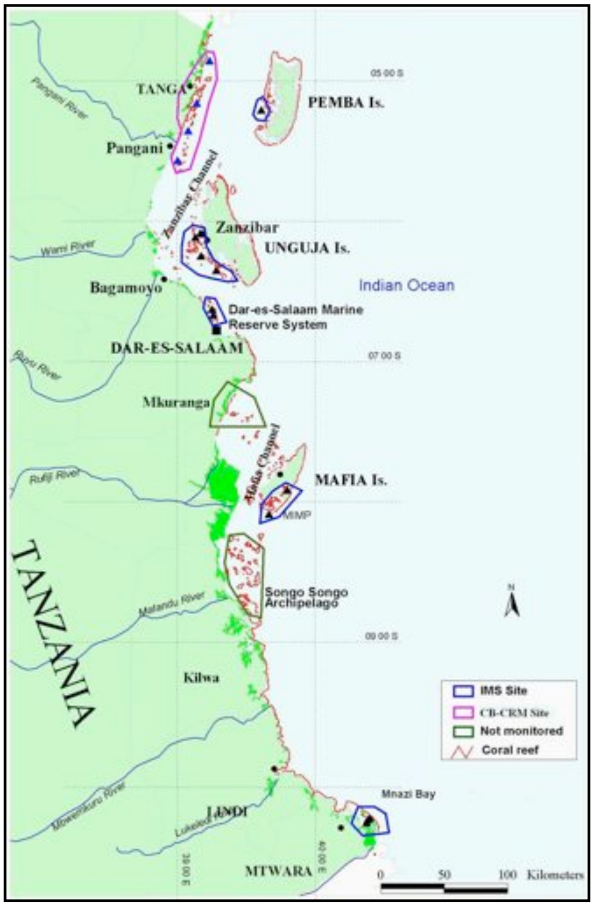

Figure 1. The distribution of coral reef monitoring sites in Tanzania.

increasingly becoming a major contributor to the economy (TCMP, 2001) and there is an increasing trend of use and extraction of natural products from reef organisms, some of which are of medicinal value (Scheuer, 2006). Besides playing a crucial role in biodiversity preservation, coral reefs provide protection for coastal zones. However, the importance of coral reefs and their proximity to the coast make them vulnerable to abuse and degradation from human activities such as over-fishing, destructive fishing, pollution by sediments, nutrients and toxic chemicals, coral mining and shoreline development, and unregulated tourism (Bryceson, 1981; Johnstone et al., 1998a, 1998b; Muhando et al., 2004). As in other parts of the world (Wilkinson, 2004; Souter and Linden, 2005), coral reefs in Tanzania are at risk from many threats including those enhanced by global climate change, e.g., coral bleaching, and Crown-of-thorns-starfish, algal and corallimorpharia proliferation (Muhando et al., 2002; Muhando and Mohammed 2002; McClanahan et al. 2007a, 2007b).

Taking into consideration the importance of coral reefs and the proliferation of stress factors, it is imperative to be aware continuously of the condition of coral reefs. Monitoring the ecology of the reefs and the socioeconomics of people dependent on them is the only way to understand the extent of use, nature and causes of the damage, and to identify ways to address threats. Monitoring provides the essential information required to make management decisions and determine whether or not the decisions are working (Wilkinson et al., 2003, Malleret-King et al., 2006). This paper considers the two main approaches to coral reef monitoring (CRM) that have conducted continuous data collection since the mid 1990s and outlines some of the benefits, challenges and lessons learned from these programmes. This analysis is used to present modifications to monitoring protocols that are being undertaken to improve the quality and usefulness of information derived from CRM in Tanzania.

2. CORAL REEF MONITORING METHODS AND INDICATORS

Coral monitoring in Tanzania started in the late 1980s. Two systems evolved: SCUBA based coral reef monitoring undertaken by academic staff, graduate students and technical staff from IMS (high tech) (Mohammed et al., 2000, 2002) and community based coral reef monitoring (low tech) (Horrill et al., 2001; Wagner, 2004). Both systems were based on internationally recognized protocols developed in Southeast Asia (English et al, 1994). Reef benthos (live coral cover, coralline algae, soft corals, sponges, fleshy algae, non-biotic cover) were assessed using Line-Intercept method, while reef fish and macro-invertebrates (lobsters, clams, gastropods, sea urchins,

Table 1. Comparison of reef benthic categories measured by IMS and TCZCDP.

	Scuba based coral reef monitoring (IMS)	Community based coral reef monitoring (TCZCDP)
Object type	Benthic objects (object id)	Benthic objects (object id)
Live hard corals (HC)	*Acropora*, branching (ACB) *Acropora*, encrusting (ACE) *Acropora*, submassive (ACS) *Acropora*, digitate (ACD) *Acropora*, tabulate (ACT) Coral, branching (CB) Coral, encrusting (CE) Coral, foliose (CF) Coral, massive (CM) Coral, submassive (CS) Coral, mushroom (CMR) Coral, *millepora* (CME) Coral, *heliopora* (CHL)	Matumbawe hai (MH) (Live hard corals)
Partly dead corals		Matumbawe yaliyokufa kidogo (MKK) (partly dead corals)
Bleached corals		Matumbawe hai maeupe (MHM) (Bleached corals)
Soft corals (SC)	Soft coral (SC)	Matumbawe laini (ML) (soft corals)
Sponges (SP)	Sponges (SP)	Spongi (SP) (Sponges)
Coralline algae (CA)	Coralline algae (CA)	
Algae (AL)	Algal assemblage (AA) Algae, Halimeda (HA) Algae, Macroalgae (MA) Algae, Turf algae (TA)	Mwani (MN) (All Algae)
Others (OT)	Seagrass (SG) Zoanthids (ZO) Clam (CLAM) Corallimorpharian (RH) Others (OT)	Majani (MJ) – (sea grass) Wengineo (WG) (Others)
Substrate (SU)	Sand (S) Silt (SI) Rock (RCK) Rubble (R) Dead coral (DC) Dead coral with algae (DCA)	Mchanga (MC) – (sand) Mwamba (MW) – (rocky surface) Matumbawe yaliyokufa (MK) (Dead corals)

Table 2. Fish recording template for Community based coral reef.

Category name	Description
Chafi	Family: Siganidae
Chewa	Family: Serranidae
Changu	Family: Lethrinidae and some members of Lutjanidae
Chazanda	*Lutjanus argentimaculatus*
Kangu wadogo	Selected members of Scaridae and Labridae
Kangu wakubwa	Selected members of Scaridae and Labridae
Kangaja	Family Acanthuridae: Members of the genus *Ctenochaetus* and *Acanthurus*, except *A. triostegus*,
Kolekole	Family Carangidae
Kitamba	*Plectorhinchus sordidus*, *P. playfairi*, *P. flavomaculatus*.
Kidui	Family Balistidae
Kipepeo	Family Chaetodontidae
Mlea	*Plectorhinchus gaterinus*, *P. orientalis*
Mwasoya	Family Pomacanthidae: Members of the genus *Pomacanthus* and *Plygoplites* only
Mkundaji	Family Mullidae
Haraki	*Lutjanus bohar*
Tembo	*Lutjanus fulviflamma*, *L.lutjanus*, *L. ehrenbergii*
Mbono	Family Caesionidae

sea cucumbers, sea stars, crown-of-thorns-starfish) were assessed using belt transects.

The community based coral reef monitoring (CB-CRM) method was first applied by the Tanga Coastal Zone Conservation and Development Program (TCZCDP) in 1996 and it extended to Dar es Salaam, Bagamoyo and Mkuranga. Efforts are underway to introduce it in Songosongo archipelago (Fig. 1). Scuba based monitoring was started in 1994 by the Institute of Marine Sciences (IMS) in Zanzibar. Coral reefs off Zanzibar town, Misali in Pemba, in Mafia Island Marine Park in Mafia and in Mnazi Bay, Mtwara are monitored using this technique (Fig. 1). There were differences in categories recorded by the two systems: TCZCDP grouped all live hard corals as one category "Matumbawe Hai", while Institute of Marine Sciences CRM Team had 13 categories representing Acropora and Non-Acropora growth forms (Table 1).

All algal types were grouped as one category "Mwani" in TCZCDP while coralline algae were separated from turf, macro-algae, *Halimeda* and other algal assemblages by IMS. Counting of coral recruits (less than 10 cm canopy width) was only done by IMS from 1999. Macro-invertebrates recorded in community and Scuba based monitoring were similar and included lobsters, clams, gastropods, bivalves, sea cucumbers, sea urchins, sea stars, and Crown-of-thorns starfish. Community based monitoring emphasized more on fished groups and paid less attention to other reef fish groups (Table 2). A calibration attempt between the two systems was carried in Tanga in 2004. Pairs of TCZCDP and IMS monitors assessed benthic cover, counted macro-invertebrates and fish in the same transects (twelve 20m transects in Mwamba Taa and Mwamba Makome reefs in Tanga and six 50 x 5 m belt transects for fish (Muhando, 2004 Unpubl). Comparisons revealed both systems provided the same estimates of live coral

Table 3. Comparison (Paired sample t test) for reef benthic cover results between Community (TCZCDP) and Scuba based coral reef monitors (IMS).

Benthic category	t	df	p	Difference between IMS and TCZCDP
Hard coral	0.70	12	0.4963	Not significant
Bleached corals	*	*	*	Extremely significant - Not observed by IMS team
Coralline algae	*	*	*	Extremely significant - Not observed by TCZCDP team
Algae	1.41	12	0.1855	Not significant
Soft coral	7.37	12	< 0.0001	Extremely significant (TCZCDP > IMS)
Sponge	0.44	12	0.6650	Not significant
Other Organisms	3.03	12	0.0105	Significant (IMS > TCZCDP)
Dead coral	0.98	12	0.3112	Not significant
Substrate	1.36	12	0.2003	Not significant

cover (Table 3). However, there were differences in algal cover and soft coral cover, mainly due to the fact that some community based monitors did not distinguish these categories from corallimorpharia and sea anemones. With more education and awareness, community based monitoring is expected to provide more or less the same results as currently contributed by the IMS coral reef monitoring team.

3. CONTRIBUTION OF THE PAST CORAL REEF MONITORING PROGRAMS

Coral reef monitoring contributed extensive and useful information on the intensity and trends of damage to reefs, including coral degradation after the 1998 coral bleaching and mortality event (Muhando, 1999; Mohammed et al., 2000, 2002; McClanahan et al., 2007b). Reef locations and coral species that suffered high mortality were identified. Local knowledge on coral reef environment and resources has improved, especially where community based coral reef monitoring was practiced (Horrill et al., 2001). Better understanding among the communities was noted when monitoring results were disseminated by trained monitors who were themselves community members.

After reading and understanding CRM reports, ICM managers became more aware of environmental processes and resource dynamics (Muhando, 2006). This understanding raised their hunger for further information on factors driving the observed changes. Resource protection efforts increased as a result of awareness derived from coral reef research and monitoring programs (e.g. Obura, 2004). Furthermore, information contributed to international forums has become more representative, elaborate and detailed than before CRM (see. CORDIO reports 1999, 2000, 2002, 2005 and Status of Coral Reefs of the World: 2002, 2004).

Scientific knowledge on biodiversity, especially of coral and reef fish species has improved tremendously, specifically after the introduction of underwater photography (Johnstone et al., 1998a). The use of local names is becoming more popular than English names as images of reef environment and organisms are presented to local communities. This has raised the need for developing standardised Kiswahili names of reef organisms. Coral reef monitoring has raised issues that require detailed research. For example, commercially important reef macro-invertebrates such as lobsters, sea cucumbers, octopus and ornamental gastropods occurred in lower numbers than anticipated in most reefs (Mohammed et al., 2000, 2002). This may be due to local growth and/or recruitment overfishing, changes in settlement and recruitment processes, or even habitat destruction in larval source reefs, which could be a nearby reef or a number of distant reefs. Studies on larval connectivity are urgently required to reveal larval dispersal processes of the reef invertebrates, including that of the notorious coral predator, the crown-of-thorns starfish.

4. LESSONS LEARNT FROM THE PAST CORAL REEF MONITORING PROGRAMS

There are lessons and challenges learnt from the CRM programs so far. Some of these are mentioned below:

a) Statistical power analysis on coral reef monitoring data revealed that a minimum of 140 transects was required in order to detect 10 % change, and that the on-going sample sizes of 12 – 24 random transects can only detect changes larger than 30%. Low power of detection is contributed mostly by high environmental variance, a characteristic of most coral reef environment. The variance between monitors was generally low, indicating that monitors were well trained and calibrated. With this high level of environmental noise, community based monitoring may not easily discriminate impacts, such as those contributed by human activities versus those from natural impacts.

b) The selection and grouping of reef indicators (categories) were probably not optimum for Tanzanian reef management needs. Feedback from some ICM managers at district level indicated that some parameters, e.g., habitat complexity and environmental forcing variables are not well represented in the ongoing monitoring programs. Factors like nutrient dynamics, fishing pressure and sedimentation levels, were not measured.

c) Change in coral reef biodiversity is not captured in the current coral reef monitoring programs as reef benthic and macro-invertebrate categories are restricted to growth forms and broad taxon groups. It is not possible to deduce change in coral species richness or isolate species tolerant to degradation forces in the current coral reef monitoring database.

d) Administration and coordination of coral reef monitoring outputs at national level is still not optimal. Currently there is no strategic plan for coral reef monitoring at the national level, nor is there a national centralized database. Capacity building (personnel and equipment) for monitoring is not coordinated and lacks continuity among institutions. There is also a problem of loss of trained coral reef monitors, often through promotion to higher levels of responsibility. The recently established National Coral Reef Task Force and the on going discussions on developing a National Coral Reef Strategic Plan are expected to contribute to the solution of this situation.

e) CRM monitoring programs are characterised by inconsistent financial support leading to interruptions. There are also inadequate procedures of tracking data and reports from individual projects by visiting scientists, denying access to potential management information.

f) Dissemination of CRM data and information is far from optimum. When available, coral reef monitoring reports are not timely and widely distributed at national level. Some managers were not aware of the biennial Status of Coral Reefs of World reports (2002, 2004) nor of the CORDIO Coral Reef Status reports (1999, 2000, 2002 and 2005).

g) CRM Reports were not optimally used by ICM managers. Some local managers had problems understanding scientific terminology and implication of changes in the monitored indicators, hence could not translate data into management options.

In conclusion, the current CRM program has increased awareness, enhanced conservation efforts and contributed knowledge on coral reef environment, resources and associated factors and processes. However, the current CRM effort is low, inconsistent and unable to detect changes at satisfactory levels. Hence it should be improved taking into consideration current management needs, field conditions and participation of scientists, local communities and other unutilized resources, including recreational divers.

5. SOME OF THE NECESSARY ACTIONS TO IMPROVE CORAL REEF MONITORING IN TANZANIA

Improvements in coral reef data collection (Scuba and community based techniques), analysis and dissemination information is necessary to guide sustainable development and conservation efforts. The following need to be considered carefully:

i. Ecological and socio-economic monitoring of coral reefs should be part of a larger ICM programme of activities. Results need to be integrated, linked and associated with other coastal ecosystems and socio-economy of coastal communities and vice versa.

ii. Existing CRM programs need to be reviewed and improved to solve ICM issues by:

- Increasing change detection level by improving sampling designs and increasing sampling efforts
- Determining the optimum (better) combination of CRM protocols to meet the requirements than is currently done, e.g., by adding photo quadrats and recent technologies, including video transects
- Including biodiversity change indicators, e.g., coral genus and/or functional groups based on the morphology (Bellwood et al., 2004) instead of current growth forms (English et al., 1994).
- Preparing better illustrations (in Kiswahili) to improve data capture and information dissemination among local communities and others.
- Including coral recruitment and/or recovery indicators in community based monitoring
- Identifying as part of the coral reef monitoring program important environmental and human indicators, e.g. water temperature, nutrients, sedimentation, chlorophyll, fishing intensity, land-based sources of pollution, etc.

iii. In consultation with Central Govt, Local authorities, Regional CRTF, GCRMN, ICM programs, donors, etc., secure stable funding sources. CRM program should include continuous capacity building, of personnel and equipment.

iv. Continuous active participation of community based monitors and scientists in environmental awareness and education

6. MODIFICATIONS ADOPTED BY SCUBA BASED MONITORING TEAM AT IMS

In order to complement what can be assessed by community based monitors and to keep pace with increased threats to reefs such as loss of biodiversity, change in species composition, proliferation of algae (Figs. 2a and 2b) and corallimorpharia, and crown-of-

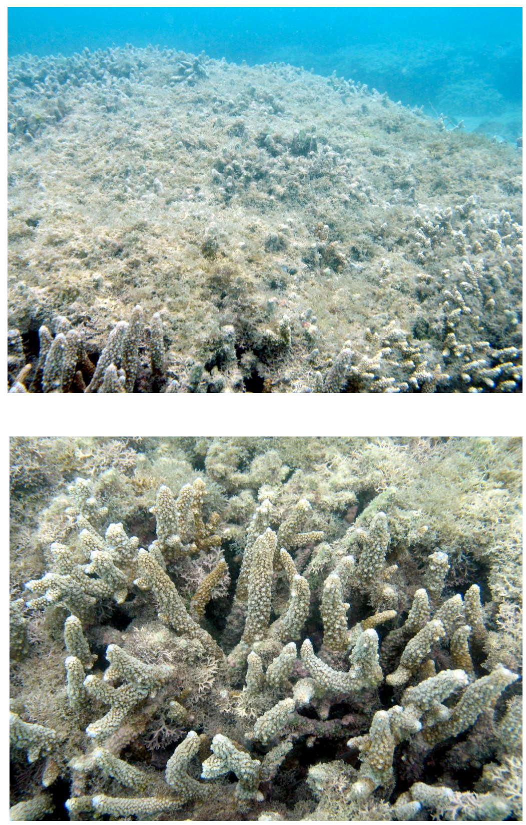

Figure 2a and 2b. Algal proliferation on Bongoyo coral reefs just north of Dar es Salaam. Impacts of eutrophication and sedimentation.

Table 4: The modified Reef benthos template for Scuba based coral reef monitoring at Institute of Marine Sciences, Zanzibar.

Object type	Benthic objects (object id)	
ACROPORA	*Acropora* branching (ACB) *Acropora* digitate (ACD) *Acropora*encrusting (ACE)	*Acropora*tabulate (ACT) *Acropora* submassive (ACS)
NON-ACROPORA	*Acanthastrea* (Acan) *Alveopora* (Alve) *Astreopora* (Astr) *Blastomussa* (Blas) *Caulastrea* (Caul) *Coscinarea* (Cosc) *Cyphastrea* (Cyph) *Diploastrea* (Dilp) *Echinophyllia* (Echph) *Echinopora* (Echpo) *Euphyllia* (Euph) *Favia* (Favia) *Favites* (Favit) *Fungia* (Fung) *Galaxea* (Gala) *Gardineroseris* (Gard) *Goniastrea* (Gonia) *Goniopora* (Gonio) *Halomitra* (Halo) *Herpolitha* (Herp) *Hydnophora* (Hydn) *Leptastrea* (Lepta) *Leptoria* (Lepto) *Lobopyllia* (Lobo)	*Merulina* (Meru) *Millepora* (Mill) *Montipora* (Monti) *Montastrea* (Monta) *Mycedium* (Myce) *Oulastrea* (Oula) *Oulophyllia* (Oulo) *Oxypora* (Oxyp) *Pavona* (Pavo) *Physogyra* (Physo) *Platygyra (*Platy) *Plerogyra* (Plero) *Pleiastrea* (Plei) *Pocillopora* (Poci) *Podabacia* (Poda) *Porites* branching (Pobr) *Porites* massive (Poma) *Psammacora* (Psam) *Seriatopora* (Seri) *Stylophora* (Styl) *Symphyllia* (Symp) *Synarea* (Syna) *Turbinaria* (Turb) *Unid-Corals* (Co-ot)
CALCAREOUS ALGAE	Coralline algae (CA)	
S-CORAL	Soft corals (SC)	
SPONGES	Sponges (SP)	
CORALLIMORPHARIA	Corallimorpharia (RH)	
ALGAE	Algal Assemblage (AA) *Halimeda* (HA)	Macroalgae (MA) Turf algae (TA)
OTHERS	Zoanthids (ZO) Clams (CLAM)	Seagrass (SG) Others (OT)
SUB_1	Dead coral (DC) Rock (RCK)	Dead coral with algae (DCA) Rubble R
SUB_2	Sand (S)	Silt (SI)

Figure 3. Crown-of-thorns-starfish infestation on Tanzania coral reefs .

thorns starfish predation (Fig. 3), IMS has modified its Scuba based CRM protocols. The main emphasis is now on biodiversity changes. Reef corals are now monitored at generic level instead of growth forms alone (Table 4). Reef macro-invertebrates (sea urchins, sea cucumbers, gastropods) include more sub-groups than before. Coral recruitment (young corals less than 10 cm corals) is also monitored at generic level based on the list in Table 4. Training and practice in the new system started in April 2006 and was repeated in May 2007 with funding from the Coral Reef Targeted Research and Capacity Building Project (www.gefcoral.org). Continuous training and calibration is part of the ongoing Coral Reef Targeted Research project activity at the Institute of Marine Sciences. Other recommended actions mentioned above will be considered at a later stage. In the near future a user friendly (and modified) manual for community based monitoring is under preparation to guide and harmonize various groups involved.

ACKNOWLEDEMENTS

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Scleractinian Coral Fauna of the Western Indian Ocean

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ABSTRACT

Scleractinian coral species surveys were conducted at 10 sites in the western Indian Ocean, between 2002 and 2006. Each site varied from approximately 50-200 km in extent and was sampled with from 7 to 27 dives. Accumulation curves based on successive samples at each site were used to construct logarithmic regression curves, which provide estimated species numbers at each site at an arbitrary value of 30 samples per site, assumed to reflect the total number of species. The highest diversity of corals was found in southern Tanzania to northern Mozambique (from Mafia Island to Pemba town), with 280-320 species estimated per site. Species diversity was lower in the central Indian Ocean islands (140-240 species) and declined steadily to a minimum in northern Kenya (150 species). These patterns are consistent with the central coast (around 10ºS in Tanzania/Mozambique) accumulating and retaining species due to the South Equatorial Current (SEC) and mixing/reversing currents locally, respectively. The islands may have restricted diversity due to low area but nevertheless be stepping stones to the East African mainland coast. Lower diversity northwards into Kenya may reflect distance and low dispersal from the center of diversity at 10ºS, and poorer conditions due to the Somali Current influence in the north. Observer effects and unclear taxonomy of scleractinian corals may significantly affect the dataset, as may faunal changes due to bleaching or other impacts at individual sites during the course of the study. Finally, it is likely that the diversity gradient northwards into Kenya is replicated southwards into southern Mozambique and South Africa, providing a means to test latitudinal changes in diversity and species distributions.

INTRODUCTION

The scleractinian coral fauna of the western Indian Ocean (WIO) is one of the least studied globally. In global biogeographic assessments, it appears as a low diversity extension of the main West-Pacific center of diversity (Wells 1957, Rosen 1971, Veron 2000), now commonly called the 'Coral Triangle'. Typically, species numbers of 200-250 are quoted for the WIO, compared to 400-600 for Southeast Asia and Eastern Australia. The mainland East African coast often is depicted with higher species numbers than the islands of the central Indian Ocean, forming a regional center of diversity.

In regional analyses, the East African mainland coast and parts of Madagascar show higher levels of species diversity, with the islands and peripheral seas (Red Sea, Arabian Sea and Gulf of Aden) showing lower diversity. Due to transport of coral larvae westwards in the South Equatorial Current, there is a shorter systematic difference between sites east-west across the Indian Ocean, compared to north-south (Sheppard 1987). Along the African coastline, the

Obura, D.O., Tamelander, J., & Linden, O. (Eds) (2008). Ten years after bleaching - facing the consequences of climate change in the Indian Ocean.CORDIO Status Report 2008. Coastal Oceans Research and Development in the Indian Ocean/Sida-SAREC. Mombasa. http//:www.cordioea.org

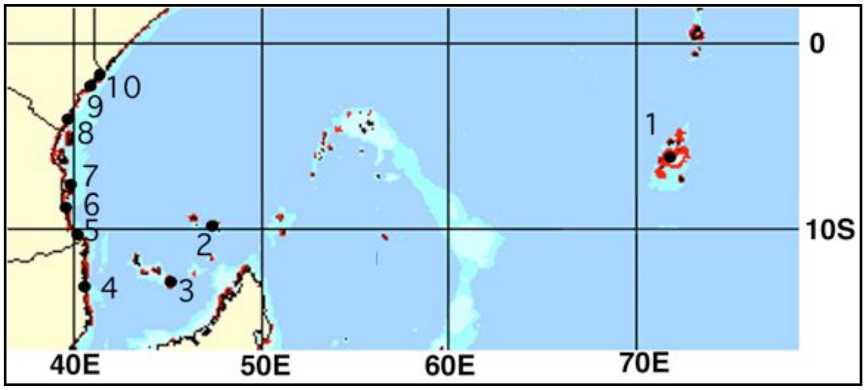


Figure 1. Map of the Western Indian Ocean showing the study sites numbered from 1 to 10 (see Table 1). Map source: Reefbase.

SEC splits at about 10ºS, with one arm flowing northwards as the East African Coastal Current and the other southwards in the Mozambique Current.

This study updates the coral species diversity of a part of the WIO taking advantage of improved resources for field-based identification of species (Veron 2000, Wallace 2000, Sheppard and Obura 2005). The region examined extends in a transect from east to west in the SEC from 72 - 40ºE (≈3500 km) and from south to north in the flow of the EACC from 12 - 2ºS (≈1500 km).

METHODS

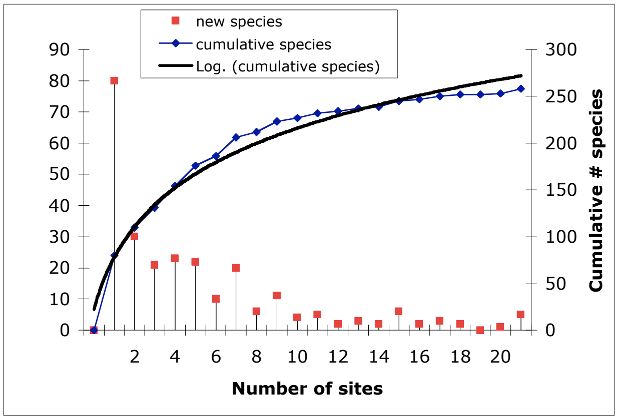
Sites were defined by the scope of survey expeditions, but were generally consistent as being reef systems of some 50-100 km extent in a consistent geomorphological unit. The largest site surveyed was the Chagos archipelago, and the smallest was individual reefs around Mombasa, Kenya, and Pemba, Mozambique.

Species inventories during individual dives were made, generally lasting 30-60 minutes and extending over the full range of depths at a site from deep to shallow. In an excel spreadsheet, the number of previously unseen species in successive samples were counted, and combined together to form an accumulation or rarefaction curve for the location (Salm 1984). Identification of species was done in situ assisted by digital UW photography, collecting a full inventory focusing on unusual or difficult species for photographs (Sheppard and Obura 2005). In cases of uncertainty collected skeletons were further examined after the dives. The principal resources used in identification were Veron 2000, 2002 and Wallace 2000.

In this study, a 'species' is defined operationally as a form that is distinguishable according to visual observation of the live colony against criteria presented in relevant texts (Veron 2000, Wallace 2000). The problems of morphological variation and plasticity, hybridization and biological species boundaries cannot be dealt with beyond this level. Thus the 'species' here is a hypothesis that is primarily based on its utility in field observation, and may change with new information and taxonomic work.

Curve Fitting

One of the simplest curves fitting the accumulation of species with successive samples is a logarithmic curve (Fig. 2). These closely fit existing data points, often with r^2 of over 0.9 and even 0.95. A further advantage is that on a semi-logarithmic scale they transform into a straight line, and the two coefficients of the curve can be easily interpreted: the intercept with the y axis is indicative of the diversity at an individual site level (within-site species-packing, i.e. alpha diversity), while the slope is indicative of diversity of species between sites (i.e. between-site variability or heterogeneity in the species pool, i.e. beta diversity). A logarithmic



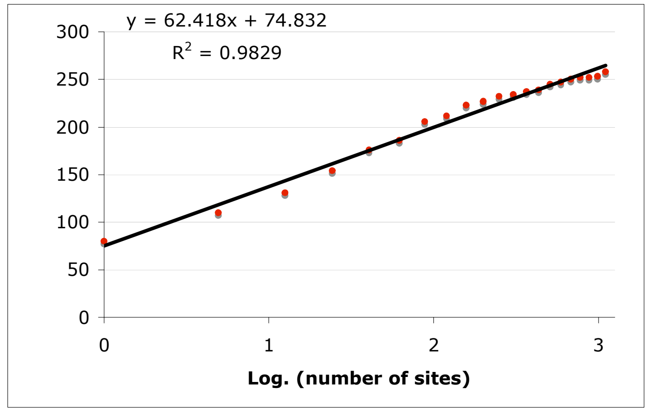


Figure 2. Illustration of number of new species, cumulative curve and logarithm regression of the cumulative species data points (left). Transformation of the logarithmic curve to a straight line (right) with the regression equation and r^2 value.

Table 1. Site and sampling details, western Indian Ocean, 2002-6.

Locations Area (#)	Country	Year	Sampling Days	samples	hours	Coordinates Lat S	min	Long E	min
Chagos – 1	UK	2006	22	27	15.2	6	30.0	72	0.0
Cosmoledo–2	Seychelles	2002	9	7	7.5	9	45.1	47	37.2
Mayotte – 3	France	2005	14	18	10.2	12	52.8	45	16.6
Pemba – 4	Mozambique	2003	3	7	5.3	12	58.3	40	32.4
Mnazi Bay – 5	Tanzania	2003	10	7	10.1	10	18.9	40	23.3
Songo Songo-6	Tanzania	2003	5	7	13.4	8	30.0	39	55.0
Mafia – 7	Tanzania	2004	8	16	13.5	7	56.9	39	47.3
Mombasa – 8	Kenya	2005	10	13	9.0	4	3.7	39	42.7
Lamu – 9	Kenya	2005	4	8	5.1	1	57.8	41	18.3
Kiunga - 10	Kenya	2005	7	15	11.7	2	18.9	41	0.4

curve however, has one major drawback for fitting species accumulation curves, as the maximum number of species in a region is limited, whereas the logarithmic curve does not asymptote – with infinite samples the curve predicts an infinite number of species. Operationally however, a maximum level of sampling can be defined for the pool of locations within a study. For the purposes of this study, a maximum sampling level of 30 sites was selected, slightly higher than the maximum sampling levels that were undertaken at Kiunga (23) and Chagos (27).

RESULTS

The dataset includes 10 locations in the central and western Indian Ocean (Table 1), from the Chagos Archipelago in the east, through the Seychelles and Comoro Islands to the central section of the East African mainland coast in northern Mozambique and southern Tanzania, and northwards to the northern Kenya coast. Surveys were conducted from 2002 to 2006, and varied from a minimum of 3 days and 7 samples to 22 days 27 samples.

Table 2. Coral species diversity for sample locations. Measured number of species, predicted number of species for 30 samples, and regression results.

Site	Number of species		Regression statistics		
	Measured	Predicted	Exponent	Intercept	r^2
Chagos	240	248	57.15	53.57	0.980
Mayotte	222	237	43.62	88.74	0.972
Cosmoledo	143	170	34.27	52.95	0.835
Pemba	206	297	61.40	88.22	0.974
Mnazi	258	288	62.39	75.41	0.984
Songo	206	244	59.16	42.76	0.955
Mafia	268	320	67.11	92.22	0.969
Mombasa	241	262	46.92	102.14	0.841
Lamu	157	245	59.31	43.26	0.952
Kiunga	154	188	48.99	21.15	0.973

Actual species numbers varied between 143 and 268 (Table 2) per site, and was correlated with the degree of sampling (# days, r = 0.396, # samples, r = 0.359), however with a high degree of variation. Logarithmic regression curves on the cumulative number of species in successive samples at each site (Fig. 3) give highly significant r^2 values of 0.841-0.984 (Table 2). At a hypothetical sample size of 30 per site, predicted species number was highest for Mafia (320), Pemba (297) and Mnazi (288), and lowest for Kiunga (154) and Lamu (157, Table 2), from 7 – 44% greater than measured species number (Fig. 4). The discrepancy between measured and predicted species number was greatest for Lamu (56%) and Pemba (44%), which were among the least-sampled sites (8 and 7 samples, respectively), and least for Mayotte (7%) and Chagos (3%), the last sites to be sampled (2005 and 2006 respectively) and with the highest degree of sampling (18 and 27 respectively).

A cluster analysis (Fig. 5) of coral species presence/absence clearly grouped the southern Tanzania/northern Mozambique sites together, and the larger island sites (Chagos and Mayotte) to these. Sites in Kenya formed an outgroup, with Lamu and Kiunga most similar to each other. The grouping clearly matches the geographic spread of the sites, the only discrepancy being the tendency of Cosmoledo (2 on the map) to group with the mainland sites before the other island sites. This may be an artifact of sampling as Cosmoledo was the earliest of the samples included in this analysis and one of the least-sampled sites, raising the probability of errors in the dataset due to inexperience and sampling artifacts.

DISCUSSION

Biogeographically, surveys cover a consistent region defined by the South Equatorial Current (SEC) as it sweeps from east to west across the island systems in the equatorial Indian Ocean, and the north-flowing East African Coastal Current (EACC) that starts where the SEC hits the African mainland coast. The southern-most sample, at Pemba, Mozambique is likely in the southern flow of the Mozambique

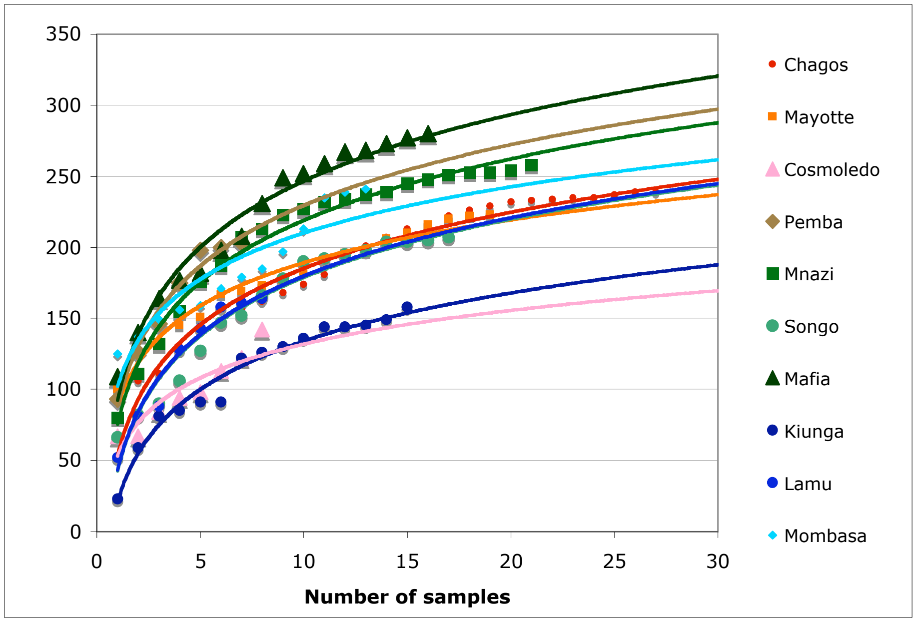


Figure 3. Accumulation curves for all sites coded by colour – red (islands), green (Tanzania-Mozambique), blue (Kenya).

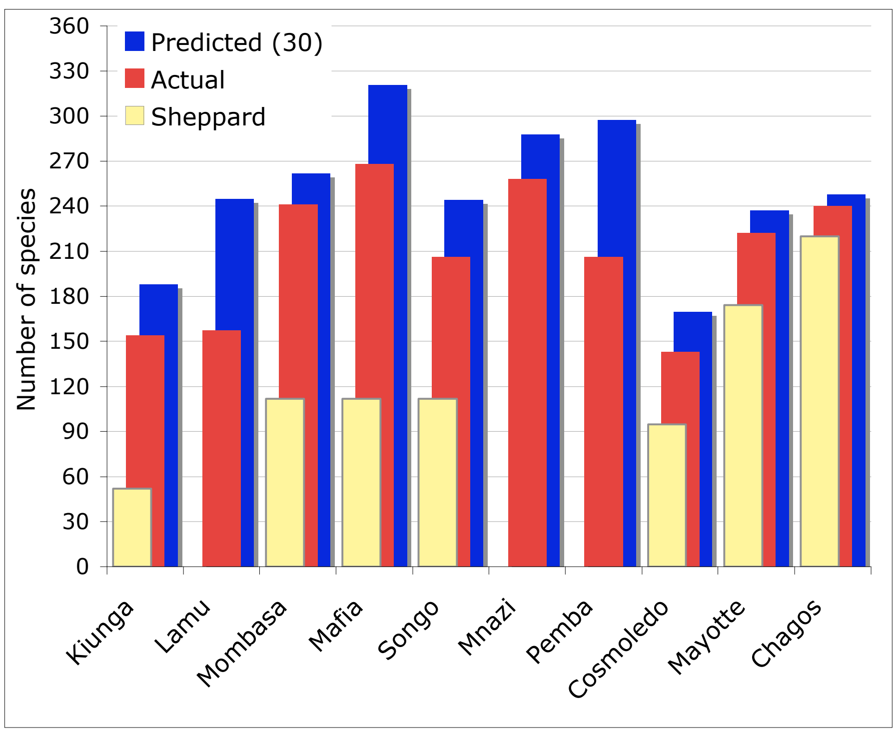
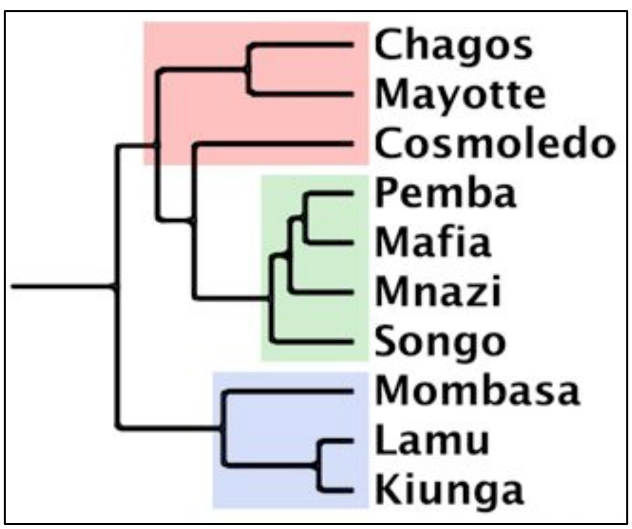


Figure 4. Number of species for each of the sample locations. The predicted and actual numbers are shown, along with values from the literature reported in Sheppard (2002).

Table 3. Factors contributing to the observed diversity patterns for the scleractinian coral fauna of the western Indian Ocean.

Region	Southern Tanzania/ northern Mozambique	Kenya (likely including northern Tanzania)	Central Islands
Diversity	High	Low	Low
Factors	inflow of the SEC carrying larvae from the Indonesian region. mixing over the large area of continental coast that may cause retention of larvae. large area of continental coastline (compared to smaller areas of the central islands) may result in a species-area effect.	uni-directional flow of the EACC results in declining species number with distance from the center of diversity. marginal conditions caused by upwelling in the Somali Current system may reduce species diversity due to poorer conditions for survival of larvae and/or adults.	uni-directional flow of the SEC preventing accumulation and retention of species. area effect of small islands resulting in lower species number. steep-sided oceanic island and platform systems may provide limited area for coral growth.



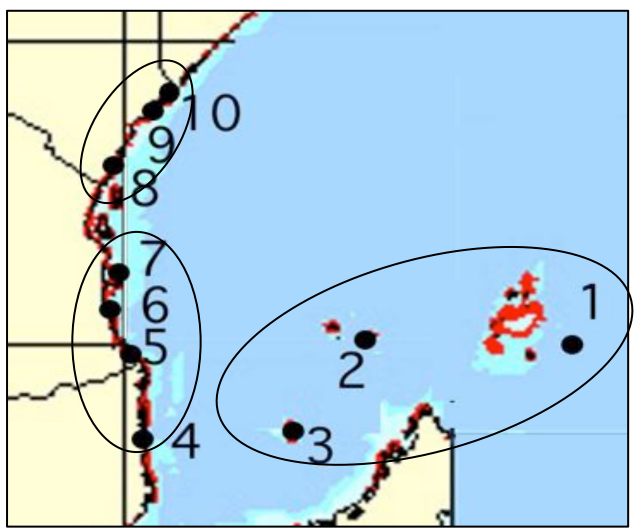


Figure 5. Cluster analysis and regionalization of study sites according by presence/absence of species.

current, though recent evidence shows this southerly flow to be highly variable, alternating between periods of apparent low net flow, and large eddies that move southwards down the Mozambique Channel (Lutjeharms 2007). The northern Mozambique-southern Tanzanian region may thus experience a high level of variable currents and mixing, and form a single region. From this region, the EACC flows consistently northwards, meeting the reversing currents of the Somali Current (SC) system before the northern-most sites in Lamu and Kiunga, Kenya (Johnson et al. 1982). This gradient northwards into Kenya is replicated southwards into southern Mozambique and South Africa, though currents may not be as linear as occurs in the EACC, and cooler water conditions as a result of the Agulhas Current in the south may have a different effect from the upwelling Somali Current in the north.

The regionalization provided by the cluster analysis (Fig. 5) and predicted species richness of the sites (Table 2, Fig. 3) support the notion that southern Tanzanian/northern Mozambique is a single region, and that it is a center of diversity for the western Indian Ocean. Lower diversity is found in the islands upstream in the SEC – thus while these do act as stepping stones that feed propagules into the region from the Indonesian region, there is a larger species pool of western species (mainland Africa and Madagascar) not found in the islands. Diversity also declines northwards along the linear coastline from Tanzania to Somalia (Table 3), likely a result of distance-dispersal factors, declining complexity of the coastline resulting in lower reef area and structural diversity, and less suitable conditions for coral survival in the higher-nutrient lower-temperature waters of the Somali Current system.

This analysis predicts 320 species for the Mafia Island coral reefs, and numbers near this level for adjacent sites. Taking into account beta-diversity between the sites reported here, and of more cryptic and non-reefal scleractinians that were likely excluded from this study, it is likely that the total species count for WIO scleractinians would top 350, and probably even 400 species. This is within the range of the species diversity reported for the Great Barrier Reef, a region of equivalent size, and even to the outer edges of the Coral Triangle around eastern Papua New Guinea and the Solomon Islands (Veron 2000). This increase in species number over historical records of < 200 (Hamilton 1975, Hamilton and Brakel 1984, Sheppard 2002) is also due to increasing taxonomic focus in the WIO and surrounding seas. Recent works (Riegl 1995a,b, Veron 2002 and Turak et al. 2007) illustrate the potential for new species descriptions from the region, further supported by a number of uncertain species (Mangubhai 2007, pers. obs.). With increased taxonomic work in the region, significant revisions of the accepted notion of Indo-Pacific coral biodiversity will be required.

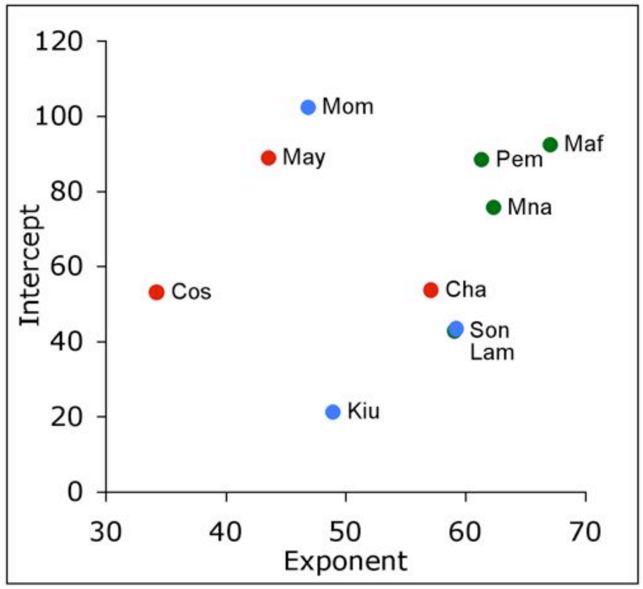


Figure 6. Scatterplot of regression coefficients (exponent vs. intercept).

The coefficients of the regression curves define 'assembly rules' for each site's fauna – the y-intercept relates to the number of species at a single site (alpha diversity) and the exponent to the heterogeneity of species among site (beta diversity), i.e. the rate of new species encountered from one site to the next. Plotting exponent and intercept for the sites (Fig. 6) shows that the high-diversity sites of southern Tanzania/northern Mozambique principally had both high exponents and intercepts. The island and Kenya sites were intermingled, with the island sites tending to have low exponents (Cosmoledo and Mayotte), signifying homogeneous species complement across sites, and the northernmost Kenya sites have low intercepts, signifying a low number of species at each site. Relating these to biogeographic processes, this suggests that high diversity in southern Tanzania/northern Mozambique is due to high alpha and beta diversity (high species packing within sites, large species pool with high mixing among sites), island sites have low beta diversity (consistent species pool with high mixing/low differential between sites) and northern Kenya sites have low alpha diversity (small species pool).

Visual identification of coral species underwater has always been problematic as primary taxonomic descriptions are based on preserved skeleton samples with no reference to live tissue characteristics. However increasingly *in situ* identification is being done and accepted in the literature (Sheppard and Obura 2005). However, there are specific issues that affect this type of dataset:

- A significant change in resources in the period 2000-3, marked by the publication of Veron (2000, 2002) and Wallace (2001) and related outputs such as the accompanying CDs. While this has improved this dataset, the learning curve from the first (2002) to last (2006) surveys is significant.
- The advent of digital photography over the same time period allowed immediate investigation of photographic records after a dive for verification with references and other observers.
- Observer experience is critically important, and with regular surveys increases over time. As found here, early samples tend to contain fewer species than later ones, particularly found for Cosmoledo and Pemba samples, and exacerbated by their small sample sizes.
- The high morphological plasticity of corals has always made identification difficult, and this is magnified when a colony is not collected or retained for verification afterwards. This is particularly important where intermediates and potential hybrids among closely related species vary in abundance, as often a decision on whether they are scored as a species depends on having visual references to the whole series at hand. Thus where species diversity is high and corals are abundant it is possible that more species will be more consistently scored, than where diversity and abundance are lower, and divergent forms are more likely to be lumped together for lack of visual references.

A final word of caution on this type of dataset is that samples are spread over a broad range of years, here from 2002-6. In a time of rapid change and increasing water temperatures major disturbance events such as bleaching may occur at some locations but not others, and between sampling periods (e.g. see for Egmont in Chagos, in Harris and Sheppard, 2007). Thus differences in diversity may reflect factors other than the biogeography and distribution of species.

The logarithmic curves used here have very high significance with r^2 values approaching 0.99. As predictors of species number at an arbitrary number of samples (e.g. 30), they therefore perform well. However theoretically they do not reflect the fact that the total number of species in a site must have a maximum (at or below the total number of coral species in the region), while logarithmic curves do not asymptote. Further work is needed to develop a regression curve that fits the data points as well as a logarithmic function, but has an asymptote to enable a theoretical (not arbitrary) maximum number of species for a site or region.

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